Retechnologization of biological sewage water treatment facilities using mathematical modelling

*Liliya Khisameeva*¹[0000-0001-9873-4886], *Runar Abitov*¹[0000-0001-6138-6419], and *Ramis Alimov*¹[0000-0003-0474-3488]

¹Kazan State University of Architecture and Engineering, 420043, Zelenaya st., Kazan, Russia

Abstract. The efficiency of sewage treatment plants is an urgent problem of the designed and operating stations. In modern conditions, efficiency is understood as the operation of facilities in which operating costs are minimized, facilities provide standard cleaning, and the company implements measures to modernize and improve energy efficiency and trouble-free operation. The article deals with the comparative analysis and selection of the most optimal scheme of biological sewage water treatment of existing sewage water treatment plants. The indicators of the efficiency of functioning and permissible loads on treatment facilities in the design of aeration tanks for biological sewage water treatment are determined. The results served as the basis for the creation of a mathematical model, with the help of which it is possible to calculate the parameters of the biological treatment system and optimize the process of biological sewage water treatment at existing treatment facilities. Mathematical modeling allows you to reduce the cost of designing and operating treatment facilities, to guarantee the degree of treatment in accordance with the requirements and standards for the discharge of treated sewage water into a reservoir for fisheries purposes.

Keywords: sewage water, eutrophication, biological treatment, biogenic elements, modeling, aeration tank, technological scheme.

1 Introduction

The main cause of pollution of water bodies with biogenic elements that violate the stability of the biosystem is the discharge of urban and industrial sewage water. Scientists from different countries of the world have been solving the problems of high-quality sewage water treatment to prevent eutrophication of water bodies for many years [1-4]. At the end of the twentieth century, our country tightened the standards for the discharge of pollutants into water bodies, introduced technologies for deep removal of nitrogen and phosphorus compounds from sewage water based on the recommendations of research organizations. Since 2012, the updated Construction Norms and Regulations (SNiP) (SP 32.13330.2012 «Sewerage. External networks and structures») allowed for the calculation of structures

* Corresponding author: khisameeva_liliya@mail.ru

with biological removal of nitrogen and phosphorus to use any, including foreign calculation methods. The degree of treatment of sewage water discharged into water bodies must meet the requirements of the current legislation in the field of environmental protection [5].

Traditional biological sewage water treatment allows to remove the bulk of organic pollutants, to oxidize ammonium nitrogen to nitrate, but cannot provide a sufficient depth of removal of nitrogen and phosphorus compounds [6-8]. The issue of removal of nutrients is a priority in improving the quality of treated sewage water before discharge into fisheries reservoirs. Biogenic elements – elements that are constantly included in the composition of organisms and perform certain biological functions. The most important biogenic elements are oxygen, carbon, hydrogen, nitrogen, phosphorus, sulfur, calcium, potassium, sodium, and chlorine. Nitrogen and phosphorus are one of the main components of sewage water, the presence of which in municipal or close to them in the composition of household water is constantly recorded. Nitrogen in sewage water can be represented by several compounds: ammonium nitrogen (NH_4^+), nitrite nitrogen (NO_2^-), nitrate nitrogen (NO_3^-), organic nitrogen (as part of organic compounds). Phosphorus in sewage water is found in organic compounds (organic phosphorus), polyphosphates (P_2O_5), and orthophosphates (PO_4).

The biological method of deep removal of biogenic substances from sewage water makes it possible to achieve the total phosphorus content in treated waters of 1.0...1.5 mg/dm³, and the total nitrogen content of 8...10 mg/dm³ (including protein, ammonium, nitrite and nitrate) in real biological treatment facilities. The biological method of phosphorus removal makes it possible to achieve a high quality of phosphorus treatment, but this process is very sensitive to the current quality of sewage water received for treatment and requires highly qualified technologists-operators [6-10].

Biological removal of nitrogen from sewage water consists in the following processes: ammonification, in the decomposition of organic nitrogen-containing compounds to non-organic ammonium; nitrification, in the two-stage oxidation of ammonium nitrogen compounds first to nitrites, then to nitrates; denitrification - in the bacterial reduction of nitrate nitrogen to molecular, accompanied by the oxidation of organic substances. At the same time, oxygen is saved, since some organic substances are not oxidized by dissolved oxygen, but by the oxygen of nitrates. To ensure the intensive course of nitrification, denitrification and biological dephosphation processes, biological treatment facilities are divided into zones with different levels of aeration - aerobic, anoxic and aerobic. Biological treatment of sewage water from nitrogen and phosphorus, based on the processes of ammonification, nitrification-denitrification and dephosphotation, is currently recognized as the most economical and environmentally friendly, due to its high efficiency and low consumption [11].

The complexity of the implementation of the developed methods of urban sewage water treatment is that most of the treatment facilities were built in the 80-90s of the last century and currently need reconstruction, as they are morally and physically outdated and do not meet modern requirements. The amount of financial resources required for reconstruction is considerable, and the possibilities are limited. Therefore, there is always a question of the need for reconstruction of sewage water treatment facilities, with minimal financial investments, maximum use of existing facilities and obtaining the required standard quality of sewage water treatment [12, 13].

The aim of this study is to define ways to improve the efficiency of nitrogen removal and phosphorus in biological processes of denitrification and deflation. At the same time, the tasks of minimizing capital investment in facilities and the use of modern technologies of sewage water treatment for nitrogen and phosphorus removal using mathematical modelling techniques in the design of new and reconstruction of existing sewage treatment plants are being solved. The interest in modeling sewage water treatment facilities is explained by the fact that the design, implementation and debugging of new technological solutions is impossible without careful preliminary technological and engineering

calculations. The use of mathematical models makes it possible to significantly reduce the time in the design and operation of sewage water treatment facilities. The software provides a fairly complete picture of the object's behavior under dynamic conditions, i.e., over time. At the same time, it is possible to consider the state of objects in static conditions, taking into account the analysis of other variables, such as the length or depth of structures, which allows us to take into account the hydrodynamic parameters of structures [14].

2 Methods

The biological treatment facilities of Almet'yevsk were built in 1967. The design capacity is 40 thousand m³ / day, the actual capacity is 38 thousand m³/day. The sewage water received for treatment is a mixture of industrial and domestic sewage water. The amount of industrial sewage water in the total volume of sewage water inflow is not significant. Sewage water is treated mechanically and biologically. Mechanical cleaning is carried out in the grate building, in horizontal sand traps and primary sedimentation tanks of the radial type. Further, the sewage water enters the aeration tanks, where organic matter is oxidized and settled in secondary sedimentation tanks. The clarified water is chlorinated in the contact tank and discharged into the Stepnoy Zai River via a scattering outlet. Sludge from secondary sedimentation tanks enters the sludge beds.

The flow of sewage water to the treatment facilities is characterized by unevenness during the day and seasonal fluctuations [8, 15].

During the operation of the treatment facilities, laboratory tests revealed that the quality of sewage water treatment does not meet the regulatory values, exceeds the maximum permissible concentrations (MPC) for a fishing reservoir (Table 1).

Table 1a. Data on the composition of incoming sewage water.

Name	Unit of measur ement	Incoming water					
		2014			2015		
		min	med	min	med	min	med
Ammonium ion	mg/l	73.5	77.8	80.0	59.2	68.4	75.0
BOD ₅	mgO ₂ /l	204.0	206.2	210.0	196.0	249.0	320.0
Suspended solids	mg/l	280.0	302.8	320.0	332.0	364.0	386.5
Hydrogen index	unit.	7.7	7.7	7.8	7.8	7.8	7.9
Total iron	mg/l	1.1	1.71	2	1.039	2.39	3.95
Cadmium	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Manganese	mg/l	0.15	0.263	0.4	0.204	0.252	0.303
Copper	mg/l	0.01	0.012	0.03	0.017	0.021	0.027
petroleum products	mg/l	0.7	1.56	2.1	1.4	1.67	2.02
Nickel	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Nitrate ion	mg/l	<0.1	0.35	0.5	<0.1	<0.1	<0.1
Nitrite ion	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Anionic surfactants	mg/l	2	3.91	5.59	2	2.68	3.4
Sulfate ion	mg/l	55.2	74.8	100	87.7	108.2	121.4
Dry residue	mg/l	584	701	875	729	816.3	121.4
Phosphate ion	mg/l	6.15	11.93	19	14.3	28.8	47.68
Fluoride ion	mg/l	0.166	0.229	0.3	0.212	0.233	0.252
Chloride ion	mg/l	73	141	197	138.3	181.2	229.7
COD	mgO ₂ /l	434	466	516	284	397	456
Chrome 3+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chrome 6+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	mg/l	0.02	0.0218	0.028	0.019	0.028	0.044

Table 1b. Data on the composition of incoming sewage water.

Name	Unit of measur ement	Incoming water					
		2016			For the first half of		
		min	med	min	med	min	med
Ammonium ion	mg/l	54.3	79.1	54.3	79.1	54.3	79.1
BOD ₅	mgO ₂ /l	188.0	263.7	188.0	263.7	188.0	263.7
Suspended solids	mg/l	130.0	292.0	130.0	292.0	130.0	292.0
Hydrogen index	unit.	7.8	7.8	7.8	7.8	7.8	7.8
Total iron	mg/l	1.17	2.04	1.17	2.04	1.17	2.04
Cadmium	mg/l	0.0046	0.0048	0.004	0.004	0.004	0.004
Manganese	mg/l	0.162	0.181	0.162	0.181	0.162	0.181
Copper	mg/l	0.0157	0.0212	0.015	0.021	0.015	0.021
petroleum products	mg/l	1.14	1.88	1.14	1.88	1.14	1.88
Nickel	mg/l	0.0073	0.0083	0.007	0.008	0.007	0.008
Nitrate ion	mg/l	<0.1	0.214	<0.1	0.214	<0.1	0.214
Nitrite ion	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Anionic surfactants	mg/l	1.3	1.94	1.3	1.94	1.3	1.94
Sulfate ion	mg/l	79.4	113.5	79.4	113.5	79.4	113.5
Dry residue	mg/l	79.4	113.5	79.4	113.5	79.4	113.5
Phosphate ion	mg/l	4.88	16.46	4.88	16.46	4.88	16.46
Fluoride ion	mg/l	0.183	0.398	0.183	0.398	0.183	0.398
Chloride ion	mg/l	116.2	210.3	116.2	210.3	116.2	210.3
COD	mgO ₂ /l	294.4	353.1	294.4	353.1	294.4	353.1
Chrome 3+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chrome 6+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	mg/l	0.02	0.0252	0.02	0.025	0.02	0.025

The analysis of the qualitative composition of the incoming sewage water showed that (Table 2.):

- the organic load in the incoming sewage water is moderately polluted;
- biogenic load in incoming sewage water: for ammonium nitrogen-highly polluted, for total phosphorus-medium polluted;
- there is an imbalance between nitrogen and phosphorus in the ratio of organic and biogenic substances;
- the average value of the suspended matter concentration is high enough to avoid primary sedimentation.

Table 2. The ratio of the main substances in the incoming sewage water.

Ratio	Meaning	Charecteristics
COD/BOD _n	1.69	Low
BOD _n /NH ₄	4.50	Middle
BOD _n /PPO ₄	24.40	High
BOD _n :N:P	100.0:13.4:3.2	-

A survey of sewage facilities and analysis of laboratory data of sewage water after secondary biological treatment tanks (Table 3) and comparison with the current discharge requirements (Table 4) showed:

- nitrates do not exceed the current regulatory requirements, but this is not a result of complete oxidation of ammonium nitrogen, but is caused by the small capacity of biological treatment facilities;

– ammonium nitrogen exceeds the discharge standard by more than $\epsilon = 89$ times, caused by a high load on the ingredient in the incoming water (including with return flows), and a short residence time of sewage water in biological treatment facilities;

– The BOD_{Π} exceeds the discharge standard by more than $\epsilon = 20$ times, caused by the small capacity of the aeration tanks and the removal of colloidal under-oxidized substances;

– suspended substances exceed the discharge standard by more than $\epsilon = 7.1$ times, the removal of suspended substances is associated with the removal of colloidal under-oxidized substances;

– iron (ion) belongs to the group of heavy metals, is toxic and inert to biochemical oxidation, and its removal is carried out by precipitation and biosorption;

– petroleum products that exceed the permissible discharge by $\epsilon = 4$ times, which indicates insufficient technological efficiency of cleaning, removal is carried out due to chemical and biodegradation during biological cleaning, and to a lesser extent when surfacing at the stage of mechanical cleaning;

– nitrogen and phosphorus are biogenic elements, the purification efficiency is as follows:

– ammonium ion - excess of MPC in $\epsilon = 89$ times;

– nitrite ion-MPC excess in $\epsilon = 16$ times;

– nitrate ion-within the MPC;

– phosphates (ion) - excess of MPC in $\epsilon = 30$ times.

Methods of sewage water treatment from petroleum products and heavy metals are presented in the works [16, 17]. The main technologies developed for the removal of phosphorus from sewage water can be classified into biological and chemical methods. The biological method often does not provide complete removal of phosphorus [6, 8]. The authors also noted the disadvantages of biological sewage water treatment [7, 8], that the use of activated sludge gives high sediment production and low efficiency of removal of many organic and inorganic pollutants. In the article [8, 18], studies have been conducted that indicate that during biological sewage water treatment, phosphorus remains intact and needs further treatment. In [8, 19], a comparative evaluation of the reagents currently used for the extraction of phosphorus is given. Analysis of methods for the removal of phosphorus from sewage water has shown that the use of bioreagent sewage water treatment, in comparison with non-reagent methods of sewage water treatment, has advantages: the specific cost of treatment is lower to the standard indicators, the volume of tank facilities is significantly reduced during new construction, and it allows to achieve deep cleaning without reconstruction of existing treatment facilities [8].

Taking into account the strict requirements for the discharge of phosphates, a combined bio-reagent removal method should be provided, and the chemical stage of phosphorus removal should be provided at the post-treatment stage.

Table 3a. Data on the composition of sewage water after treatment.

Indicator name	Unit of measurement	Treated water					
		2014			2015		
		min	med	min	med	min	med
Ammonium ion	mg/l	42	52.1	58.1	14.1	40.2	64
BOD ₅	mgO ₂ /l	8.1	40.5	71	31	76.1	120
Suspended solids	mg/l	13.6	215	410	21.5	60	96.5
Hydrogen index	unit.	7.3	7.6	7.9	7.5	7.7	7.8
Total iron	mg/l	0.227	1	1.72	0.38	0.96	1.5
Cadmium	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Manganese	mg/l	0.168	0.228	0.288	0.114	0.156	0.197
Copper	mg/l	< 0.001	0.0125	0.025	0.023	0.012	0.020
Petroleum products	mg/l	0.115	0.4	0.683	0.055	0.248	0.439
Nickel	mg/l	<0.005	<0.005	<0.00	<0.00	<0.00	<0.00
Nitrate ion	mg/l	< 0.1	3.6	7.02	0.304	0.2	< 0.1
Nitrite ion	mg/l	< 0.02	1.5	2.9	<	0.48	0.92
Anionic surfactants	mg/l	0.219	2.1	4	0.108	0.9	1.68
Sulfate ion	mg/l	58	83	107.9	73	117.5	160.3
Dry residue	mg/l	704	758	811	596	721	843
Phosphate ion	mg/l	1.54	9.3	17.04	0.25	6.7	13.1
Fluoride ion	mg/l	0.022	0.138	0.253	<0.01	0.038	0.065
Chloride ion	mg/l	79	169	257.4	111.1	148.5	183.8
COD	mgO ₂ /l	24.3	59.1	92	31	107	183
Chrome 3+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chrome 6+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Zinc	mg/l	0.0114	0.015	0.018	0.009	0.016	0.022

Table 3b. Data on the composition of sewage water after treatment.

Indicator name	Unit of measurement	Treated water					
		2016 r.			For the first half of		
		min	med	min	med	min	med
Ammonium ion	mg/l	23.4	45	23.4	45	23.4	45
BOD ₅	mgO ₂ /l	9	38.1	9	38.1	9	38.1
Suspended solids	mg/l	12.5	65	12.5	65	12.5	65
Hydrogen index	unit.	7.5	7.7	7.5	7.7	7.5	7.7
Total iron	mg/l	0.178	1.3	0.178	1.3	0.178	1.3
Cadmium	mg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.
Manganese	mg/l	0.11	0.17	0.11	0.17	0.11	0.17
Copper	mg/l	< 0.001	0.022	<	0.022	<	0.02
Petroleum products	mg/l	0.031	0.51	0.031	0.51	0.031	0.51
Nickel	mg/l	<0.005	<0.005	<0.005	<0.005	<0.005	<0.0
Nitrate ion	mg/l	0.94	19.7	0.94	19.7	0.94	19.7
Nitrite ion	mg/l	0.059	3.13	0.059	3.13	0.059	3.13
Anionic surfactants	mg/l	0.095	3.7	0.095	3.7	0.095	3.7
Sulfate ion	mg/l	82.5	134	82.5	134	82.5	134
Dry residue	mg/l	639	760	639	760	639	760
Phosphate ion	mg/l	0.146	7.2	0.146	7.2	0.146	7.2
Fluoride ion	mg/l	0.032	0.11	0.032	0.11	0.032	0.11
Chloride ion	mg/l	57	125	57	125	57	125
COD	mgO ₂ /l	42	81	42	81	42	81
Chrome 3+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.
Chrome 6+	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.
Zinc	mg/l	0.0076	0.016	0.007	0.016	0.007	0.01

Table 4. Standard of permissible reset.

Indicator name	Unit of measurement	Current discharge requirements
Ammonium ion	mg/l	0.50
BOD ₅	mgO ₂ /l	2.05
Suspended solids	mg/l	13.0
Total iron	mg/l	0.11
etroleum products	mg/l	0.08
Nitrate ion	mg/l	40.00
Nitrite ion	mg/l	0.10
Anionic surfactants	mg/l	0.99
Phosphate ion (on P)	mg/l	0.22
COD	mgO ₂ /l	30.0

In the current situation, with the «traditional» scheme, the low efficiency of biological treatment processes, namely in the operation of aeration tanks, is revealed, and achieving the requirements for the discharge of pollutants is impossible without the use of special technologies that require the reconstruction of treatment facilities and the re-technology of biological treatment facilities.

The simulation of the operation of biological treatment facilities was carried out using a computer program based on the mathematical models ASM (ASM2d, ASM3), EAWAG, which were first published in 2000-2003 [14, 20, 21]. The developer of the models is a special group for mathematical modeling of the International Water Association [22]. The simulation allows us to calculate biological sewage water treatment facilities that operate according to various technological schemes. Currently, the modeling of cleaning processes using such models is a mandatory attribute of international design requirements.

In the program, the ASM and EAWAG models are supplemented with a hydraulic model, where the aeration tank is presented in the form of several full mixing reactors, to which any amount of liquid can be added or removed from them. The processes of secondary sedimentation tanks are described by the balance equations.

To perform calculations in a computer program, the aeration tanks were conditionally divided into equal sections, taking into account the existing layout of aeration elements, taking into account the presence of primary sedimentation tanks and the joint removal of sediment. In addition, to refine the initial data for calibration of the models, additional studies of the qualitative composition of incoming sewage water were conducted during a 24-hour period of two separately selected days (Table 5).

Table 5. Qualitative composition for model calibration.

Indicator name	Unit of measurement	00-00	3-00	6-00	9-00	12-00	15-00	18-00	21-00
Sampling 24.08.2017									
COD shaken up	mgO ₂ /l	560	380	320	720	980	700	340	300
COD filtered	mgO ₂ /l	280	210	240	340	300	340	210	200
BOD ₅ shaken up	mgO ₂ /l	216	297	224	270	199	300	280	333
BOD ₅ filtered	mgO ₂ /l	100	180	116	147	143	187	155	108
Suspended solids	mg/l	547	207	148	534	467	222	249	295
Ammonium ion	mg/l	40,5	41.7	47.6	74.0	58.5	46.4	45.7	40.3
Total phosphorus	mg/l	2.43	2.25	2.28	4.76	3.40	3.07	3.00	2.39
Phosphate ion	mg/l	7.36	6.82	6.90	14.4	10.3	9.3	9.1	7.24
Sampling 28.08.2017									
COD shaken up	mgO ₂ /l	620	480	340	980	680	760	760	980
COD filtered	mgO ₂ /l	320	300	210	210	370	200	260	360
BOD ₅ shaken up	mgO ₂ /l	348	229	180	345	341	364	400	385
BOD ₅ filtered	mgO ₂ /l	201	94	81	156	180	148	171	170
Suspended solids	mg/l	358	232	183	494	214	505	469	564
Ammonium ion	mg/l	46.1	50.8	51.9	70.7	53.1	55.6	46.2	55
Total phosphorus	mg/l	2.60	2.97	2.60	3.68	3.38	2.04	2.60	3.20
Phosphate ion	mg/l	8.80	9.00	7.90	11.2	10.2	6.20	7.90	9.70

All organic substances containing biogenic elements were represented as biologically degradable and biologically non-degradable [23]. Each substance from these groups can be attributed to compounds that are in dissolved and undissolved form (colloidal and suspended particles). In addition, sewage water contains mineral forms of biogenic elements.

For calculations based on a computer model, carbon-containing substances are decomposed according to the above characteristics in units of COD (Figure 1) [14, 22]. All substances in the sewage liquid are divided into dissolved (indicated by the letter S with indexes) and undissolved (indicated by the letter X with indexes) substances [14]. In turn, each of these types of substances, including those containing nitrogen and phosphorus, is divided into biologically non – degradable (hereinafter referred to as the lower index I- inert) and biologically degradable (other indices). As a generalized characteristic of carbon-containing substances, COD is used, which is possessed by biologically degradable and biologically non-degradable substances.

Fig 1. Division of carbon-containing components.

It is obvious that biologically decomposable substances, dissolved and undissolved and evaluated by the indicators of BOD and COD, can not represent a single compound [24]. An accurate description of the kinetics of their use in the processes of assimilation and dissimilation of microorganisms is currently impossible. However, the division into two groups – fast decomposable and slow decomposable, allowed us to create a satisfactory mathematical description of this process.

The values of COD and BOD₅ samples obtained in the laboratory were used as initial data for the distribution of fractional indicators. Subsequently, the fractionation data was used as a source for creating a mathematical model and obtaining cleaning results similar to the operational data. The results of the fractional distribution of the main organic indicators are shown in Table 6 and in Figure 2 and Figure 3.

Table 6. Fractionation of COD and BOD₅ for sewage treatment plants.

Indicator name	Dissolved inert gases (Si)	Colloidal Substrate (Scol)	Oxidizable (Ss)	Suspended inert (Xi)	Slowly oxidized (Xs)
COD, mgO ₂ /l	31.9	59.4	127.8	83	336.6
BOD ₅ , mgO ₂ /l	0	59.4	127.8	0	142.3

Fig 2. Fractional distribution of COD: 1-slowly oxidizable (Xs), 2-inert (Si), 3 – colloidal substrate (Scol), 4-oxidizable (Ss), 5-inert (Xi)

Fig 3. Fractional distribution of BOD₅: 1-slowly oxidizable (Xs), 2-inert (Si), 3 – colloidal substrate (Scol), 4-oxidizable (Ss), 5-inert (Xi)

It should be noted that the presented values of the fractional distribution of COD show that the latter in the incoming sewage water is largely represented by suspended slowly oxidized substances, which causes a low efficiency of sewage water treatment in aeration tanks at present. In the case of BOD, slowly oxidized substances also predominate.

After mathematical processing, the results obtained were comparable to the operational values. Accordingly, the separation into fractions of organic compounds represented by COD is made accurately, and the obtained values will be used to adjust the mathematical model.

3 Results and discussion

The choice of a scheme for the reconstruction of biological treatment facilities is the main stage that determines the concept of the development of sewage treatment facilities. The technological efficiency of biological treatment facilities at the modeling stage is determined depending on the loads on the facilities for organic and biogenic elements.

The first stage for designing the technological scheme and predicting the quality of sewage water treatment is the modeling of the initial quality of treatment (calibration of the

model) [14, 25-27]. The model was adapted to the actual composition and consumption of sewage water, as well as the actual air consumption for aeration.

The calculations showed that the calculated and actual values have a sufficiently high degree of convergence, and are the basis for further research by mathematical modeling of biological purification processes using the program. The initial data for the simulation is taken from Table 1, with the refinement of the additional fractional coefficients noted in the additional analyses in Table 3.

The following parameters were studied: the concentration of ammonium nitrogen, nitrite nitrogen, nitrates, phosphate phosphorus, and sludge growth.

The real volume mass transfer coefficient of oxygen (K_{La}) is taken into account according to the model as follows [21, 27]:

$$\frac{dSO_2}{dt} = \frac{CR_{so_2} \cdot SO_2}{CRT} + K_{La} \cdot (C_a - SO_2) + V_{so_2} \tag{1}$$

$$K_{La} = SOTE \cdot \frac{Q_{air}}{I_{air}} \cdot \frac{24 \cdot K_3 \cdot K_1 \cdot p}{C_{ast} \cdot \frac{V_{yq}}{I_{air}}} \cdot 10 \cdot 0,232 \tag{2}$$

where $SOTE (q_{air}, h_a)$ – is the mass transfer coefficient of oxygen; $K_3 (a)$ – a-factor, sewage water quality coefficient; K_t – temperature coefficient of sewage water; p – air density at normal pressure; C_{ast} – oxygen solubility at 20°C at a depth of h_a ; V_{uch} – specific volume of air per 1 p. m. of the aerator; 0.232 – mass fraction of oxygen in the air; 10 – conversion factor.

The required number of aerators is determined by the formula [21, 27]:

$$n = \frac{Q_{air}}{q_{dif}} = \frac{I}{q_{dif}} \times \frac{OU_h \cdot C_{st,h} \cdot 100}{0,232 \cdot 1,2 \cdot SOTE_{h,qdif} \cdot k_i \cdot \alpha \cdot (\beta \cdot C_{st,h} - C_f)} \tag{3}$$

where Q_{air} – is the calculated air flow rate under normal conditions, m³/h; q_{dif} – nominal value of specific air flow, m³/m (pcs.)*h, Table measurement; $C_{st,h}$ – the average value of the saturation concentration of dissolved oxygen at the depth of the aeration tank h (m), mg/dm³, at a temperature of 20°C; $SOTE_{h,qdif}$ – value of the standard efficiency of air oxygen use during aeration; $a = 0,8$ – water quality coefficient; $B = 1$ – the coefficient of influence of the sewage liquid on the solubility of oxygen.

The throughput capacity of the «aeration tank-secondary sedimentation tank» system according to the calculation of the ATV standard with the actual quality composition of incoming sewage water is given in Table 7.

Table 7. Simulation results.

Source data		
Name		Data
Sewage water consumption: daily		40000 m³/day
maximum hourly		2515 m³/h
Kgen max		1.509 SNiP
Movement of water in secondary sedimentation tanks		horizontal
Activated sludge consumption (in fractions)		0.57
Sludge index		100 ml/g
Average winter water temperature		12°C
Quality of drains with primary sedimentation		
Sewage water parameters		Supplied
		Required purified
COD		584
		30 mg/l
BOD ₅		345
		2 mg/l

Suspended solids	338.6	13 mg/l
Ammonium nitrogen	59.5	0.39 mg/l
Nitrogen of nitrates+nitrites	0.3	9.03 mg/l
Phosphorous of phosphates	14.1	0.072 mg/l
Characteristics of structures		
Surface area of secondary sedimentation tanks		1985 m ²
Depth of secondary sedimentation tanks		3.7 m
Secondary sedimentation tank capacity		7360 m ³
Calculation of the work		
load BOD ₅		13800 kg/day
Stock ratio		1.45
Estimated aerobic age of sludge		6.62 days
Updated age of slit		13.14 days
Calculation of secondary sedimentation tanks:		
Duration of settling of the sludge mixture		2.926 h
Bottom sludge concentration in secondary sedimentation tanks		14.3 g/l
Return sludge concentration		8.58 g/l
The dose of sludge in the aeration tank		3.065 g/l
Removal of sewage water from secondary sedimentation tanks		18.66 mg/l
Load on the volume of sludge in secondary sedimentation tanks		388.4 l/m ² *h
Maximum surface load secondary sedimentation tanks		1.267 m ³ / m ² *h
Organic nitrogen at the inlet		18.55 mg/l
Total incoming nitrogen		78.4 mg/l
Organic nitrogen output		2.0 mg/l
Nitrogen included in the biomass		15.53 mg/l
Nitrogen removed		51.4 mg/l
Percentage of denitrification zones		0.497
Phosphorus concentration in treated waters		8.19 mg/l
Phosphorus accumulated in biomass		3.45 mg/l
Phosphorus required for biomass growth		4.31 mg/l
Total phosphorus of incoming sewage water		15.96 mg/l
Daily increase in sludge when organic matter is removed		13139 kg/day
Daily increase in sludge when phosphorus is removed		518 kg/day
Sludge growth		13657 kg/day
Weight of suspended substances in aeration tanks		179500 kg
Required capacity of aeration tanks		58565 m ³
Internal recycling (in fractions)		5.03
Consumption of activated sludge by calculation (in fractions)		0.556
Volume load by BOD ₅		0.236
Load on sludge by BOD ₅		0.077
Average aeration period		35.14 h
Minimum aeration period		23.28 h
Oxygen consumption for organic oxidation		649 kg/h
Oxygen consumption for nitrification		431.0 kg/h
Oxygen release during denitrification		248.5 kg/h
Total oxygen consumption taking into account unevenness		1095 kg/h
Estimated sewage water consumption: daily		9697 m ³ /day
Maximum hourly		1214 m ³ /h
Kgen max		1.458 SNiP

The result of the simulation protocol according to the ATV standard (Table 7), showed that the throughput capacity of treatment facilities when operating under the existing sewage

water treatment scheme was $Q=9,697\text{ m}^3/\text{day}$. The limiting factor is the capacity of the aeration tanks and the significant introduction of pollutants in the inefficient primary sedimentation of sewage water. The limitation in the throughput capacity of biological sewage water treatment is due to high concentrations of organic substances and nitrogen compounds, as well as limited routine recycling for their disposal.

The result of the simulation protocol according to the ATV standard of the «aeration tank-secondary sedimentation tank» system with a qualitative composition of incoming sewage water after primary sedimentation tanks without co-deposition of raw sludge and excess sludge, showed that the throughput capacity of treatment facilities was $Q=19,997\text{ m}^3/\text{day}$, the limiting factor is also the capacity of the aeration tanks.

The variants of reconstruction of aeration tanks, arrangement and modification of recycles for deeper biological treatment according to the following schemes are considered:

- option 1 - scheme without supplying excess activated sludge into the primary sedimentation tank;
- option 2 - scheme with the supply of excess activated sludge to the primary sedimentation tank and the specified concentration of suspended substances at the entrance to the aeration tank (automated removal of sediment from the sedimentation tank);
- option 3 - scheme involving the use of existing primary sedimentation tanks, their conversion to anoxic and anaerobic zones with the installation of mechanical agitators.

Table 8 presents the data of the cleaning scheme for option 1.

Table 8a. Scheme of biological sewage water treatment in aeration tanks-Option 1.

Aeration tank section N		1	2	3	4
Section length, m	-	30	30	30	30
Sewage water discharge, m^3/day	-	8163	-	-	-
Recirculation flow inlet from the secondary sedimentation tank, m^3/day	-	4898	-	-	-
Recirculation flow inlet: from the end of 4 section, m^3/day from the end of 8 sections, m^3/day	-	200000 8163	-	-	-
Heterotrophic biomass, $\text{mg} / \text{l XH}$	0	824	825	824.8	825
Autotrophic biomass, $\text{mg} / \text{l XA}$	0	145.8	145.7	145.9	145.8
COD of spare substances, mg/l XSTO	0	10.4	10.5	10.21	9.74
Inert part of BB, mg/l XI	28.5	2850	2850	2850	2850
Oxidizable part of BB, mg/l XS	85.6	20.74	20.23	19.73	19.25
Phosphates-accumulating organisms, mg/l HRAO	0	0.0057	0.0057	0.0057	0.0057
Phosphorus-accumulating organic products, $\text{mg} / \text{l XPHA}$	0	0.00009	0.0001	0.00009	0.00009
Polyphosphates, $\text{mg} / \text{l XRP}$	0	0.00072	0.00072	0.00072	0.00072
Biodegradable part of dissolved organic matter, $\text{mg BOD} / \text{l SS}$	111.5	1.619	0.674	0.3216	0,2458
Inert organic matter, $\text{mg} / \text{l SI}$	33.7	33.7	33.7	33.7	33.7
Ammonium nitrogen, $\text{mg} / \text{l SNH}$	57.1	14.03	14.05	13.17	13.12
Nitrogen of nitrates+ nitrites, $\text{mg} / \text{l SNO}$	78	8.55	8.2	8.97	8.78
Molecular nitrogen, mg/l	0	37.98	38.3	38.44	38.67
Phosphorous of phosphates, mg / l	5.8	5.717	5.71	5.71	5.709

PO ₄					
Oxygen, mg / l SO	0	0.00562	0.00019	261	0.00952
Alkalinity, mmol / l SHCO	6	2 323	2 348	2.23	2.24
Suspended solids, mg / l	-	3017	3016.9	3016.7	3016.4
Oxygen consumption, kgO ₂ /h	-	0	0	42.77	0
Total oxygen consumption	109.5 kgO ₂ /h	-	-	-	-
Total nitrogen	19.07 mg/l	-	-	-	-
Total phosphorus	5.82 mg/l	-	-	-	-
Number of rows of aerators	0	0	4	0	0
Total length of aerators, m	0	0	112	0	0
Air consumption for oxidation, m ³ /h	0	0	1120	0	0
for mixing ATV, m ³ /h	0	0	394	0	0
Specific air consumption, m ³ /h*m	0	0	10.00	0	0
SOTE, %	0	0	16.6	0	0

Table 8b. Scheme of biological sewage water treatment in aeration tanks-Option 1.

Aeration tank section N	5	6	7	8
Section length, m	30	30	30	30
Heterotrophic biomass, mg/l XH	827	825	822.9	818
Autotrophic biomass, mg / l XA	145.4	145.9	146.4	146.4
COD of spare substances, mg/l XSTO	6.48	4.44	3.18	2 466
Inert part of BB, mg/l XI	2851	2852	2853	2854
Oxidizable part of BB, mg/l XS	15.2	12	9.48	7.48
Phosphates-accumulating organisms, mg/l XPAO	0.0057	0	0.00568	0.00566
Products of phosphorus-accumulating organic matter, mg/l XPHA	0.00008	0.00006	0.00005	0.00004
Polyphosphates, mg / l XPP	0.00072	0.00073	0.00073	0.00074
Biodegradable part of dissolved organic matter, mg COD/l SS	0.1755	0.1208	0.0928	0.0656
Inert organic matter, mg / l SI	33.7	33.7	33.7	33.7
Ammonium nitrogen, mg/l SNH	13.14	8.38	3 765	0.2996
Nitrogen of nitrates+ nitrites, mg/l SNO	6.81	10.67	14.67	18.43
Molecular nitrogen, mg/l	40.64	41.66	42.44	42.5
Phosphorous of phosphates, mg/l SPO4	5.707	5.72	5.75	5.82
Oxygen, mg / l SO	0.00004	0.1250	0.1645	2.84
Alkalinity, mmol/l SHCO	2 383	1 767	1.15	0.6310
Suspended solids, mg / l	3012.8	3009.3	3305.6	3000.0
Oxygen consumption, kgO ₂ /h	0	21.69	21.6	23.44
Number of rows of aerators	2	2	3	0
Total length of aerators, m	56	56	84	0
Air consumption for oxidation, m ³ /h	560.0	560.0	840.0	0
for mixing ATV, m ³ /h	394	394	394	0
Specific air consumption, m ³ /h*m	10.00	10.00	10.00	0
SOTE, %	16.6	16.6	16.6	0
Required air flow per section Qa = 3080 m ³ /h.				

Due to the lack of organic pollutants at very high concentrations of ammonium nitrogen compounds, it is possible to reduce the nitrogen of nitrates to only 18 – 19 mg/l. Thus, the

imbalance of organic and nitrogen compounds noted in Table 2 ultimately affects the efficiency of biological purification, with low denitrification.

Table 9 presents the data of the purification scheme with effective denitrification according to option 2. The scheme of biological sewage water treatment according to option 2 is shown in Figure 4.

Table 9a. Scheme of biological treatment in aeration tanks-Option 2.

Aeration tank section N	-	1	2	3	4
Plot length, m	-	30	30	30	30
Sewage water discharge, m ³ /day	-	8966	-	-	-
Recirculation flow inlet from the secondary sedimentation tank, m ³ /day	-	7173	-	-	-
Recirculation flow inlet: from the end of 4 sections, m ³ /day from the end of section 8, m ³ /day	-	300000 8966	-	-	-
Heterotrophic biomass, mg/l XH	0	1710	1711	1712	1712
Autotrophic biomass, mg / l XA	0	123.4	123.4	123.5	123.5
COD of spare substances, mg/l XSTO	0	34	34.5	34.19	33.60
Inert part of BB, mg/l XI	55.48	1725	1725	1725	1725
Oxidizable part of BB, mg/l XS	312.7	80.7	79.3	78.00	76.7
Phosphates-accumulating organisms, mg/l XPAO	0	8.460	8.46	8.46	8.47
Products of phosphorus-accumulating organic matter, mg/l XPHA	0	0.5628	0.5670	0.5598	0.5557
Polyphosphates, mg / l XPP	0	1.304	1 303	1 305	1 306
Biodegradable part of dissolved organic matter, mg COD/l SS	180.2	2.297	1 378	0.5566	488
Inert organic matter, mg / l SI	35.6	35.6	35.6	35.6	35.6
Ammonium nitrogen, mg/l SNH	59.5	8.96	8.99	8.03	7 868
Nitrogen of nitrates+ nitrites, mg/l SNO	0.32	1.004	579	1.48	1 336
Molecular nitrogen, mg/l	0	55.38	55.8	55.87	56.16
Phosphorous of phosphates, mg/l SPO ₄	14.1	13.79	13.79	13.78	13.78
Oxygen, mg / l SO	0	0.00953	0.00038	1.088	0.05886
Alkalinity, mmol/l SHCO	6	2.357	2.390	2.257	2.256
Suspended solids, mg / l	-	3036.9	3036.7	3036.3	3035.7
Oxygen consumption, kgO ₂ /h	-	0.00001	0	91.6	0.00001
Total oxygen consumption		185 kgO ₂ /h	-	-	-
Total Nitrogen		8.33 mg/l	-	-	-
Total phosphorus		13.86 mg/l	-	-	-
Number of rows of aerators	-	0	0	6	0
Total length of aerators, m	-	0	0	168	0
Air consumption for oxidation, m ³ / h	-	0	0	2688	0
for mixing ATV, m ³ / h	-	0	0	394	0
SOTE, %	-	0	0	16.2	0

Table 9b. Scheme of biological treatment in aeration tanks-Option 2.

Aeration tank section N	5	6	7	8
Plot length, m	30	30	30	30
Heterotrophic biomass, mg/l XH	1713	1718	1717	1712
Autotrophic biomass, mg / l XA	123.5	124.6	124.2	123.7
COD of spare substances, mg/l XSTO	38.29	28.57	20.97	16.48
Inert part of BB, mg/l XI	1725	1727	1730	1733
Oxidizable part of BB, mg/l XS	62.9	51.4	42.06	34.36
Phosphates-accumulating organisms, mg/l XPAO	8 469	8.51	8.52	8.51
Products of phosphorus-accumulating organic matter, mg/l XPHA	835	701	615	0.56
Polyposphates, mg / l XPP	1 208	1 259	1 305	1 346
Biodegradable part of dissolved organic matter, mg COD/l SS	4.6	0.2954	0.1749	0.1416
Inert organic matter, mg / l SI	35.6	35.6	35.6	35.6
Ammonium nitrogen, mg/l SNH	8.09	947	0.0799	0.13457
Nitrogen of nitrates+ nitrites, mg/l SNO	0.0354	6.64	7.54	7.93
Molecular nitrogen, mg/l	7.46	58.0	58.20	58.3
Phosphorous of phosphates, mg/l SPO4	13.93	13.83	13.82	13.86
Oxygen, mg / l SO	0.00014	1.845	2.96	4.115
Alkalinity, mmol/l SHCO	2.354	1.379	1.254	1.222
Suspended solids, mg / l	3028.8	3021.6	3010.9	2999.9
Oxygen consumption, kgO ₂ /h	0	52.29	22.49	18.7
Number of rows of aerators	0	4	2	2
Total length of aerators, m	0	112	56	56
Air consumption for oxidation, m ³ / h	0	1680	840	840
for mixing ATV, m ³ / h	0	394	394	394
SOTE, %	0	16.2	16.2	16.2
Required air flow per section Qa = 6048 m ³ /h.

Fig 4. Scheme of biological treatment in aeration tanks according to Option 2: 1-active sludge supply, 2-sewage water supply, 3-mixing zone, 4-aeration zone, 5-sludge mixture recycling, 6-sludge mixture output.

As can be seen from the ATV simulation protocol, in order to reconstruct structures using nitrification-denitrification technology, it is necessary to increase the capacity of aeration tanks. However, the circulation of excess activated sludge and its co-deposition with the sediment

of primary sedimentation tanks increases the load on the biological treatment of phosphates and produces problems in operation with inefficient sediment removal, as well as increases the operating costs of chemical reagent dephosphotation.

In the scheme according to option 3, the formation of raw sludge is excluded, the return activated sludge is fed to the mixing zone (repurposed primary sedimentation tanks), and a «nitrate recycle» is also sent to this zone from the end of the aeration tank (Table 10).

Table 10a. Scheme of biological treatment in aeration tanks-Option 3.

Aeration tank section N		1	2	3	4
Plot length, m	-	34	34	30	30
Sewage water discharge, m ³ /day	-	13330	-	-	-
Recirculation flow inlet from the secondary sedimentation tank, m ³ /day	-	11000	-	-	-
Recirculation flow inlet: from the end of the 10 section, m ³ /day	-	100000	-	-	-
Heterotrophic biomass, mg/l XH	0	1089	1091	1092	1093
Autotrophic biomass, mg/l XA	0	125	124.9	124.9	124.8
COD of spare substances, mg/l XSTO	0	18.16	1.36	17.25	16.04
Inert part of BB, mg/l XI	42.5 7	1304	1304	1304	1304
Oxidized part of BB, mg/l XS	127. 7	35.17	33.47	32.03	30.66
Phosphates-accumulating organisms, mg/l XPAO	0	0.0036 25	0.0036 27	0.0036 29	0.0036 3
Products of phosphorus-accumulating organic matter, mg/l XPHA	0	0.0000 89	0.0000 91	0.0000 9	0.0000 88
Polyphosphates, mg/l XPP	0	0.0004 81	0.0004 80	0.0048 1	0.0004 81
Biodegradable part of dissolved organic matter, mg COD/l SS	166. 4	3.709	0.854	0.394	0.3094
Inert organic matter, mg/l SI	50.3	50.3	50.3	50.3	50.3
Ammonium nitrogen, mg/l SNH	57.1	6.59	6.628	6.609	6.59
Nitrogen of nitrates+nitrites, mg/l SNO	0.1	4.968	3.94	3.287	2.707
Molecular nitrogen, mg/l	0	49.46	50.49	51.1	51.7
Phosphorous of phosphates, mg/l SPO ₄	3.92	3.556	3.545	3.536	3.530
Alkalinity, mmol/l SHCO	7	3.06	3.139	3.184	3.224
Ash-free part of BB, mg/l, MLVSS XTSS	-	2108.1	2108.1	2107.3	2106.4
Oxygen consumption, kg O ₂ /h	-	0	0	0	0
Total oxygen consumption	204 kgO ₂ /h	-	-	-	-
Total nitrogen	22.95 mg/l	-	-	-	-
Total phosphorus	6.649 mg/l	-	-	-	-
Sludge growth	95.9 mg/l	-	-	-	-
Number of rows of aerators	-	0	0	0	0
Total quantity of aerators	-	0	0	0	0
Air consumption for oxidation, m ³ /h	-	0	0	0	0
for mixing ATV, m ³ /h	-	0	0	0	0
Specific air consumption, m ³ /h*m	-	0	0	0	0
SOTE, %	-	0	0	0	0

Table 10b. Scheme of biological treatment in aeration tanks-Option 3.

Aeration tank section N	5	6	7	8	9	10
Plot length, m	30	30	30	30	30	34
Heterotrophic biomass, mg/l XH	1094	1094	1094	1094	1094	1093
Autotrophic biomass, mg/l XA	124.8	124.7	125.3	125.6	125.8	125.7
COD of spare substances, mg/l XSTO	14.96	14.03	12.88	11.8	10.86	10.01
Inert part of BB, mg/l XI	1304	1304	1305	1305	13.05	1306
Oxidized part of BB, mg/l XS	29.34	28.08	26.87	25.7	24.60	23.40
Phosphates-accumulating organisms, mg/l XPAO	0.0036 34	0.0036 36	0.003 637	0.0036 38	0.0036 38	0.0036 3
Products of phosphorus-accumulating organic matter, mg/l XPHA	0.0000 87	0.0000 86	0.000 081	0.0000 77	0.0000 73	0.0000 7
Polyphosphates, mg/l XPP	0.0004 82	0.0004 83	0.000 484	0.0004 86	0.0004 88	0.0004 9
Biodegradable part of dissolved organic matter, mg COD/l SS	0.2929	0.2924	0.189 3	0.1693	0.16	0.152
Inert organic matter, mg/l SI	50.3	50.3	50.3	50.3	50.3	50.3
Ammonium nitrogen, mg/l SNH	6.57	6.55	3.67	1.513	0.4330	0.1032
Nitrogen of nitrates+nitrites, mg/l SNO	2.172	1.678	45	6.62	7.7	8.06
Molecular nitrogen, mg/l	52.25	52.7	52.79	52.8	52.9	52.88
Phosphorous of phosphates, mg/l SPO ₄	3.524	3.53	3.514	3.51	3.515	3.524
Alkalinity, mmol/l SHCO	3.26	3.296	2.889	2.583	2.429	2.380
Ash-free part of BB, mg/l, MLVSS XTSS	2105.5	2104.7	2103. 8	2102.8	2101.6	2100.0
Oxygen consumption, kg O ₂ /h	0	0	87.8	58.78	37.59	19.9
Number of rows of aerators	0	0	5	4	3	2
Total quantity of aerators	0	0	215	172	129	98
Air consumption for oxidation, m ³ /h	0	0	3511	1978	1290	529.5
for mixing ATV, m ³ /h	0	0	394	394	394	446.8
Specific air consumption, m ³ /h*m	0	0	16.33	11.50	9.38	5.4
SOTE, %	0	0	14.18	16.86	18.9	22.89
Required air flow per section Qa = 7228 m ³ /h.						

As can be seen from the protocol for modeling processes according to option 3-reformatting part of the primary sedimentation tanks under the mixing zone, and using the remaining sedimentation tanks for their intended purpose, allows for high-quality cleaning according to organic indicators and the nitrogen group (nitri-denitrification). However, the biological removal of phosphorus is carried out with a low degree of removal. The advantage of this scheme is lower loads for phosphates and, accordingly, lower operating costs for its chemical reagent removal compared to option 2. The scheme of biological treatment for option 3 is shown in Figure 5.

Fig 5. Scheme of biological treatment in aeration tanks according to Option 3: 1-sewage water supply, 2-anaerobic reactor, 3-sludge mixture, 4-aeration tank, 5-mixing zone, 6-aeration zone, 7-sludge mixture recycling, 8-secondary sedimentation tank, 9-activated sludge supply.

4 Conclusions

Calculations have shown that the existing technological scheme of sewage treatment facilities in Almet'yevsk does not allow to achieve the quality of treated sewage water at the level of the MPC for fisheries reservoirs.

The obtained calculation data made it possible to make a variant study of the technological schemes of reconstruction for the design capacity of 40 thousand m³/day. Modeling of nitri - denitrification and biological phosphorus removal schemes showed that the quality of purification is affected by the ratio of the size of mixing zones (anaerobic and anoxic), the size and location of the sludge mixture recycle. When performing the calculations, the concentrated and dispersed sewage water supply to the aeration tanks was considered.

The most effective option 3 of biological purification in aeration tanks with the use of nitri-denitrification technology was selected, which allows removing not only organic substances, but also nitrogen and partially phosphorus compounds.

The low efficiency of the transport of dissolved oxygen into the sludge mixture contributes to the minimum number of rows of aerators and their wall-mounted arrangement in the aeration tanks. The reconstruction of the existing aeration tanks with the replacement of the aeration system and the introduction of an automatic air supply control system, will ensure the effective removal of organic compounds and ammonium nitrogen, and will also reduce energy consumption.

The achievable quality of sewage water treatment after the reconstruction of sewage treatment plants is presented in Table 11.

Table 11. Stage-by-stage cleaning efficiency and VAT requirements.

N	Name of indicators	Value in incoming water	Effect BT, %	After BT, mg/l	Effect PT, %	After PT, mg/l	MPC f
1	2	3	4	5	6	7	8
1	COD	387	88	46.4 4	35	30.2	35
2	BOD ₅	245.55	98.9	2.82	30	202	2
3	Ammonium ion	73.425	99.4	0.44	0	0.44	0.5
4	Nitrite anion	0.007	0	0.08	0	0.08	0.08
5	Nitrate anion	0.3	0	40	0	40.0 0	40
6	Suspended solids	310.1	96	12.4 0	60	4.96	5
7	Petroleum products	1.9	95	0.10	45	0.05	0.05
8	Active surfactants	2.49	93	0.17	45	0.1	0.1
9	Phosphate ion	15.6	5.0	14.7 9	95.9	0.61	0.61/0. 2
10	Total iron	2.07	94.5	0.11	10	0.1	0.1

As can be seen from Table 11, as a result of the reconstruction, the estimated quality of cleaning will meet the standard of permissible discharge in all indicators. The cost of sewage water treatment in accordance with the cost of implementing technological solutions (CAPEX) and operating costs (OPEX) for option 3 is shown in Table 12.

Table 12. Cost indicators.

N	Type of deduction		Cost name, RUB/ year	% of costs	
1	2		3	4	
1	Depreciation charges for buildings and structures		9 600 000.0	8.16	
2	Depreciation on equipment		11 721 278.0	9.96	
3	Major repairs, current repairs, other expenses		14 214 185.0	12.08	
4	Reagent costs (without transportation)				
	- iron sulfate	3626.3	kg/day	24 658 502.0	20.95
	- flocculant	106.5	kg/day	17 492 625.0	14.86
5	Electric power	750	kW / h	28 607 094.0	24.31
6	Salary	21	h	6 804 000.0	5.78
7	Water for process requirements	965.1	m³/day	1 461 864.0	1.15
8	Removal of sludge to the landfill	98.6	m³/day	2 159 248.0	1.83
9	Placement of sludge at the landfill	98.6	m³/day	1 079 624.0	0.92
	Total		117 689 114.0	100.0	
	Cost of cleaning 1 m³		8.06		

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