α-factor experimental determination of aeration system in aeration tanks

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Abstract. The article is dedicated to determine the α-factor of aeration systems in case of changing the wastewater treatment line (transfer of aeration tanks to the nitri-denitrifier aeration mode). The studies were performed on an experimental installation with sewage and activated sludge at one of the sewage treatment facilities of the Udmurt Republic. During the process of determining the parameter under consideration, pure water and the sludge mixture from the experimental plant were sequentially aerated at the same conditions; thus, the $K_L\alpha$ was sequentially determined for two different types of liquids. The ratio of different liquids defined under the same conditions of $K_L\alpha$ determines the α-factor. Plate aerators with a dispersing element made of a rubber membrane were used as an experimental plants, thanks to which a high calculated value of the α-factor was found - 0.95 ± 0.03.

1. Introduction

Nowadays the main function in wastewater treatment processes from organic and biogenic pollution is performed by artificial biological structures – aerotanks, equipped with various aeration systems. According to estimates, from 50 to 80% [1] of the operating costs of treatment facilities refer to costs for aerating the sludge mixture in aeration basins [2,3].

The aeration system is a complex of engineering equipment that provides the supply and distribution of air (oxygen) in the aerobic zones of aerotanks to create the necessary oxygen regime, for implementing biochemical processes and maintaining activated sludge in a suspended state [4].

2. Theoretical basis

Aeration systems used in aerotanks are divided into mechanical, pneumatic, mechanical-air and jet one (ejector). The choice of aeration system and its implementation scheme for specific aeration tanks is made individually for the treatment facilities, taking into account such factors as [5-7]:

- biological wastewater treatment technology implemented in aerotanks (oxidation of carbon-containing compounds (with or without activated sludge recovery), nitrification, nitriding denitrification, nitri denitrification and biological phosphorus removal);
- the quality of incoming wastewater and the requirements for purified water;
- hydrodynamic characteristics of aeration tanks (mixers, propellants, intermediate hydrodynamic flow reactors, aeration tanks with distributed water supply, etc.).
The efficiency of air oxygen transfer is an integral indicator of the efficiency of aeration systems and is the ratio of the amount of air consumed to oxidize the mass of contaminants entering the biological treatment facility to the total airflow supplied to the facility, and estimated at percentage. The efficiency of air oxygen transfer is proposed to be used as an assessment of the efficiency of aeration systems, as one of the main characteristics of the operational control of the facilities [5, 8].

During aerotanks operation, which work only for oxidation of organic compounds, the oxygen demand \( S_{O,L} \), mg/l, is defined as [9]:

\[
S_{O,L} = 1.1(L_{en} - L_{ex})
\]  
(1)

where \( L_{en} \) – BOD value of wastewater before biological treatment, mg/l; \( L_{ex} \) – BOD value of wastewater after biological treatment, mg/l.

The amount of oxygen for the oxidation of organic compounds \( Q_{O,L} \), kg/h, is defined as:

\[
Q_{O,L} = 0.001S_{O,L} \cdot Q_h
\]  
(2)

where \( Q_h \) – current hourly flow of wastewater, m³/h.

During calculating the required amount of oxygen for nitrification and nitriding denitrification technologies, the calculation should be carried out taking into account the oxygen demand of the nitrification process and reducing the amount of organic compounds oxidized with dissolved oxygen, due to the consumption of part of the organic compounds during the denitrification process.

At 100% (ideal) efficiency of using oxygen in the air, air consumption for the oxidation of organic compounds \( Q_{air,100\%} \), m³/h is defined as:

\[
Q_{air,100\%} = \frac{Q_{O,L}}{0.21 \cdot 1.43}
\]  
(3)

where 0.21 – volume of oxygen in the air (20.9 %); 1.43 – oxygen density, kg/m³, at normal conditions.

3. Materials and methods
In common practice [10-14], the criterion for evaluating the efficiency of aeration systems is the \( \alpha \)-factor, which relates the ratio of mass transfer coefficient with specific area of water-air contact for sludge water and mass transfer coefficient with specific area of water-air contact for pure water:

\[
\alpha = \frac{K_{L,a}(\text{wastewater})}{K_{L,a}(\text{tap water})}
\]  
(4)

where \((K_{L,a})_{\text{wastewater}}\) – volumetric mass transfer coefficient in the sludge mixture, min⁻¹; \((K_{L,a})_{\text{tap water}}\) – volumetric mass transfer coefficient for pure water, min⁻¹.

In most cases, \( \alpha < 1 \).

From an economic point of view, the \( \alpha \)-factor is more important than the effects of denitrification: when the quality factor decreases, for example, from 0.9 to 0.6, the power consumption for aeration of wastewater increases almost 1.5 times.

In the absence of real data, usually, the operation of sewage treatment facilities is taken as the average negative value of this argument – 0.8.

4. Results
The studies were performed on an experimental installation (figure 1) with sewage and activated sludge at one of the sewage treatment facilities of the Udmurt Republic. The aim of the study was to determine the \( \alpha \)-factor of aeration systems in case of changing the wastewater treatment process line (transfer of aeration tanks propellants with regenerators to the nitri-denitrifier aero flow regime).
Figure 1. Experimental installation of nitri-denitrification: 1 - screw pump supplying waste water; 2, 3, 4 - paddle mixers; 5 - screw pump circulation of nitrate flow; 6 - screw pump circulation of activated sludge from the secondary clarifier; 7 - compressor; 8 - screw pump removal of excess activated sludge; 9 - denitrifier; 10 - first stage aero tank; 11 - second stage aeration tank; 12 - secondary settling tank.

In the process of determining the target parameter, clean water and sludge mixture from the experimental plant were sequentially aerated at the same conditions.

So in the case of drinking water, oxygen was removed from the experimental reactor with a volume of sodium sulfite in the presence of cobalt chloride. [15].

$$\text{Na}_2\text{SO}_3 + \frac{1}{2}\text{O}_2 \xrightarrow{\text{CoCl}_2} \text{Na}_2\text{SO}_4$$  \hspace{1cm} (5)

After that, compressed air was supplied to the reactor. After slight delay (a few tens of seconds – the oxidant is consumed for neutralization of residual sulfite concentration) value of the coefficient of dissolved oxygen in the reactor began to rise gradually (see Figure 2). As the reactor was saturated with oxygen, the gas transport rate dropped, since the driving force of the process is the lack of concentration – the difference between the actual and the equilibrium value of the dissolved oxygen ratio at a given temperature. However, the mass transfer coefficient ($K_t\alpha$) remains constant and must be determined.

Figure 2. The curve of the changing the ratio of dissolved oxygen in pure water.
When working with the sludge mixture in the above-described capacity, the volume of the sludge mixture was poured the same as in the first case. The level of endogenous respiration of biomass was determined. After that, the ratio of dissolved oxygen in the tank was lowered to zero by switching off the compressed air supply system. Further, the container was supplied by the flow of compressed air strictly the same as in the first case. After a few seconds, the dissolved oxygen ratio began to increase, which was recorded with an oximeter. The intensity of increasing the ratio of dissolved oxygen in the sludge mixture in the presence of biomass breathing determined a new value $K_La$.

Further, the required coefficient was determined from formula:

$$\frac{dDO}{dt} = K_La \cdot (C_S - C_L) - OUR_v$$

(6)

where $K_La$ – volumetric mass transfer coefficient, min$^{-1}$; $C_S$ - the value of dissolved oxygen constant for a particular temperature and pressure, mgO$_2$/l; $C_L$ – concentration of dissolved oxygen at a specific point in time, mgO$_2$/l; $OUR_v$ – oxygen consumption rate, mgO$_2$/min [16].

In this case, because of the presence of steady-state conditions $\frac{dDO}{dt} = 0$. Volumetric mass transfer coefficient:

$$K_La = \frac{OUR_v}{C_S - C_L}$$

(7)

From findings, the mass transfer coefficient for drinking water: $K_La_{ TW} = 0.26$

Results for sludge mixture:

- $OUR_v = 0.4$ mgO$_2$/l·min
- $C_S = 9.2$ mgO$_2$/l
- $C_L = 7.6$ mgO$_2$/l

$$K_La_{ WW} = \frac{0.4}{9.2 - 7.6} = 0.25 \text{ min}^{-1}$$

(8)

The ratio of the two found coefficients (oxygen transport in the sludge mixture ($K_La_{ WW}$) to the same indicator in drinking water ($K_La_{ TW}$)) determined the value of the “α-factor”:

$$\alpha = \frac{K_La_{ wastewater}}{K_La_{ tap \ water}} = \frac{0.25}{0.26} = 0.96$$

(9)

5. Conclusions

During developing any wastewater treatment technology, one of the main component of the complex of structures will still be the aeration system of aerotanks. All the issues of energy saving will be based on the efficiency of this site [5,9,12,17]. Therefore it is necessary to take a number of measures to improve the efficiency and reliability of this equipment.

First of all, we are talking about the dispersing element of aerators (tubular or dish-shaped form), made of a rubber membrane [2,15]. It is precisely with such aerators that the oxygen transport efficiency ratio (SOTE) reaches 30% [2,5,18-21]. Of course, the efficiency decreases during operation of any equipment, however, it is possible to focus on 22-26% of SOTE in this case, which is practically not achievable even for new fibrous polyethylene aerators. For the experimental plant, plate aerators with a dispersing element made of a rubber membrane were used, thanks to which a high calculated value of α-factor – 0.95 ± 0.03 was determined. To identify seasonal variations in the value of the α-factor, a repeat of the tests is required.
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