The influence of some factors on the efficiency of the processes of nitrogen biological removal from sewage

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Abstract. The chemical processes causing the bacterial destruction of nitrogen-containing compounds in the process of biological wastewater treatment are considered. The influence of nitrogen-containing compounds concentration, oxygen concentration, temperature, pH of the medium, and oxidation-reduction potential on the efficiency of the biological treatment processes was studied.

1. Introduction
One of the most important ways to solve environmental problems associated with the treatment of household or industrial wastewater is the biological method. The method of biological wastewater treatment is based on the removal of various chemical contaminants from wastewater by means of activated sludge.

The efficiency of biological treatment processes is influenced by many different factors: nitrogen compounds concentration, oxygen concentration, temperature, the pH of the medium, and oxidation-reduction potential. This article presents the results of the study of environment acidity, oxidation-reduction potential, oxygen concentration, and seasonal changes influence on the efficiency of purification from nitrogen compounds [1, 2, 3].

2. Research objects and methods
As the material for the study, model solutions that fully repeated the composition of the wastewater of one of the enterprises of Veliky Novgorod were used. The studies were carried out under continuous conditions in an experimental setup which was a mini-aerotank. The determination of dissolved oxygen amount and the concentration of ammoniacal, nitrate and nitrite nitrogen was conducted according to the relevant methodologies.

Ammoniacal nitrogen removal from wastewater occurs as a result of the nitrification process, which is carried out by autotrophic bacteria that use inorganic carbon (carbon dioxide, carbonates, bicarbonates) for nutrition [4].

The chemistry of the nitrification process is conducted in two stages: first, an ammonium ion is oxidized to a nitrite ion by bacteria of the genus Nitrosomonas, while only ammonium nitrogen, urea, uric acid, and guanine are consumed:

\[ \text{NH}_4^+ + 3\text{O}_2 \rightarrow 2\text{NO}_2^- + 2\text{H}_2\text{O} + 4\text{H}^+ \]

Then, bacteria of the genera Nitrobacter, Nitrospina, Nitrococcus Nitrocystis, Nitrospira engage in the process and nitrite ions are oxidized to nitrate ions.

\[ 2\text{NO}_2^- + \text{O}_2 \rightarrow 2\text{NO}_3^- \]

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For the normal functioning of bacteria of the genera *Nitrobacter, Nitrospina, Nitrococcus Nitrocystis, Nitrospira*, such conditions as the acidity of the medium and dissolved oxygen concentration are extremely important. Under high-acidity conditions, the bacteria do not develop because of the presence of undissociated nitric acid; under low-acidity conditions, un-ionized ammonia negatively affects them [5, 6, 7, 8].

Then, the denitrification process proceeds in which nitrite and nitrate ions are reduced to molecular nitrogen [1, 7, 9, 10].

\[
\begin{align*}
    4\text{NO}_3^- + \text{CH}_3\text{OH} & \rightarrow 4\text{NO}_2^- + \text{CO}_2 \uparrow + 2\text{OH}^- + \text{H}_2\text{O} \quad (1) \\
    2\text{NO}_2^- + \text{CH}_3\text{OH} & \rightarrow \text{CO}_2 \uparrow + 2\text{OH}^- + \text{N}_2
\end{align*}
\]

3. Results and discussions

The efficiency of the nitrification process is influenced by the acidity of the medium, temperature, oxidation-reduction potential, and the content of toxic compounds.

The influence of the pH of the medium on the nitrification process efficiency is shown in figure 1.

![Figure 1. Diagram of changes in the concentration of \(NH_4^+\), \(NO_3^-\) and alkalinity in the primary sedimentation tank (PST-1), in the secondary sedimentation tank (SST-1) and in the zones of A – denitrification, C – nitrification.](image)

The selected pH values range corresponds to the growth limit of bacteria of the genera *Nitrobacter, Nitrospina, Nitrococcus Nitrocystis, Nitrospira*. At pH less than 6, the intensity of the nitrification process is significantly reduced, the presence of free ammonia and heavy metals salts inhibit the process [4]. Studies indicate that the greatest efficiency of biological destruction processes is observed in a weakly alkaline solution at pH 7.3–8.3.

The oxidation-reduction potential value determines oxidation-reduction reactions direction and intensity. The presence of organic compounds in water affects the value of oxidation-reduction potential. A high positive redox-potential of 200–400 indicates the dominance of oxidation reactions over reducing ones. The graph presented in figure 2 shows that the maximum nitrate ions concentration corresponds to the maximum ORP value:
Figure 2. Diagram of changes in the concentration of $NO_3^-$ and the oxidation-reduction potential in the primary sedimentation tank, in the secondary sedimentation tank and in the zones of A and C.

In order to make nitrification processes in the aerotank efficient, it is necessary to take into account the additional oxygen demand; because of poor aeration conditions occurrence, nitrification may cease completely. The dependence of nitrate ion concentration on the dissolved oxygen concentration is presented in table 1. Studies show that dissolved oxygen concentration should not be less than 2mg/dm$^3$, and a further increase in the oxygen concentration does not significantly affect the intensity of the processes. A decrease in the oxygen concentration leads to nitrification cessation and sludge decay.

Table 1. The dependence of the concentration of $NO_3^-$ on the concentration of dissolved $O_2$.

| $C_{NO3}$, mg/dm$^3$ | 24.20 | 24.16 | 24.12 | 26.4 | 24.8 | 30.22 | 24.88 | 33.13 | 25.95 |
|----------------------|-------|-------|-------|-------|------|-------|-------|-------|-------|
| $O_2$, mg/dm$^3$     | 1.12  | 1.67  | 2.18  | 2.22  | 2.47 | 2.75  | 2.8   | 2.83  | 5.21  |

The main factor in calculating the degree of wastewater treatment efficiency to assess nitrification process is an indicator of ammonium nitrogen concentration. And for denitrification, it is an indicator of total nitrogen concentration and chemical oxygen demand. The treatment efficiency in the experimental aerotank for the period under study was:

The treatment efficiency of $NH_4^+$ = 99.81%.
The treatment efficiency of $N_{total}$ = 89.73%.

The concentration of nitrogen-containing compounds in wastewater is influenced by seasonal changes related to changes in temperature, oxygen concentration changes, development and depression periods of activated sludge. The findings are presented in figure 3.
As can be seen from the diagram, \( \text{NH}_4^+ \) ion content in the water coming to the treatment facility exceeds the norm of 20.56 mg/l, and in some months it almost doubles the norm. These changes in the concentration during the year are characterized by the presence of two maxima: winter peak and autumn peak.

In winter, the content of dissolved oxygen in water decreases, which reduces the nitrification process efficiency and contributes to an increase of the ammonium ion concentration. Analysis of the data showed that \( \text{NH}_4^+ \) ion content in the water coming to the treatment facility in December exceeds the norm by 97%. By spring, due to the influence of the flood and micro-organisms spring development, a decrease in the ammonium ion concentration is observed. Thus, for example, in May, we see the minimum of its content: the excess of the norm was only 27%.

In the summer months, the concentration of these ions is also low. In August, September, October, decay processes and precipitation contribute to the entry of a large number of organic substances into the water bodies, and it leads to an increase in ammonium ion concentration.

Seasonal changes in temperature do not significantly affect biological wastewater treatment efficiency, because 20-30°C is considered the optimal temperature for aerobic processes, and the temperature of sewage entering the treatment facility, as a rule, does not fall below this limit.

Analysis of the data showed that despite seasonal changes associated with nitrogen content, changes in temperature, and oxygen concentration changes, the biological treatment process is effective throughout the year. Thus, for example, in December, the efficiency of the nitrification process is 97.5% and in May, it is 98.3%.

4. Conclusion
According to the results of the study, the following conclusions can be drawn:
1. Seasonal changes in the nitrogen-containing compounds concentration do not significantly affect the efficiency of their bacterial destruction processes.
2. The main factors that influence nitrogen-containing compounds biological treatment are identified and analyzed:
   - the greatest efficiency of biological destruction processes is observed in a weakly alkaline solution at pH 7.3-8.3;
• dissolved oxygen concentration should not be lower than 2 mg/l, which contributes to sludge effective functioning;
• high positive redox potential of 200-400 mV makes nitrification processes more efficient;
• seasonal changes in temperature do not significantly affect biological wastewater treatment efficiency because the optimum temperature for aerobic processes is considered to be 20-30°C, and the temperature of sewage entering the treatment facility, as a rule, does not fall below this limit.

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