Domestic wastewater treatment facilities of small towns

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Abstract. The urgency of biogenic elements removal is caused by ever-increasing degree of eutrophication of surface water, which increases the mass of phytoplankton, water turbidity, oxygen concentration in the upper water layers and reduces in thickness. To remove biogenic elements from wastewater, a method based on the use of bioreagents – chemical compounds of trace elements based on biologically active copolymers – is successfully implemented. This article presents the results of a survey of existing facilities of a biological wastewater treatment plant in a small locality. The survey revealed low efficiency of processes at the stage of biological purification, primarily with regard to the speed of biochemical processes, namely, the time-limited ability of dephosphotation, and as a result, a small withdrawal of total phosphorus at the stage of biological purification directly by active sludge microorganisms. In order to intensify the work of biological wastewater treatment facilities, an experiment was conducted on the use of bioreactor in real operation at these treatment facilities.

Keywords: wastewater, biological treatment, aerotank, biogenic elements, bioreagent, total phosphorus.

1 Introduction

Water security which protects human lives and supports sustainable development is one of the greatest global challenges of our century [1, 2]. Surface water pollution is mainly caused by the discharge of industrial and domestic wastewater that has not been sufficiently treated. This situation leads to the decomposition of organic pollutants, anaerobic processes, algae blooms and excessive growth, and prevents the use of water bodies for recreational purposes. Nutrients contained in water lead to secondary water contamination, changes in colour and temperature, depletion of dissolved oxygen and deterioration of organoleptic parameters of water. These factors not only complicate the use of water in the water supply of residential areas and businesses, but also affect the natural processes occurring in reservoirs. Therefore, prevention of eutrophication by minimizing the content of phosphates in wastewater seems rational [3]. The authors [4] also note that significant concentrations of pollutants that can contribute to eutrophication of water, if they are not cleared before final discharge, can damage not only the ecosystem, but also negatively affect human health.

The accumulation of biogenic elements in the water (particularly nitrogen and phosphorus) starts the process of eutrophication (saturatation) of water, which increases the mass of phytoplankton (blue-green algae), water turbidity, oxygen concentration in the upper water layers and reduces thickness. This can lead to the formation of sediments with an increased concentration of organic substances. The last stage of eutrophication is anaerobic fermentation with the release of hydrogen sulphide.

Over the past 30 years, measures have been taken to combat eutrophication of coastal waters in Europe, North America, Asia and Australia. The fight against eutrophication has proved to be more difficult than expected, and ecosystem improvement has only recently begun and has not yet reached its goals [5]. Legislation tightens requirements for the content of nitrogen and phosphorus in wastewater, forces the use of expensive treatment technologies, and the public is increasingly aware of the growing cost of paying for drinking and waste water. The task of wastewater treatment companies is to determine which methods will best meet their needs, both technically and financially. The authors [6] consider methods of wastewater treatment from an ecological and economic point of view.
The main technologies developed for removing phosphorus from wastewater [7] can be classified into biological and chemical methods. The biological method often does not provide complete removal of phosphorus [8]. The authors also noted [9, 10] disadvantages of biological wastewater treatment, that the use of activated sludge gives a high production of sediment and low efficiency of removing many organic and inorganic pollutants. The authors of the work [11] found out the origin of some microorganisms, factors and mechanisms that lead to changes in biological purification processes. The effectiveness of biological wastewater treatment systems is fundamentally related to the hydraulic characteristics of each treatment stage. These steps should guarantee adequate contact between microorganisms and waste water, taking into account the set time. The study of various hydraulic conditions of wastewater treatment, mainly in relation to biological technologies, is considered in [12, 13]. In [14, 15, 16], recent research on phosphorus extraction technologies is reviewed, with a particular focus on modern approaches and treatment tools, including seed material, micro-organisms, wetland plants, and membrane materials. Within the framework of general measures for environmental protection, waste water coming even from small localities must be treated at treatment facilities and ensure the discharge of treated wastewater according to standardized requirements [17, 18]. Most of the phosphorus removal technologies have been developed for the use in large wastewater treatment plants that have strict monitoring and their own operational experience. Small treatment plants often do not have this capability, which is problematic. In the work [19], we consider phosphorus removal technologies that can be used in these treatment facilities. However, as the review shows, there is a shortage of phosphorus removal technologies that require minimal operating and maintenance experience. Sewage treatment plants should be simple, economical and prevent the spread of infectious diseases, unpleasant odours and harmful gases [17, 20].

To remove biogenic elements from the wastewater of small treatment plants, a method based on the use of bioreagents was applied. Bioreagents are chemical compounds of microelements based on biologically active copolymers that allow the development of some types of microorganisms and suppress others in the active sludge, depending on the task at hand.

The object of the survey is a biological wastewater treatment plant of a small settlement in the Republic of Tatarstan, a modular version of the SBO-2000 series, with a capacity of 2000 m³/day. The station consists of four technological lines, which makes it possible to increase the capacity of treatment facilities gradually to 2000 m³/day. The actual load is 500 m³/day, two lines are operating. Discharge of treated effluents is carried out in a reservoir for fisheries purposes.

During the operation of this station, laboratory tests revealed that the quality of wastewater treatment does not meet the standard values and exceeds the maximum permissible concentrations (MPC) for a fishing reservoir, in particular for suspended substances and phosphorus. The concentration of phosphorus (P) up to 10 mg/l can lead to eutrophication of natural waters [21].

The operation of small structures has specific difficulties and is characterized by instability of the composition of wastewater, uneven flow. The paper [22] also notes the high sensitivity of treatment facilities with activated sludge to the uneven amount and composition of incoming wastewater.

The SBO-2000 series biological wastewater treatment plant is designed for mechanical and biological treatment, post-treatment and disinfection of domestic wastewater, as well as treatment of precipitation and waste water generated as a result of treatment. The basic technological scheme of wastewater treatment at this station is presented in Figure 1.

Wastewater from residential development of a small locality in the gravity mode is diverted to the external network of household sewage and the main collector and gets to the sewage pumping station (sewage system). Wastewater is supplied by submersible pumps of the sewage system to a mechanical cleaning unit consisting of grates and sand traps. After passing the sand trap, the mechanically cleaned drains, in the gravity mode, enter the averaging tank, in which they are averaged by composition by mixing with an ejector pump without air supply. From the averager, wastewater is pumped through a pressure pipeline to the distribution chamber for its uniform distribution between the process lines. The process line consists of a primary sump, denitrifier, aeration tank, and a contact filter. From the distribution chamber, wastewater flows through a gravity pipeline to the primary vertical sump. From
where the clarified wastewater flows through the overflow hole for biological treatment to a denitrifier designed for biological removal of nitrogen nitriles and nitrates (\(\text{NO}_2\), \(\text{NO}_3\)) under anoxic conditions. After passing the denitrification process, the effluents enter a multi-section aeration tank-displacer. The denitrifier and aeration tank-displacer have stationary loading in the form of bioblocks, which have a large working surface for the growth of attached biofilm. Additional treatment for biochemical oxygen consumption, suspended solids, nitrogen and phosphorus takes place under anaerobic conditions in the contact filter, which is fed into the reagent polyoxychloride aluminum which is an effective coagulant based on highly charged ions of aluminum Akva-Aurat. Then the waste water enters the microfiltration unit, where the suspension of solid particles, chemical oxygen consumption, biochemical oxygen consumption (BOC₅), and phosphates is reduced. Disinfection with ultraviolet rays, in order to destroy pathogenic microorganisms remaining after biological treatment, takes place at the plant Lazur-M.

The survey revealed low efficiency of processes at the stage of biological purification, primarily with regard to the speed of biochemical processes, namely, the time-limited ability of dephosphotation (transition of polyphosphates to orthophosphates), and as a result, a small withdrawal of total phosphorus at the stage of biological purification directly by active sludge microorganisms. Low temperature of the incoming runoff did not provide high-quality flow of biochemical processes in denitrifiers and nitrifiers.

2 Materials and methods

In the article [23], studies show that during biological wastewater treatment, phosphorus remains intact and needs further treatment. In [24], a comparative assessment of the reagents currently used for phosphorus extraction is given.
Analysis of methods for removing phosphorus from wastewater has shown that the use of bioreagent wastewater treatment, in comparison with non-reagent methods of wastewater treatment, has the following advantages: it lowers the specific cost of treatment to standard indicators, significantly reduces the volume of storage facilities in new construction, allows you to achieve deep cleaning without reconstruction of existing treatment facilities.

Bioreagents, thanks to their unique composition, can solve the tasks of neutralizing the main pollutants contained in wastewater, and achieve a comprehensive environmental and economic effect when used in biological treatment facilities, namely: to perform deep removal of phosphates from wastewater, due to chemical binding and activation of phosphat accumulating bacteria that accumulate and neutralize the effect of phosphorus; almost completely eliminate the removal of suspended substances after wastewater treatment due to the positive charge of the bioreagent, high-quality flocculation and high deposition rate; create a high-quality, stress-resistant biocenosis of activated sludge, excluding the presence of parasitic microorganisms, including dangerous filamentous bacteria and blue-green algae; increase the hydraulic load (productivity) of treatment facilities up to 47 %, without major investment and without loss of cleaning quality; reduce energy costs by up to 33 % due to the rational use of blower and UV equipment and UFOs.

The following devices and materials were used during the study of wastewater from the biological treatment plant of the SBO-2000 series: mobile equipment-photometer "Expert 003", with calibration for total phosphorus and turbidity; electron microscope with the possibility of 1000-fold magnification and photography through a microscope lens; glass cuvettes 10 mm; reagents for determining total phosphorus; domestic bioreagent.

The degree of contamination of water with organic compounds is defined as the amount of oxygen required for their oxidation by microorganisms in aerobic conditions. The biochemical oxidation of various substances occurs at different rates. In laboratory conditions, both the total biochemical oxygen consumption (Biochemical oxygen consumption) and the biochemical oxygen consumption for 5 days (BOC₅) are determined. The total biochemical oxygen consumption is the amount of oxygen required for the oxidation of organic impurities prior to nitrification processes. At the same time, for domestic wastewater, the Biochemical oxygen consumption is determined for 20 days (BOC₂₀); it is considered that this value is close to the Biochemical oxygen consumption (BOCcomplete). It is believed that complete oxidation of organic inclusions takes 20 days.

Industrial tests with a duration of 20 days were carried out in real operation of the biological treatment plants of the SBO-2000 series modular design at the same time on two technological lines independent of each other. The test line is the 1st technological line from two existing ones. The volume of incoming wastewater and quality biological indicators of activated sludge of the 1st and 2nd technological lines correspond to each other.

Before starting the work, the results of quantitative chemical analysis of wastewater in the receiving chamber and the release of secondary settling tanks, performed before the bioreagent test (Table 1), were studied.

| Indicators                  | Project indicators | Distribution chamber | Release after secondary settling tanks | Permissible concentration |
|-----------------------------|--------------------|----------------------|----------------------------------------|---------------------------|
| Weighted substances, mg/L   | 260-300            | 230.8                | 4.2                                    | 3.0                       |
| Total phosphorus, mg/L      | 8                  | 20.5                 | 8.2                                    | 0.2                       |
| The minimum allowable effluent temperature, °C | 13-25              | 7.0                  | 9.0                                    | -                         |
Based on the data obtained, the preliminary bioreactor dosing point was selected at the beginning of the aeration tank of the tested process line, in order to: ensure maximum effect on the active sludge for bioreactor saturation; to bind phosphate compounds in the aeration tanks as efficiently as possible.

The bioreactor dosage is calculated by the volume of incoming water to the treatment facilities and the concentration of phosphorus phosphates at the outlet from the treatment facilities, the content of which should be reduced to the standard indicator.

The amount of phosphorus phosphates \( Q_P \), kg/day, forming in the wastewater per day that must be removed, is calculated by the formula:

\[
Q_P = \frac{Q_d (C_p - C_{ppcf})}{1000},
\]

where \( Q_d \) – average daily waste water flow, m\(^3\)/day; \( C_p \) – concentration of phosphorous phosphates at the OS outlet, mg/L; \( C_{ppcf} \) – permissible concentration for fish-purpose phosphorus, 0.2 mg/L.

To remove 1 kg of phosphorus at the saturation stage of the system, 10 kg of bioreagent are required. Bioreagent dosing should be carried out in two stages: the first stage is the period of saturation of the biological treatment system, which on average is 15-30 days (determined by the technologist based on qualitative and quantitative indicators of wastewater treatment); the second stage is the period of stabilization of the biological treatment system (reaching the calculated values of 3.0 - 5.0 kg/1000 m\(^3\)).

Bioreagent dosing at the biological treatment plant of the modular version of the SBO-2000 series was carried out in two stages (Figure 2):
1) the period of saturation of the biological treatment system;
2) the period of stabilization of the biological treatment system.

![Figure 2](image)

According to the regulations of industrial tests, the saturation period lasted 14 days. The saturation period was characterized by an increased dose of bioreagent, on average 2-3 times more than during the stabilization process. The end of the saturation period was due to the stabilization of the quality of wastewater treatment according to controlled indicators, in particular, the concentrations of phosphorus and suspended substances, as well as the achievement of standard indicators of the values of the sludge index. During the first week of bioreagent dosing, the following processes were
observed: adaptation of active sludge microorganisms to a new diet regime; changing the structure of cotton in the secondary settling tank; increasing the dose of silt by weight; reducing foaming in the zone of secondary settling tanks. The low temperature of the incoming wastewater has limited the possibility of effective operation of active sludge microorganisms, since at the temperature of less than 12 °C microorganisms show little activity, and as a result, low efficiency in removing pollutants of the phosphate and nitrogen groups.

Temperature is a key element that affects the activity of microorganisms in the activated sludge. Low water temperature usually leads to a decrease in the efficiency of wastewater treatment and destruction of sediment deposition [25]. The authors [26, 27] also note the influence of low temperature on nitrification processes and a decrease in microbial activity during biological wastewater treatment. The paper [28] presents the results of a study where the influence of temperature on the process of wastewater treatment was studied. The rates of nitrification and denitrification were determined in a laboratory purification system operating at low temperatures, in the range from 6 to 15 °C. Ethanol was used as an external carbon source. The addition of ethanol resulted in an increase in the nitrification rate at a lower temperature (up to 71 % at 6 °C and up to 11 % at 15 °C). A similar trend was observed in the process of denitrification. The rate of denitrification increased to 81 % at 6°C and 10 % at 15°C, respectively. The rate of nitrification was slightly higher than the rate of denitrification. Based on experimental data, two-variant model equations were composed to calculate the required amount of external carbon and to achieve the desired process speed at a certain wastewater temperature. There was a direct dependence of nitrification and denitrification rate on the temperature of wastewater and the amount of loaded carbon.

Due to the instability of biology at the surveyed station for the above reason, after saturation of the biological system with a bioreagent, the point of bioreagent dosing was changed, so that the dosage was carried out directly at the end of the aeration tank, so that the bioreagent can affect the reduction of suspended substances during secondary sedimentation. The volume of dosing was reduced by half during the saturation period compared to the initial one, which did not affect the quality of wastewater treatment in the future. Unfortunately, the output of the 1st technological line under test to stable standards did not take place due to the inability to raise the temperature of incoming wastewater, and as a result, to make active sludge microorganisms work, which is a determining factor in biological treatment. However, the use of bioreagent technology has shown that even in this situation, the quality of purification for phosphorus and suspended substances has significantly improved: for phosphorus by 3-4 times, for suspended substances by 1.5-2 times.

3 Results and Discussion
The results of research on the use of bioreagent are presented in the form of diagrams. The 1st process line was selected as the test line. The 2nd process line is selected as the control line.

Phosphate compounds are effectively bound by coagulants (FeO and Al₃(OH)₃Cl) included in the bioreagent, both chemically and biochemically, inhibiting the development of lipases, thereby ensuring the dominance in the development of flocculating, including phosphate-accumulating bacteria, which allows for deep removal of Pₜₐ at the stage of biological wastewater treatment. A diagram of values for the Pₜₐ is shown in Figure 3.

The dynamics of effective reduction of the concentration of suspended substances at the exit from biological treatment facilities in the first two weeks of testing showed stable values close to the Permissible concentration, including below the Permissible concentration (Figure 4). After changing the dosing point (before the secondary settling tanks) in the last days of the tests a good dynamics of deposition of suspensions to the established Permissible concentration standards was shown. Due to the low temperature of the runoff in the secondary settling tanks, small white-yellow fat flakes periodically surfaced, which failed to dissolve and decompose at the stage of biological purification.
To calculate the main qualitative hydrobiological indicator, the silt index, which was 103 ml/g on the experimental line, and 136 ml/g on the control line, at a rate of 80-120 ml/g, samples of active silt were taken to determine the dose of silt by weight and volume. It was also noted that the number of protozoa on the experimental production line is higher than on the control line.

The silt index, which is the main qualitative hydrobiological indicator (the ratio of the silt dose by volume to the silt dose by weight) on the experimental technological line, was within the norm, and on the control line above the norm, which is an unsatisfactory indicator and can lead to swelling and
removal of active silt into the reservoir. As a result, the efficiency of using a bioreagent can improve the hydrodynamic parameters of activated sludge by a third and, consequently, improve the quality of cleaning.

In Figure 5 and Figure 6 it shows the formation of large, well-compacted flakes of activated sludge at the stage of secondary sedimentation, as well as a clear separation of activated sludge and nadil liquid with a high degree of transparency.

![Figure 5](image1.png)

**Figure 5.** Microbiology of the 1st technological line: a - before the start of bioreagent testing, b - at the end of the test (14 days after the start of the bioreagent application)

![Figure 6](image2.png)

**Figure 6.** Microbiology of the 2nd technological line: a - before the start of the bioreagent testing, b - at the end of the test (14 days after the start of the bioreagent application).

Final output at stable low values of bioreagent doses and stable quality of wastewater treatment recorded 10 days after the start of bioreagent application when all the main quality parameters gradually leveled off and were on the one hand relatively constant, and the other as close to the Permissible concentration – total phosphorus ($P_{gen}$), suspended solids, sludge index. The volume of dosing was also reduced in the daytime by half of the minimum dosage rate during the saturation of the biological system, which resulted in a two-mode schedule of bioreactor dosing per day-0.2 L/h daily dosing mode and 0.4 L/h night dosing mode.

In the decomposition of pollutants, the main role belongs to heterotrophic flake-forming bacteria. As a result of bioreactor dosing, by the beginning of the stabilization period, the populations of flocculating bacteria were saturated with this bioreactor, and it also allowed for sorption and adhesion of pollutants to the flake surface.

### 4 Conclusion

Bioreagent technology for wastewater treatment at small treatment plants during industrial tests has shown high efficiency in terms of the quality of water treatment and maintaining high hydrobiological indicators.

The effect of bioreagent technology on total phosphorus in the treated runoff on the experimental line was achieved at a dosage of 0.2 L/h, which provided the reduction of the total phosphorus in more
than 10 times in comparison with the incoming runoff to biological treatment facilities and an average of 4 times in comparison with the control 2nd technological line.

The effect of bioreagent technology on suspended substances, a positive dynamics of reducing the concentration of suspended substances to the standard indicators, was recorded when the bioreagent was dosed in the amount of 0.2 L/h.

Feedback bioreagents technology on the hydrological parameters of the active II - recorded positive dynamics of the main hydrobiological indicators on a pilot production line, with a minimum dosing of bioreagent in a volume of 0.2 L/h, compared to control production line, namely:
- stable biomass growth in the system is 50% more efficient;
- 25% more effective reduction of the volume of silt dose;
- the silt index is reduced by 30%, which makes it possible to proportionally increase the content of useful biomass in the same volume.

The result of bioreagent technology impact on Microbiology, the development of flocculating (colonies of roundworms (Vorticella), gastropods (Aspidisca) and protozoan species of bacteria, was recorded, while observing the minimum dosage of the bioreagent in the amount of 0.2 L/h. In comparison with the control line, the following changes were recorded when dosing the bioreagent: the species composition of bacteria (Vorticella) increased; the activity of ciliated zones of all varieties of the microbial community with this ability increased.

To achieve the standard treatment parameters, it is necessary to take measures to increase the temperature of wastewater at the entrance to biological treatment. The bioreagent consumption when this requirement is met will decrease by 2-3 times.

From the results of wastewater treatment quality achieved by the end of industrial tests (Table 2), it can be seen that certain indicators managed to reach the standard values or as close to them as possible, giving the low temperature of the effluent.

**Table 2.** The average results of the quantitative chemical analysis of treated wastewater.

| Indicators                      | Permissible concentration | Before the test  | At the end of the test |
|--------------------------------|---------------------------|-----------------|-----------------------|
| Weighted substances, mg/L       |                           |                 |                       |
|                                |                           | 3               | 4.5                   |
|                                |                           | 4.8             | 0.6                   |
|                                |                           |                 | 2.5                   |
| Total phosphorus, mg/L          |                           | 0.2             | 7.2                   |
|                                |                           | 7.4             | 2.1                   |
|                                |                           |                 | 2.4                   |
| The sludge index ml/g           |                           | -               | -                     |
|                                |                           | 103             | 136                   |

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