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APPLICATION OF AERATION-OXIDATIVE JET-LOOPED SETUP FOR BIOLOGICAL WASTEWATER TREATMENT

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The purpose of the study was the design of an aerator-oxidizer and optimal parameters of its work to ensure the conditions of mixing and dissolution of oxygen, in which there is no disturbance of the state of activated sludge. The testing of the work of the aeration-oxidation setup of rotor type with the use of a sludge mixture with different design of aerator-oxidizers and in different operating modes was performed. The assessment of the effect of processing on the state of the activated sludge was carried out according to standard parameters: sludge index, chemical oxygen demand. In addition, the number and state of activated sludge organisms were evaluated. The results of qualitative and quantitative analysis of activated sludge before and after processing in the setup are presented. The parameters in which the activated sludge functions in satisfactory mode are revealed.

Key words: activated sludge, wastewater, aerator-oxidizer, sludge index.

The effectiveness of biological wastewater treatment depends on many factors: the dose of activated sludge, temperature, pH, daily wastewater consumption, etc. However, the most important and most energy-consuming is the degree of sewage saturation with oxygen. In the process of sewage aeration, pneumatic systems are widely used, which provide sufficient concentration of dissolved oxygen in the sludge mixture and its mixing. The search for ways to saturate the sludge mixture with air oxygen with reduced energy consumption remains an urgent problem [1, 2]. One of these methods is the use of hydromechanical systems of aeration. It is known that such aeration systems have lower specific energy expenditure compared with more commonly used pneumatic systems [3, 4]. Loop reactors with jet mixing are not widely used in biological treatment of sewage. However, it is known that such reactors create favorable conditions for the effective dissolution of oxygen in water. The induced air in the conditions of intense mixing and turbulent flows is dispersed in the form of microbubbles, greatly increasing the phase separation surface, which facilitates its dissolution [5]. However, the passage of sludge mixture through a centrifugal pump and high velocities of passage through pipelines can cause mechanical damage to microorganisms of activated sludge [6, 7]. In addition, the sedimentation properties of activated sludge deteriorate as a result of mechanical damage to the activated sludge, which complicates its further separation [8].

The purpose of the study is to search for the design of an aerator-oxidizer and rational parameters of its work to ensure the mild conditions of oxygen mixing and dissolution, in which there is no violation of the state of activated sludge.

The objectives of the study are:

– estimation of the stability of sludge mixture parameters at different setup modes and aerator-oxidizer design;

– determination of the efficiency of contaminants removing by the criteria of chemical oxygen demand (COD).

Materials and Methods

The research was carried out on the basis of the experimental aeration-oxidative jet-looped setup at the Institute of Engineering

Thermophysics of the National academy of sciences of Ukraine (Fig. 1). Oxygen saturation of the treated medium and its mixing takes place in the aerator-oxidizer, which is rotary-pulsating apparatus (RPA). The research was carried out using two aerator-oxidizers of different design.

The working volume of the first aerator-oxidizer is 0.0014 m^3. The main element of this device is the rotary-pulsating knot (RPK_1), which consists of two rotors, connected in a single rotor knot (RK), and stator. The rotors have the following design parameters: internal radius of a small rotor R_{sr} = 56 mm, of a large rotor R_{lr} = 65 mm; the dimensions of the slits a = 3 mm; height h_{sl} = 5 mm; angle between them is 6°; number m = 60. The gap between the rotor and the stator in the RPK is δ = 0.15 mm. Structural parameters of the stator are as follows: internal radius R_{st} = 61 mm; the dimensions of the slits a = 3 mm; height h_{sl} = 5 mm; angle between them is 6°; number m = 60.

The second type of aerator-oxidizer, with a volume of 0.0014 m^3, contains RPK_2 consisting of one rotor and a stator. The structural parameters of the rotor are: internal radius R_{int} = 40 mm; external radius R_{ext} = 70 mm. The rotor contains 12 round holes with a diameter d_h = 12 mm. Structural parameters of the stator: internal radius $R_{st.int}$ = 70 mm; external radius $R_{st.ext}$ = 75 mm. The number of holes is 20. The gap between the rotor and the stator is δ = 0.3 mm.

As a parameter characterizing the conditions of medium processing in the RPA and can serve for different structures of the RPA comparison, the rate of the flow shift was chosen, which is determined by the formula:

$$\nu = \frac{\omega \cdot R}{\mu}, s^{-1}, \quad (1)$$

where ω is the angular velocity of the rotor, s^{-1}; R is the radius of rotor, m; μ is the gap thickness between the cylinders, m.

In the work, the determination of the doses of activated sludge by dry substance a and volume V, and sludge index I were performed.

The dose of activated sludge was calculated by the formula:

$$a = \frac{(m_2 - m_1)}{v} \cdot 1000, \text{g/dm}^3. \quad (2)$$

Determination of the dose of activated sludge by volume lie in gravity sedimentation of the sludge mixture (V_s = 200 cm^3) for 30 min with subsequent determination of the volume V_{sl}, which takes the sludge after sedimentation, and recalculated to 1 dm^3:

$$V = \frac{v_{sl}}{v_s} \cdot 1000, \text{cm}^3/\text{dm}^3 \quad (3)$$

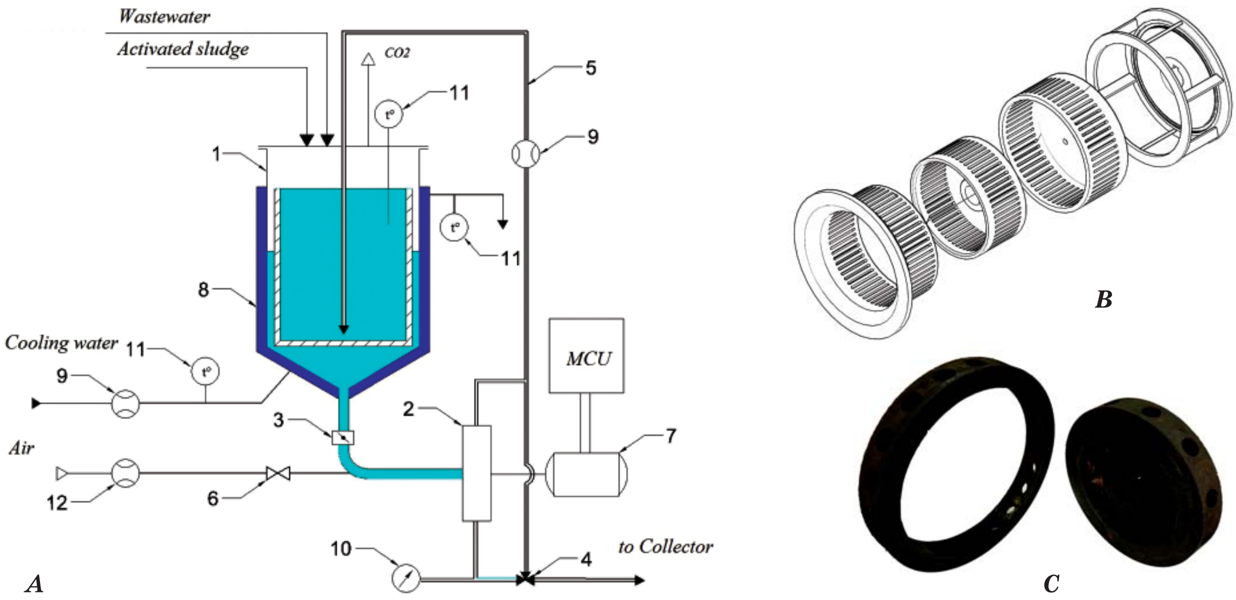


Fig. 1. **Aaeration-oxidative jet-looped setup:**
A — the chart; *B* — RPK 1; *C* — RPK 2.
1 — storage capacity with internal cylinder; *2* — aerator-oxidizer; *3* — damper; *4* — three-way valve; *5* — recirculation pipeline; *6* — two-way valve; *7* — engine; *8* — cooling shirt; *9* — flow meter; *10* — manometer; *11* — thermometer; *12* — air flow meter; MCU is a management and control unit

In order to determine the dose of activated sludge a, the sludge mixture of volume V = 50 cm^3 was collected, which was filtered on a pre-dried and weighed paper filter "white tape" of mass m_1 and dried to constant weight m_2 at 105 °C for six hours.

The sludge index is defined as the ratio of activated sludge dose of volume V to its dose a of dry matter:

$$I = \frac{V}{a}, \text{cm}^3/\text{g} \quad (4)$$

Investigation of activated sludge was carried out using a trinocular microscope of XSP-139TP Ulab model, equipped with an eyepiece with an increase of ×10 and lenses with magnifications of ×10, ×20 and ×40. In addition, the Carl Zeiss Axio Imager microscope was used.

To calculate the number of groups of activated sludge organisms, the method of "Calibrated drop" [9] was used. A sample of 150 cm^3 of sludge mixture was collected, 0.1 cm^3 of fluid was collected from it after preliminary mixing with a micropipette, placed on object glass and covered with 18×18 mm cover glass. Three such specimens were made. In each specimen, the number of organisms was counted in 10 fields of vision under a microscope with an increase of ×100. The number of organisms D in 1 cm^3 of sludge mixture was determined by the formula:

$$D = \frac{S \cdot d}{\pi \cdot r^2 \cdot \rho}, \text{cell}/\text{cm}^3, \quad (5)$$

where d is the number of organisms in one field of view (the arithmetic mean of the examined fields of view); r is radius of field of view in mm; S is the area of cover glass in mm^2; ρ is the volume of used liquid, cm^3.

Active sludge for research was taken from the sludge chamber after the secondary settling stations of Bortnitskaya aeration station in Kyiv. It represents an association of microorganisms such as bacteria, mushrooms, actinomycetes, diatoms, green microalgae, as well as protozoa and some multicellular animals (flagellates, sarcodes, infusoria, worms, rotifers, etc.). Microphotographs of activated sludge are shown in Fig. 2.

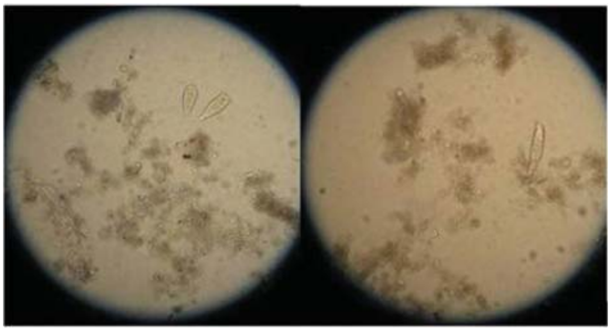


Fig. 2. **Microphotography of activated sludge with magnification of ×200**

The studies were conducted in two replicates. In both samples, the sludge is moderately-laden, no filamentous bacteria, but infusoria of the genera: *Paramecium, Vorticella, Epistylis, Euplotes;* rotifers of the genera*: Habrotrocha, Epipheres, Rotaria, Pleurotrocha* are present. In the second sample, the estimated number of organisms was determined, where the number of infusoria was 3 335 individuals per cm^3, and the number of rotifers — 205 individuals per cm^3. The both samples of activated sludge parameters are presented in Table 1. For further investigation of the purification effect by the COD parameter, a new sample of activated sludge was selected: the dose of sludge in volume is 880 cm^3/dm^3. Sludge index is 110 cm^3/g.

For a qualitative assessment of sewage pollution, a standard method for chemical oxygen demand determining for 2 hours was used — COD.

The volume of sludge mixture was 30 dm^3 with a sludge concentration of 2.5 g/dm^3, which was obtained by diluting the activated sludge with settled tap water (when evaluating the parameters of activated sludge in the first stage of the research) and with sewage (in determining the degree of sewage treatment) in the apparatus before the start of experiments.

Results and Discussion

Table 1 shows the initial parameters of activated sludge, which was selected for research conducting at Bortnitskaya aeration station.

The first 3 experiments were aimed at rational parameters of setup work and its design finding. The following two studies were conducted to assess the depth of sewage treatment by COD index.

The first study of the parameters of activated sludge in the aeration-oxidative jet-looped setup was carried out at a rate of flow shift of 112·10^3 s^{-1}, which is minimal for this apparatus. The temperature of the sludge mixture was 21.7 °C. The treatment time was 40 minutes. Sampling was performed every 10 minutes. An aerator-oxidizer with RPK$_1$ was used. The results are presented in Table 2 and in Fig. 3.

Table 1. **Parameters of activated sludge selected at Bortnitskaya aeration station**

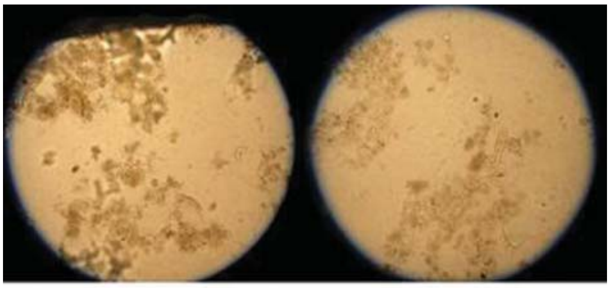
Samples №№	Dose of activated sludge, a, g/dm^3		Average dose of activated sludge, a_{av}, g/dm^3	Dose of activated sludge V, cm^3/dm^3		Average dose of activated sludge V_{av}, cm^3/dm^3	Sludge index, I, dm^3/g
	I	II		I	II		
1	8.28	8.46	8.37	925	935	930	111.11
2	7.3	8.54	7.92	950	960	955	120.58

Note: 1 and 2 are successive samples; I and II are parallel samples.

Table 2. **Parameters of activated sludge after processing with a flow shift rate of 112·10^3 s^{-1}**

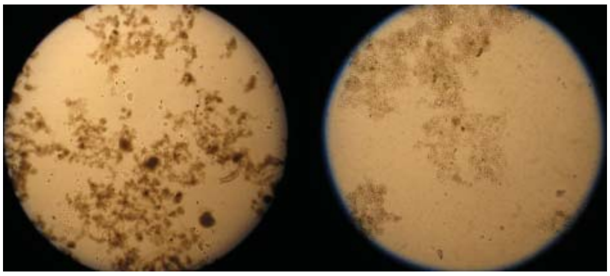
Samples №№	Dose of activated sludge, a, g/dm^3		Average dose of activated sludge, a_{av}, g/dm$_3$	Dose of activated sludge V, cm^3/dm^3		Average dose of activated sludge V_{av}, cm^3/dm^3	Sludge index, I, dm^3/g
	I	II		I	II		
C	0.8	0.74	0.77	60	65	62.5	81.17
4	0.68	0.74	0.71	60	65	62.5	88.02

Note: C — control, 4 — sample taken after 40 min of setup working; I and II are repeated experiments.



A *B*

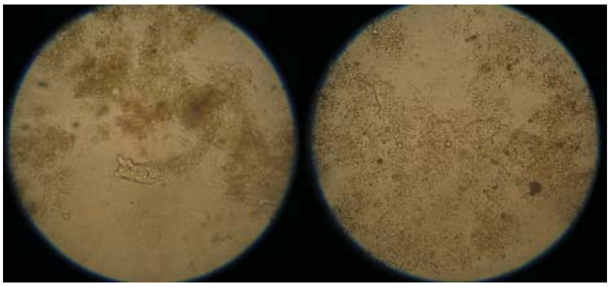
Fig. 3. **Microphotography of activated sludge with magnification of ×200:**
A — control; *B* — the 4th sample



A *B*

Fig. 4. **Microphotography of activated sludge with magnification of ×100:**
A — control; *B* — the 4th sample

The second study of activated sludge in setup was carried out at a rate of flow shift of 140·10^3 s^{-1}. The temperature of the sludge mixture was 21.7 °C. An aerator-oxidizer with RPK$_1$ was used. Processing time was 40 minutes. Sampling was performed every 10 minutes. The results are presented in Table 3, in Fig. 4 and Fig. 5.



A *B*

Fig. 5. **Microphotography of activated sludge with magnification of ×400:**
A — control; *B* — the 4th sample

The third study of activated sludge in the setup was carried out at a rate of flow shift of 70·10^3 s^{-1}. The temperature of sludge mixture was 21.7 °C. An aerator-oxidizer with RPK$_2$ was used. Processing time was 28 minutes. The results are presented in Fig. 6 and Fig. 7.

The following studies were conducted using an aerator-oxidizer with RPK$_2$.

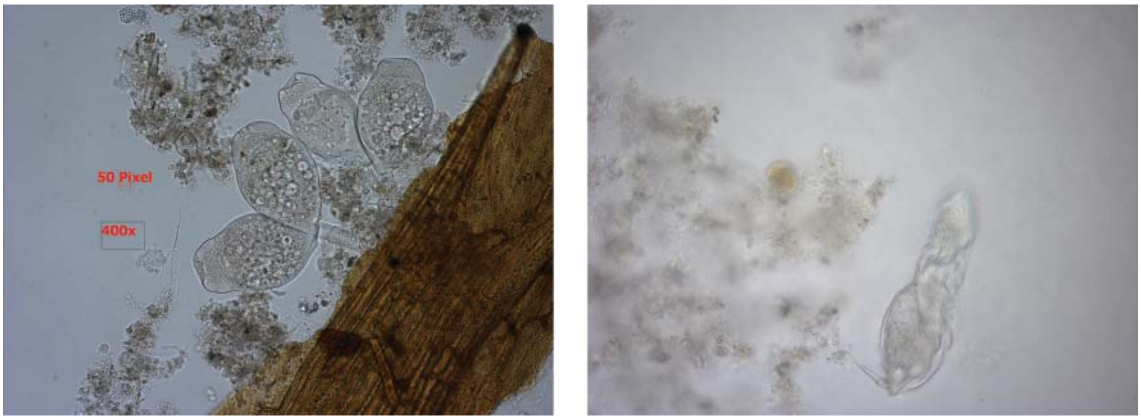
The fourth biological wastewater treatment experiment was conducted at a rate of flow shift of 70·10^3 s^{-1}. The temperature of the sludge mixture was 24 °C. Processing time was 4 hours. Sampling was carried out before the study, at the 2nd hour, at the 3rd hour and at its completion. The results are presented in Table 4.

The fifth experiment on biological wastewater treatment was carried out with a reduced rate of flow shift — 56·10^3 s^{-1}. The temperature of the sludge mixture was 24 °C. Processing time was 4 hours. Sampling was carried out before the study, at the 2nd hour, at the 3rd hour and at its completion. The results are presented in Table 4.

Table 3. **Parameters of activated sludge after processing with the rate of flow shift of $70 \cdot 10^3$ s^{-1}**

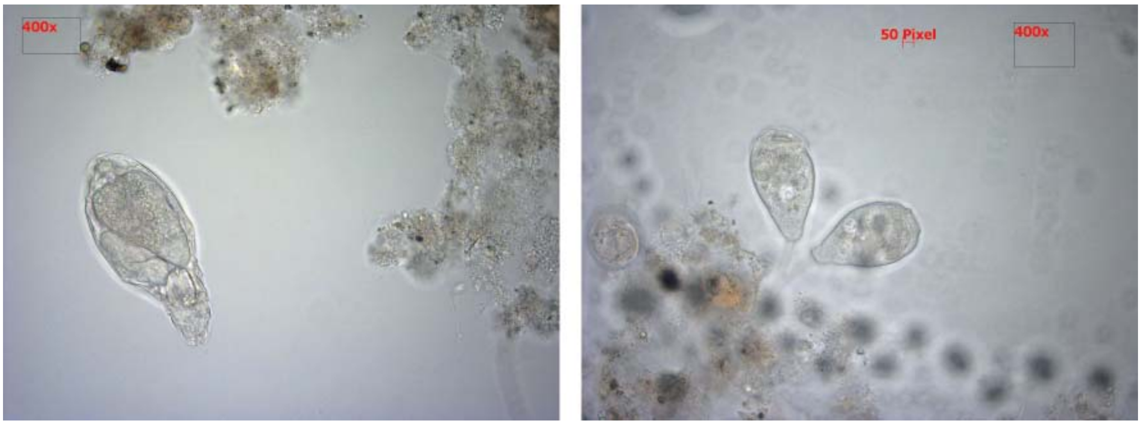
Samples №№	Average dose of activated sludge V_{av}, cm^3/dm^3	Average dose of activated sludge, a_{av}, g/dm^3	Sludge index, I, dm^3/g	Time from the start of the setup working t, min
C	82.5	0.64	128.91	0
1	90	0.61	147.54	10
2	90	0.56	160.71	20
3	90	0.52	173.08	30
4	77.5	0.47	164.89	40

Note: see note to the Table 2.



A *B*

Fig. 6. **Microphotography of activated sludge with magnification of ×400:**
A — control; *B* is a sample



A *B*

Fig. 7. **Microphotography of activated sludge with increase of ×400:**
A — control; *B* is a sample

Studies performed using an aerator-oxidizer with RPK_1, demonstrate the constancy of activated sludge parameters at a minimum angular rate of setup.

During the study of activated sludge at maximal angular rate, the destruction of activated sludge flakes and the death of eukaryotes were detected according to the results of microscopy (Fig. 5, *B* and Fig. 6, *B*). Significant growth of sludge index was noticed (Table 3).

Thus, in the third study with the usage of aerator- oxidizer with RPK_2, it was established that the parameters of activated sludge at maximum angular rate of the setup were unchanged.

Table 4. **Effect of sewage treatment in the setup**

Experiment	Sample №№	Processing duration, *t*, h	COD, mg O_2/dm^3
I	control	0	200
	2	1	–
	3	2	160
	4	3	220
	5	4	240
II	control	0	113
	2	1	180
	3	2	167
	4	3	167
	5	4	–

During the fourth study, the crushing of activated sludge flakes starting from the first hour of the experiment was observed. At the 3rd hour of the experiment, there was a complete destruction of activated sludge flakes and the death of infusoria and rotifers — the remnants of the outer shells of these organisms are present. Further destruction of particles in the sludge mixture has led to an increase of pollution by the index of COD.

During the fifth study, the sludge retained viability throughout the experiment, but still there was a crushing of activated sludge from the first hour of treatment, which also led to the re-contamination of sewage.

It should be noted that secondary contamination of sewage apparently was the result of a fairly harsh conditions of the experiment. Thus, when the rate of flow shift was $70{\cdot}10^3$ s^{-1} and the volume of sludge mixture was 30 dm^3, the frequency of its passing through the slotted holes of RPK aerator-oxidizer was 240 times per hour, or four times per minute, that does not meet the actual processing on treatment facilities.

It is found that using the second option of aerator-oxidizer provides soft mixing and aeration mode of the mixture that does not lead to the destruction of sludge and significant changes in its parameters (sludge index, sludge flakes integrity, protozoa and multicellular animals by samples microscopy). Further research will be directed to study the dynamics of wastewater biological treatment, removal efficiency of organic pollution and rational parameters of the purification process finding.

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ВИКОРИСТАННЯ АЕРАЦІЙНО-ОКИСНЮВАЛЬНОЇ УСТАНОВКИ РОТОРНОГО ТИПУ ДЛЯ БІОЛОГІЧНОГО ОЧИЩЕННЯ СТІЧНИХ ВОД

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Метою дослідження був пошук конструкції аератора-окиснювача та оптимальних параметрів його роботи для забезпечення умов перемішування та розчинення кисню, за яких не відбуватиметься порушення стану активного мулу.

Проведено випробування роботи аераційно-окиснювальної установки роторного типу з використанням мулової суміші з різними конструкціями аераторів-окиснювачів і за різними режимами роботи. Оцінювання впливу обробки на стан активного мулу здійснено за стандартними показниками: муловий індекс, хімічне споживання кисню. Також оцінено кількість і стан організмів активного мулу. Наведено результати якісного й кількісного аналізів активного мулу до та після обробки в установці. Виявлено параметри, за яких активний мул функціонує в задовільному режимі.

Ключові слова: активний мул, стічні води, аератор-окиснювач, муловий індекс.

ИСПОЛЬЗОВАНИЕ АЭРАЦИОННО-ОКИСЛИТЕЛЬНОЙ УСТАНОВКИ РОТОРНОГО ТИПА ДЛЯ БИОЛОГИЧЕСКОЙ ОЧИСТКИ СТОЧНЫХ ВОД

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Целью исследования был поиск конструкции аэратора-окислителя и оптимальных параметров его работы для обеспечения условий перемешивания и растворения кислорода, при которых не будет происходить нарушение состояния активного ила.

Проведены испытания работы аэрационно-окислительной установки роторного типа с использованием иловой смеси с различными конструкциями аэраторов-окислителей и в разных режимах работы. Оценку влияния обработки на состояние активного ила осуществляли по стандартным показателям: иловый индекс, химическое потребление кислорода. Также оценивали количество и состояние организмов активного ила. Приведены результаты качественного и количественного анализов активного ила до и после обработки в установке. Выявлены параметры, при которых активный ил функционирует в удовлетворительном режиме.

Ключевые слова: активный ил, сточные воды, аэратор-окислитель, иловый индекс.