Efficiency of air regeneration of sludge immobilized on a floating loading in a biotank

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Abstract. The purpose of the research was to determine the optimal parameters of air regeneration of the floating loading that are necessary and sufficient for its high efficiency. Finding similar indicators on an industrial aerotank is very difficult and costly. The model biotank and the experimental setup allow varying in a wide range the intensity of the airy medium-bubble regeneration of the floating loading, the regeneration time, the specific mass of loading, and control the concentration of free floating sludge. To study the kinetics of sedimentation of sludge on the loading, original techniques based on the laws of physical chemistry have been developed and used. An express method for determining the concentration of free floating sludge has been developed and applied. For the first time, the dependences of the efficiency of medium-bubble air regeneration of immobilized sludge on a floating bio-loading of the "Biremax" type on the time and intensity of regeneration, as well as on the specific mass of the loading, were obtained. It is shown that the optimal parameters the air of regeneration of a floating loading energy-saving and necessary for its high efficiency, make it possible to ensure the presence of an immobilized biocenosis, which is necessary for deep wastewater treatment.

1. Introduction
Wastewater treatment in biotanks, using two biocenoses of activated sludge, free floating and immobilized, ensures the required quality of wastewater treatment, reducing the anthropogenic load on surface water sources. For the stable operation of biotanks, which are part of biological treatment facilities, it is necessary to ensure uniform distribution of the inert loading throughout the entire volume of the aerated biological facility and periodic renewal of the sludge adsorbed on it [1–3].

The gas-hydrodynamic situation in the bio-tank has a decisive influence on the efficiency of wastewater treatment. The dynamics of hydrodynamic flows carrying free-floating and immobilized activated sludge and dissolved oxygen determines the oxidative capacity of the biotank [4–6].

The biomass of the sorbed biocenosis on the loading ensures the protection of denitrifying microorganisms from high concentrations of incoming harmful substances. Sorbed or immobilized sludge increases the total dose of activated sludge in the bioreactor, which contributes to an increase in the oxidative power of the biotank [6–12].

The sludge immobilized on the floating loading needs its periodic renewal, that is, its removal from the inert loading, transfer to a free floating state, and subsequent adsorption on the floating bio-loading "Biremax S800". Spontaneous removal of spent biomass from the loading does not occur, since the
hydrodynamic flows in the biotank have a velocity of 0.05 to 0.07 m/s, which is not enough to remove biomass. Removal of the immobilized biocenosis from a floating load is advisable to carry out using of air medium-bubbly regeneration [3, 13].

2. Experimental part

The purpose of the scientific work was to determine the efficiency of using of air medium-bubble regeneration of immobilized sludge on a floating loading located in an aerated structure.

To study the efficiency of using water-air regeneration of immobilized sludge on a floating loading in a biotank, an experimental laboratory setup with a model bioreactor was created, which is a vertical cross-section of an industrial bioreactor. The model biotank is made of silicate polished glass and has dimensions 0.06×0.77×0.88 (m). The amount of air supplied by the compressor to the cell was controlled by valves, and the instantaneous air consumption was controlled by a rotameter RM-0.63 GUZ. The aerator for the water-sludge mixture AQUA-LINE provided fine-bubble aeration and was located in the left corner of the bioreactor [2, 6, 13, 14].

The activated sludge, which was in the water-sludge mixture of the bioreactor with a concentration of ~0.3 g/dm³, was adsorbed on a floating loading carried by hydrodynamic flows. The specific intensity of aeration of the water-sludge mixture was 7.5 m³/(m²·h). The model, with a volume of 80 dm³, was filled with tap water, which had a room temperature of ~20 °C. To create a water-sludge mixture with a given concentration of floating sludge, activated sludge brought from city sewage treatment plants was used.

The dynamics of adsorption of free floating sludge on the loading was monitored with a luxmeter by changing the intensity of the light flux passing through the water-sludge mixture. To prevent the floating loading from distorting the luxmeter readings, the control square in the model was shielded with perforated material. The luxmeter readings in lux were converted using a calibration graph into the concentration of free floating sludge in g/dm³. The sludge adsorption process was controlled to constant values of a luxmeter, which corresponded to a quasi-stationary process.

3. Discussion of the results

To study the kinetics of adsorption of activated sludge on a floating load, in a model with a volume of 80 dm³, 10 dm³ (10 kg) of biomass "Biremax S800" (figure 1) was placed, which corresponded to 125 kg/m³ of the specific mass of the floating loading. Loading "Biremax" has a special shape of the material, which provides a large space for biofilm growth and uniform growth of bacteria. The loading design allows withstand high mechanical loads during operation.

![Figure 1. Floating loading "Biremax" with a density of 0.98 g/dm³.](image)
The floating loading is constantly moving in the water column under the influence of hydrodynamic flows. Therefore, there is a constant renewal of the biofilm, which has a positive effect on the purification of wastewater from nitrogen compounds, since a thin, renewed layer of biofilm has a more active effect on these pollution. The loading contains closed zones, where a protected adsorbed biocenosis is formed, which promotes the growth of biofilm on open surfaces.

The specific intensity of fine-bubble aeration of the water-sludge mixture was set at 7.5 m³/(m² h). When a quasi-stationary process was reached, at a sludge concentration of 0.2 g/dm³ = Const, the regeneration of the floating loading with air was carried out with a specific intensity of 9.5 m³/(m² h). It should be noted that the concentration of floating sludge varied in a small range from 0.3 g/dm³ to 0.2 g/dm³.

The kinetics of the concentration of free floating sludge during its adsorption on the loading and its subsequent regeneration are shown in figure 2.

![Figure 2](image_url)

**Figure 2.** Kinetics of activated sludge adsorption on a floating loading and its removal by airy regeneration.

Within two hours, a decrease in the concentration of free floating sludge is observed due to its adsorption on the floating loading. The rate of adsorption smoothly decreases. After two hours of sludge adsorption, a quasi-stationary state occurs, characterized by the equality of the rates of adsorption and desorption of sludge on the loading.

After medium-bubble airy regeneration of immobilized (adsorbed) sludge with an intensity of 9.5 m³/(m² h), the current concentration of free floating sludge was determined, and, taking the initial concentration \(C_F = 0.3 \text{ g/dm}^3\) as 100%, the efficiency of regeneration (washing away from the loading) of sludge was calculated. In our case, the efficiency was \(\sim 96\%\).

Thus, we can state the presence of the process of adsorption of activated sludge on the floating loading "Biremax", with the formation of immobilized sludge, which allows intensifying the process of biological wastewater treatment.

When studying the dependence of the efficiency of airy regeneration of a floating loading on the time of its regeneration in a physical model of a bioreactor, the regeneration time of the load was changed from 0.5 to 3 minutes. The efficiency of regeneration of immobilized sludge was calculated from the residual concentration of sludge on a floating loading. The process of adsorption of floating sludge on the loading was carried out to a quasi-stationary state, i.e. to constant values of a luxmeter. Then, aerial regeneration was carried out with an intensity \(J_g = 9.5 \text{ m}^3/(\text{m}^2 \text{ h})\). By the difference in the readings of the luxmeter (the difference in the concentration of floating sludge), the efficiency of regeneration was determined. The specific mass of the floating loading placed in the biotank was \(m = 125 \text{ kg/m}^3\). The obtained experimental dependence is shown in figure 3.
A mathematical equation is found that describes the dependence of the efficiency of aerial regeneration $E$ of a floating load on the time of its regeneration $t$:

$$E = -0.0011 \cdot t^2 + 0.372 \cdot t + 65.533,$$  \hspace{1cm} (1)

with the coefficient of determination $R = 0.9897$.

An increase in the efficiency of the air regeneration of the immobilized sludge is observed up to a regeneration time of approximately two minutes. A further increase in the regeneration time by 60 seconds increases the efficiency of air regeneration by 1%, which is not economically viable. Thus, the required and sufficient time for airy regeneration of the "Biremax" loading is two minutes.

To obtain the dependence of the efficiency of airy regeneration of the floating loading on the mass of the floating loading, the specific mass of the floating loading was changed from 37.5 to 187.5 kg/m$^3$. The process of adsorption of floating sludge on the loading was carried out to a quasi-stationary state, followed by airy regeneration with an intensity $J_g = 9.5$ m$^3$/(m$^2 \cdot$ h), for two minutes, necessary and sufficient. By the difference in the concentration of floating sludge before and after regeneration, the efficiency of medium-bubble airy regeneration was determined. The obtained experimental dependence is shown in figure 4.

The dependence is quadratic and is described by a mathematical expression with a coefficient of determination $R = 0.9851$:

$$E = -0.0003 \cdot m^2 + 0.164 \cdot m + 76.899.$$  \hspace{1cm} (2)
The efficiency of airy regeneration alter from 82% and reaches 97% with mass a floating loading equal to \( \sim 187.5 \, \text{kg/m}^3 \). The increase in mass by 5 times, increased the efficiency of regeneration by 15%. An increase in the mass of the floating loading from 125 to 187.5 kg/m\(^3\) increases the efficiency of airy regeneration by only 5%, which is not economically feasible. Thus, the optimal and sufficient effect of regeneration of the floating loading "Biremax" is observed for its specific mass of 125 kg/m\(^3\). This loading value was used by us in all our experiments when changing other parameters in the experiment.

In the work to determine the optimal value of the intensity of airy regeneration to remove immobilized sludge on a floating loading, we used an air circuit of the scheme [13], which allows changing the specific intensity of airy regeneration \( (Jg) \) in the range from 5.2 to 12 m\(^3\)/(m\(^2\) h). The process of adsorption of floating sludge on the loading was carried out to a quasi-stationary state, i.e. to constant values of a luxmeter. The experiment was carried out with a specific mass \( m \) of the floating loading placed in the bioreactor equal to 125 kg/m\(^3\), and the regeneration time was two minutes. The obtained experimental dependence is shown in figure 5.

Figure 5. Dependence of the efficiency of airy regeneration \( E \) of a floating loading on the intensity of its regeneration \( J_g \).

The resulting dependence is described by a quadratic equation with a coefficient of determination \( R = 0.9997 \):

\[ E = -0.702 \cdot J_g^2 + 16.163 \cdot J_g + 4.997. \]  

\[ (3) \]

4. Conclusion

The possibility of physical modeling of gas-hydrodynamic processes in a biotank with the use of a floating loading "Biremax", which immobilizes activated sludge, is shown. A vertical planar physical model of the bioreactor was used, which allows using the express method for determining the concentration of floating activated sludge.

For the first time, the dependences of the efficiency of medium-bubble airy regeneration of immobilized sludge on a floating loading "Biremax" on the time and intensity of specific air regeneration, as well as on the specific mass of the load were obtained.

Optimal parameters of airy regeneration of a floating loading, necessary and sufficient for high efficiency, can be stated as the following: the air regeneration time is equal to two minutes; the intensity of specific air regeneration is 9.5 m\(^3\)/(m\(^2\)·h); the specific mass of the loading is 125 kg/m\(^3\).

References

[1] Ermolin Yu A and Alekseev M I 2017 Water Ecol. 2 pp 18–27
[2] Kul'kov V N, Solopanov E Yu, Evteeva I V and Razum A S 2008 Bulletin of Irkutsk State Technical University 4 pp 48–52
[3] Zhmur N S 2003 *Technological and Biochemical Processes for Wastewater Treatment at Facilities with Aerotanks* (Moscow: AKVAROS) p 512

[4] Popkovich G S and Repin B N 1986 *Wastewater Aeration Systems* (Moscow: Stroyizdat) p 136

[5] Meshengisser Yu M and Marchenko Yu G 2001 *Water Ecol.* 2 pp 11–13

[6] Ku’kov V N and Solopanov E Yu 2009 *The Phase Contact Surface in Aerobic Wastewater Treatment* (Irkutsk: Irkutsk State Technical University Publ.) p 144

[7] Ku’kov V N and Solopanov E Yu 2020 *Water-air Regeneration of a Synthetic Brush Loading Located in an Aerotank* (Irkutsk: Irkutsk National Research Technical University Publ.) p 162

[8] Martí-Calatayud M C, Schneider S, Yüce S and Wessling M 2018 *Water research* 147 pp 393–402

[9] Abdalla K Z and Khafagy K 2014 *IJSER* 5–2 pp 619–23

[10] Hamza R A, Sheng Z, Iorhemen O T, Zaghloul M S and Tay J H 2018 *Water research* 147 pp 287–98

[11] Shvetsov V N, Morozova K M, Smirnova I I, Semenov M Yu, Lezhnev M L, Ryzhakov G G and Gubaidullin T M 2010 *VST* 2 pp 33–40

[12] Shvetsov V N, Morozova K M, Smirnova I I, Semenov M Yu, Lezhnev M L, Ryzhakov G G and Krasnov A A 2007 *VST* 2 pp 25–31

[13] Solopanov E. Yu, Kulkov V N and Shirokov A E 2016 *Proceedings of the Universities. Investment. Construction. Real Estate* 4 pp 138–46

[14] Ku’kov V N, Solopanov E Yu and Kudryavtseva E V 2006 *Materials of 2nd Int. Scientific-Practical Conf.* pp 114–117