The influence of seasonality on the technological parameters of biological wastewater treatment at existing wastewater treatment plants

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Abstract. The work carried out monitoring of the process of biological treatment of municipal and industrial wastewater at operating wastewater treatment plants in months that differ in temperature and flow rate of process influent. The analysis of wastewater pollution indicators was carried out at three main points of the process line (receiving chamber, settling tank and Venturi tray) with a sampling frequency of 1 every 5 days. It was found that in March and April, the flow rate of process influent and the concentration of suspended solids significantly exceed the specified parameters in February and May. At volley of sewage on wastewater treatment plants in March, the concentration of BOD5 is more than 600 mg l^{-1}. It is shown that overestimated indicators of wastewater pollution at the entrance in the spring period significantly reduce the effectiveness of biological removal of nitrogen and phosphorus compounds.

1 Introduction

One of the serious environmental problems that pose a threat to human and animal health is associated with the process of eutrophication of reservoirs. The creation of new highly efficient waste treatment technologies and the improvement of traditional water treatment systems is becoming the basis for rational environmental management and environmental protection. Intensive management of industrial and municipal emissions is becoming an important area of scientific and technical development in the Russian Federation and the European Union [1-4].

When talking about wastewater treatment from biogenic elements, it implies the removal of nitrogen and phosphorus [5-6]. The lack of nitrogen and phosphorus leads to a decrease in the development of representatives of the aquatic organisms, but an excess of these elements leads to eutrophication of reservoirs [7]. Their main source is untreated or insufficiently treated industrial, household wastewater contaminated as a result of anthropogenic activities, therefore their presence is repeatedly recorded. An obvious sign of eutrophication of a reservoir, i.e. nutrient enrichment as a result of human activity is the

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active growth of blue-green algae on the surface of the water, creating an obstacle to sunlight entering the lower layers. The increase in the number of algae is accompanied by a decrease in the content of dissolved oxygen (pO_2), depletion of flora and fauna, including the death of fish, and the acquisition of turbidity by water. Some cyanobacteria, after dying off, release toxins that accumulate in the biomass of other inhabitants of the reservoir, and can get through trophic chains to warm-blooded terrestrial animals, humans, causing their intoxication, therefore, restrictions on nitrogen and phosphorus emissions in order to reduce the number of violations are very strict. For example, the free-living gram-negative freshwater cyanobacterium *Microcystis aeruginosa* produces microcystin that are actively transported to liver cells, followed by inhibition of phosphatases, leading to hemorrhages and stagnation of blood in the liver.

The main groups of bacteria in the microbiocenosis of activated sludge involved in the oxidation of nitrogen and phosphorus compounds are ammonium oxidizing and phosphate accumulating strains. In order to intensify the processes of biological oxidation of biogenic elements in wastewater, microbial communities are often used, whose cells are immobilized on the surface of an inert carrier as part of a biofilter. Positive examples of bioaugmentation of ammonium-oxidizing microorganisms in biofilms of a filtration reactor are known, which made it possible to increase the efficiency of removal of nitrogen compounds [8,9]. Currently, numerous studies are being conducted on the formation of biofilms among various groups of microorganisms, gram-positive and gram-negative bacteria [10-13], which can be used in the development of highly efficient wastewater treatment technologies.

The rapid development of industry, the constant improvement of the degree of well-being of settlements, cities, complicate the implementation of highly effective purification from nitrogen and phosphorus compounds. Most of the structures installed during the existence of the USSR are considered obsolete, unable to cope with modern anthropogenic loads [5].

Initially, it was supposed to solve the problem of eliminating the eutrophication of reservoirs by the tactic of removing only nitrogen from wastewater, since it is cheaper and technically simpler. But it turned out that it is phosphorus compounds that have a predominant effect on the sharp increase in cyanobacteria in reservoirs, and the removal of nitrogen alone does not cope with the problem [8,9].

Forms of nitrogen in wastewater: inorganic nitrites (NO_2^-), ammonium salts (NH_4^+), nitrogen as part of an organic compound. Nitrogen is disposed of mainly using biological methods, with the following processes:

- Ammonification (conversion of organic nitrogen into ammonia nitrogen).
- Nitrification (conversion of ammonia nitrogen into nitrate).
- Denitrification (conversion of nitrate into nitrogen gas).

Let's take a closer look at the methods of removing phosphates from wastewater. Phosphorus (P) in wastewater can exist in different forms of compounds:

- Insoluble (in the form of insoluble phosphates, in the composition of proteins, suspended particles, i.e., phosphorus in the solid phase, bound, thereby inert to the soil).
- Slightly soluble (aluminum phosphate).
- Dissolved (soluble orthophosphates, meta-, pyro-, polyphosphates (nucleic acids, waste products of hydrobionts, humans), orthophosphoric acid anions).

Phosphorus removal from the aqueous system is proposed in various ways: by converting phosphorus into a chemical compound by adding a metal salt (iron aluminum) or lime (precipitation) – chemical; physic-chemical; incorporation of phosphorus into biomass – biological.

It was found that as a result of an increase in the concentration of phosphates by 0.08 mg l^{-1}, cyanobacteria grow and reservoirs bloom. Phosphorus compounds enter the liquid

phase in the form of polyphosphates and orthophosphates (they average 70-90% of the total phosphorus content), and in small amounts as part of organic molecules. The concentration of total phosphorus in incoming domestic wastewater averages 6.5-19.5 mg 1^{-1}, in effluents from agro-industrial complexes varies in the range of 1.8-3.5 mg 1^{-1}.

The biological accumulation of phosphorus in microbial cells is one of the important processes in the technological scheme of purification of household wastewater from biogenic elements. Increasing the efficiency of phosphate removal by microorganisms of activated sludge at the stage of waste disposal contributes to the preservation of the purity of natural reservoirs and the rational use of environmental resources. The key link in the technology under consideration is the use of biological objects - phosphate accumulating microorganisms (e.g., *Accumulibacter* sp., *Actinobacteria* sp*., Tetracoccus* sp*., Tetrasphaera* sp., etc.).

The species composition of the studied microbial communities and the effectiveness of the technology of deep removal of phosphorus compounds depend on a number of factors: the ratio of easily biodegradable carbon substrate, macro- and microelements in wastewater, the concentration of dissolved oxygen and pH of the medium, the presence of electron acceptors at the stage of anaerobiosis, the activity of enzymes responsible for the synthesis of polyphosphates.

The aim of the work is to study the influence of the main physical-chemical parameters on the process of biological treatment of ammonium and phosphate ions in the composition of incoming sewage. The temperature regime, and the acidity of wastewater in different climatic conditions were evaluated at wastewater treatment plants.

2 Materialsandmethods

The biological method is aimed at treatment industrial and household waste from dissolved organic and some inorganic substances.

The objects of the study were wastewater selected at the main stages of the technological line operating at the biological treatment facilities in the winter and spring periods.

The mass concentration of dissolved oxygen and temperature in the selected samples were measured using an Ulab UP-7041O oximeter. The acidity of the medium in the liquid was analyzed using an electronic pH meter with two electrodes. To assess the effectiveness of biological dephosphorization, the mass concentration of phosphate ions was determined according to the standard HDPE F 14.1:2.112-97 method.

The main investigated and controlled indicators in the research work were the values of wastewater flow, temperature and pH of wastewater, the content of suspended solids, ammonium ions, phosphates, which were determined using standard research methods. The mass concentration of ammonium ions in wastewater was determined by photometric method with Nessler reagent according to the method of HDPE F 14.1.1 – 95.

The experimental studies consisted of conducting four consecutive stages at biological wastewater treatment plants for municipal and industrial wastewater, depending on the seasonality of their functioning. For the analysis of biological oxidation of biogenic elements by activated sludge, 4 months were selected – February, March, April and May, which differ significantly in temperature, flow rate of incoming wastewater and composition of polluting components.

3 Results

Initially, analyses of wastewater contamination indicators were carried out in the analytical laboratory with a sampling rate of 1 every 5 days. The following parameters were selected for analysis: suspended solids, BOD5 biological oxygen demand, ammonium ion, phosphates, temperature, pH reaction of the medium. Studies have been carried out at three points in the technological scheme of biological treatment facilities: a receiving chamber, a primary sump and a Venturi tray. Minimum, average and maximum values were calculated for each indicator.

The results of calculating the average daily wastewater consumption are shown in the Table 1.

Table 1. Average daily wastewater consumption at biological treatment plants, m^3 per day.

	February	**March**	**April**	**May**
Minimum	25619±415	26006±671	26141±340	24200±625
Maximum	28126±923	30308±903	35850±630	29962±740
Average	26873±642	28024±694	30001±720	26312±421

The average ambient temperature during the study period was -3...-5°C in February, -2...-8°C in March, +8...+2°C in April, +13...+6°C in May. Table 2 shows the temperature and pH values of wastewater in the receiving chamber at biological treatment plants.

Table 2. Average wastewater temperature (°C) and pH at biological treatment plants.

	February	**March**	**April**	**May**
temperature, °C	16.3±1.3	17.5±1.5	16.6±1.4	18.3±1.5
pH	7.7±0.3	7.8±0.3	7.5±0.3	7.3±0.3

The concentration of suspended solids in wastewater entering the receiving chamber, as well as after primary sedimentation and after biological oxidation in the Venturi tray are shown in Table 3.

Table 3. Average concentration of suspended solids at biological treatment plants, mg l^{-1}.

	February	**March**	**April**	**May**
Receiving chamber	227.3±15.1	693.7±16.7	520.3±13.4	364.0±9.4
I settling tank	115.3±7.4	194.0±11.2	118.7±6.1	149.3±7.2
Venturi Tray	8.1±1.2	9.8±1.1	7.2±0.9	5.3±0.9

To assess the effectiveness of the removal of biogenic elements in the considered months of the year, the concentrations of ammonium ions and phosphates in the incoming wastewater (receiving chamber) and purified wastewater (Venturi tray) were determined. The results of the studies are presented in Table 4.

Table 4. Average concentration of ammonium ions, phosphates and BOD5 at biological treatment plants, mg l^{-1}

	February	**March**	**April**	**May**
Receiving chamber				
BOD5	327.2±7.1	643.7±12.1	361.7±9.4	375.3±8.8
ammonium ions	73.4±5.1	81.3±2.1	52.3±4.3	86.7±5.5
phosphates	7.3±1.1	6.1±0.7	6.2±0.9	5.5±0.7
Venturi Tray				
BOD5	11.2±1.1	12.2±3.1	12.5±1.2	11.3±0.9
ammonium ions	2.3±0.3	10.2±3.0	6.5±0.5	16.3±1.3
phosphates	3.1±0.4	2.8±0.2	2.3±0.1	3.6±0.4

4 Discussion

Comparing measurements of the daily flow rate of wastewater entering biological treatment plants, the average flow rate in the presented months of the year is equal to 28,000 m^3 per day. The increase in wastewater intake in April is due to an increase in the volume of meltwater in the receiving chamber of mechanical treatment.

The temperature of incoming wastewater is in the range of 16.3 - 18.3 °C and pH 7.3 - 7.8, which in the spring period corresponds to optimal values for the biochemical oxidation of pollutants and the development of microorganisms of activated sludge.

It should be noted that the wastewater indicators in the receiving chamber reflect the overall contamination of the runoff when entering biological treatment facilities. The flow rate of wastewater entering biological treatment is measured directly in the receiving chamber. In the future, incoming sewage is supplied from the receiving chamber to the next stage - mechanical treatment [4, 6, 10].

The second point of wastewater sampling corresponds to the end stage of primary wastewater sedimentation. According to the calculation of the material balance of the technological process, at the stage of primary settling, the concentration of suspended solids decreases by about 30-35% and BOD5, ammonium ions and phosphates.

The third point is the Venturi tray located at the end of the flow chart. In the Venturi Tray, the process of mixing purified water after secondary settling with concentrated chlorine takes place. It is at the third point that the efficiency of biological treatment facilities can be analyzed.

Suspended solids are particles of insoluble solids that float throughout the entire volume of a liquid. When characterizing wastewater, it is customary to take pollutants for such substances, which are delayed at the stage of mechanical cleaning. The concentration of suspended solids in wastewater entering the treatment is inversely related to the daily measure for wastewater disposal per person. A comparison of the suspended solids content in the treated waters allows us to judge in what form the main pollution is represented (dissolved, undissolved).

In urban wastewater, the concentration of suspended solids is normally more than 60% of the chemical oxygen demand (COD) with a decrease in this percentage, we can talk about an increase in the proportion of pollutants present in dissolved form.

The high content of suspended solids is explained by the fact that as a result of the melting of surface wastewater, some of them enter the domestic sewerage system. Sand washed off roads also gets into surface waters. The high content of suspended solids is associated with the flow of reverse fluxes of filtrate water after dehydration.

For the nutrition of microorganisms, the need for basic nutrients is checked, usually estimated by the BOD:N:P ratio, which should correspond to 100:5:1 [9]. In order to assess the required nutrient components, including organic carbon and basic nutrients in the composition of incoming wastewater, the ratios for each month of the year were calculated: in February it was 100:(22.3):(2.07), in March 100:12.6:0.94, in April 100:(14.5):(0.34), in May 100:(23.1):(1.47).

Based on the results of chemical analysis, microbial removal of ammonium nitrogen in the nitrification process and biological removal of phosphates occurs together with the removal of total pollutants from wastewater.

The average efficiency of the process of biological dephosphorization of wastewater has been calculated in February 60.0%, in the spring period as much as possible 63.0%.

5 Conclusion

This paper presents the results of monitoring the operation of biological treatment plants in the period from February to May in order to assess the effectiveness of removing nitrogen and phosphorus compounds under conditions of changing seasonal factors (flow rate of incoming wastewater, temperature, pH and initial concentration of pollutants). Studies have shown an average wastewater consumption of 28,000 m^3 per day with monthly average temperatures of 16.3-18.3 °C and pH 7.3 - 7.8. The initial concentration of suspended solids at the entrance to the treatment facilities increases significantly in March and April and reaches 693 mg l^{-1}. In the process of biological purification of water in the primary settling tank, the content of suspended solids decreases by 50-60% of the initial value and reaches 5.3 - 9.8 mg l^{-1}in purified water. This work confirms the significant influence of seasonality and salvo wastewater discharges at wastewater treatment plants on the effectiveness of biological removal of nitrogen and phosphorus compounds.

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