Intensification of the wastewater treatment process with electrolytic gases

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Abstract. High regulatory requirements for the quality of treated water discharged into watercourses and wear and tear of local treatment facilities dictate the need to develop new technological solutions in the field of water treatment systems. In this regard, technologies that implement methods of electrophysical or electrochemical impact on polluting components in the processed liquid have found wide application in the treatment of waste and substandard waters. In this case, on the one hand, in order to increase the efficiency of collecting pollutants, it is necessary to strive to increase the number and decrease the size of electrolytic gas bubbles providing this collection, and on the other hand, it is necessary to optimize the operating modes of the electrode system and the material execution of the electrodes themselves, since the time of their operation depends on this. To solve this compromise problem, the design of an electroflotator has been developed, in which an electrode system is installed in the lower part of the tank, consisting of vertical anodes and cathodes. Each pair of them has the shape of cylinders and is fixed on the side surfaces of the dielectric ring separating them. The height of the ring from above and from below is made greater than the height of the anode and cathode by an amount equal to the annular gap between the adjacent anode and cathode. This design of the spacer ring prevents current leakage from the cathode to the anode and, accordingly, the dissolution of the anode ends. If the height of the ring above and below is executed by an amount less than the annular gap, there is a twofold increase in the density of the anode current at the ends of the anode and cathode, intensifying the dissolution of the anodes and the ingress of dissolution products into the solution and onto the walls of the electrodes, increasing their electrical resistance and reducing the performance of treatment facilities by liquid to be cleaned.

1. Introduction
The problem of the preparation of industrial, agricultural and municipal wastewater is becoming increasingly important, which is mainly caused by the need for rational use of the resource, including due to the growth in consumption and the shortage of clean water, and the preservation of the environmental sustainability of natural systems [1, 2]. High regulatory requirements for the quality of treated water discharged into watercourses and wear and tear of local treatment facilities dictate the need to develop new technological solutions in the field of water treatment systems [3, 4].
Electrochemical and electrophysical methods, despite the high energy consumption, are actively used in solving specific problems in the treatment of waste and substandard waters. Particularly successful in the recovery of petroleum products, dyes, surfactants, biological components and other contaminants electroflotation and electrocoagulation have proven themselves [5, 6, 7]. Here, the efficiency of collecting pollutants in the liquid to be cleaned depends on the size of the bubbles of electrolytic gases - with a decrease in their size, the degree of purification of the liquid increases. It is also necessary to take into account the type and concentration of contaminating components, residence time in the apparatus, operating and design parameters of the electrode system - the difference in electrical potentials, the strength and density of the current, the type and material design of the electrodes themselves, etc. [8, 9].

For example, in studies on the removal of fatty acids from wastewater from a fatty plant using an electroflotator with graphite anodes, it was found that what at temperature 20-25 °C, residence time of the liquid to be cleaned 10-15 min. and current density \( j_s = 350 \text{ A/m}^2 \) the highest degreasing efficiency is achieved [10]. In work [11], studying the organoleptic properties and COD of slaughterhouse wastewater after their treatment in an electrocoagulator with aluminum electrodes, the turbidity variation was determined in the range 92.8-99.3%, chromaticity – 81.3-98.9%, COD – 58.6-81.0% and dissolved aluminum – 15.2-54.3 mg/l. In this case, the best values of the parameters were obtained under the conditions: potential difference 25 V, residence time 25 min., amperage \( J_a = 1.08 \text{ A} \) and current density \( j_a = 216 \text{ A/m}^2 \).

However, the analysis of review and experimental work showed that the issues of operation and repair are not covered enough, while the performance of local treatment facilities depends, among other things, on downtime in repairs due to replacement and cleaning of electrodes from deposits of electrolysis products and dissolution of anode plates, for which anode current density affects.

Thus, the purpose of the study was to intensify the process of wastewater treatment with electrolytic gases in the reactor and to optimize the current density of the electrode system to reduce the dissolution rate of the anode plates.

2. Methods and materials

Figure 1 [12, 13] shows the design of a reactor for processing industrial, household and agricultural wastewater, in which biological treatment processes are combined with the electrolysis process. Bubbles of electrolytic gases promote intensive oxidation of organic matter dissolved in water by the biocenosis of activated sludge.

The peculiarity of the developed apparatus lies in the fact that an electrode system is installed in the lower part of the reservoir, consisting of vertical anodes and cathodes. Each pair of them has the shape of cylinders and is fixed on the side surfaces of the ring separating them, made of a dielectric material, while the height of each cylinder is determined by the proportion:

\[
\frac{h_1}{h_2} = \frac{\ln \left( \frac{r_{a1}}{r_{a1} - \delta} \right)}{\ln \left( \frac{r_{a2}}{r_{a2} - \delta} \right)},
\]

where \( h_1, h_2 \) - height of adjacent cylindrical anodes, m;
\( r_{a1}, r_{a2} \) - radii of adjacent cylindrical anodes, m;
\( \delta \) - annular gap between adjacent anode and cathode, m.

The height of the ring from above and below is made greater than the height of the anode and cathode by the value \( \Delta h \), equal to the annular gap \( \delta \):

\[
\Delta h = \delta.
\]

This design of the spacer ring prevents current leakage from the cathode to the anode and, accordingly, the dissolution of the anode ends.
Figure 1. Biological wastewater treatment reactor.

An increase in the height of the cathode or anode leads to a decrease in electrical resistance, an increase in the current from the end of the anode to the cathode, and an additional accelerated dissolution of the anode. This shortens the life of the electrode system and increases the repair time,
including due to replacement and cleaning of electrodes from deposits of electrolysis products and dissolution of anode plates.

3. Results and discussion
In the process of flotation of wastewater in a biological reactor, a potential is supplied to the anodes 8 and cathodes 9 from a direct current source. Through the branch pipe 2, the liquid to be cleaned enters the storage tank 1. In the gap δ between adjacent anodes 8 and cathodes 9, a current flows through the water to be purified. Oxygen bubbles are released on the surface of the anodes 8, and hydrogen bubbles on the surface of the cathodes 9. In the developed design of the apparatus, the dividing rings 10, on which the anodes 8 and cathodes 9 are fixed in pairs, are made with a height above and below the height of the adjacent anode 8 and cathode 9 by size δ. This prevents leakage of current from the cathode to the anode, and, accordingly, the dissolution of the ends of the anode.

Oxygen bubbles interact with suspended particles of activated sludge in the treated water, thereby intensifying the process of biological oxidation of organic matter. In addition, bubbles of hydrogen and oxygen, rising upward, collide with suspended particles and carry them out during flotation into foam. The spent mixture of electrolysis gases is discharged through the branch pipe 5 into the ventilation system. Large particles formed as a result of coagulation sink on the bottom δ of the storage tank 1 and are discharged through the branch pipe 7 into the sludge reservoir. Purified water is discharged from storage tank 1 via branch pipe 3.

Consider the options for the operation of the reactor with the following values of the design parameters: the radius of the tank \( R = 250 \text{ mm} \); the gap between the adjacent anode and cathode \( \delta = 10 \text{ mm} \); the thickness of the plates of the anode and cathode forming the cylinders, \( \varepsilon = 5 \text{ mm} \); the number of anode ends \( N = 14 \).

Table 1 shows the calculation results for the standard design of anodes and cathodes made of steel strips of the same height \( h = 50 \text{ mm} \) and alternating current in the gap.

| No. electrode, from the wall of the apparatus | Radii of electrodes \( r_a \) and \( r_a - \delta \), mm | Current in the gap \( J_a \), A | Current density \( j_a \), A/m² |
|------------------------------------------|-----------------------|----------------|-------------------|
| 1 | cathode - 235, anode - 225 | 19.26 | 260.9 |
| 2 | anode - 220, cathode - 210 | 18.00 | 260.6 |
| 3 | cathode - 205, anode - 195 | 16.74 | 260.1 |
| 4 | anode - 190, cathode - 180 | 15.50 | 259.6 |
| 5 | cathode - 175, anode - 165 | 14.20 | 259.0 |
| 6 | anode - 165, cathode - 150 | 13.00 | 258.2 |
| 7 | cathode - 145, anode - 135 | 11.72 | 257.4 |
| 8 | anode - 130, cathode - 120 | 10.46 | 256.3 |
| 9 | cathode - 115, anode - 105 | 9.20 | 254.9 |
| 10 | anode - 100, cathode -90 | 7.94 | 253.1 |
| 11 | cathode - 85, anode - 75 | 6.70 | 250.6 |
| 12 | anode - 70, cathode - 60 | 5.43 | 247.1 |
| 13 | cathode - 55, anode - 45 | 4.17 | 241.6 |
| 14 | anode - 40, cathode - 30 | 2.91 | 231.7 |
| 15 | cathode - 25, anode - 15 | 1.64 | 208.8 |

\[ \sum = 156.7 \]

Analysis of calculations (table 1) shows that with equal gaps between the electrodes and their heights, the current between the electrodes changes from 19.3 to 1.6 A, that is, 12 times, and the current density from 260.9 to 208.8, then there is 30%. This means that electrolysis in the gaps between the anodes and cathodes over the cross section of the reactor is extremely uneven, since the volume of evolved gas bubbles is directly proportional to the current, which means that in biochemical processes there will be unequal treatment of the treated waste water. In addition, not the same and high
current density, even at not high values of the current itself between the anodes and cathodes, will lead to a rapid dissolution of the anodes and secondary pollution of waste water by molecules of the material from which they are made. These processes generally reduce the productivity of local treatment facilities.

Table 2 shows the results of calculations for the execution of anodes and cathodes with different heights and direct current $J_a = 4.05$ A in the gap. According to calculations, the height of the anodes and cathodes increases more than 10 times from 30 to 329 mm, and the average current density in the gap is $j_a = 94$ A/m$^2$, which is less than the limiting value $j_{lim} = 100$ A/m$^2$ (voltage 20 V), at which begins the dissolution of the anodes.

| No. of electrode, from the wall of the apparatus | Radius anode $r_a$, mm | Radius cathode $r_c$, mm | Current in the gap $J_a$, A | Current density $j_a$, A/m$^2$ | Electrode height $h$, mm |
|-----------------------------------------------|------------------------|--------------------------|-----------------------------|-------------------------------|-------------------------|
| 1                                            | 220                    | 210                      | 4.05                        | 97.71                         | 30.00                   |
| 2                                            | 205                    | 195                      | 4.05                        | 97.54                         | 32.25                   |
| 3                                            | 190                    | 180                      | 4.05                        | 97.34                         | 34.87                   |
| 4                                            | 175                    | 165                      | 4.05                        | 97.11                         | 37.94                   |
| 5                                            | 160                    | 150                      | 4.05                        | 96.84                         | 41.62                   |
| 6                                            | 145                    | 135                      | 4.05                        | 96.51                         | 46.08                   |
| 7                                            | 130                    | 120                      | 4.05                        | 96.10                         | 51.62                   |
| 8                                            | 115                    | 105                      | 4.05                        | 95.60                         | 58.67                   |
| 9                                            | 100                    | 90                       | 4.05                        | 94.91                         | 67.94                   |
| 10                                           | 85                     | 75                       | 4.05                        | 93.99                         | 80.72                   |
| 11                                           | 70                     | 60                       | 4.05                        | 92.67                         | 99.41                   |
| 12                                           | 55                     | 45                       | 4.05                        | 90.60                         | 129.0                   |
| 13                                           | 40                     | 30                       | 4.05                        | 86.90                         | 185.5                   |
| 14                                           | 25                     | 15                       | 4.05                        | 78.30                         | 329.4                   |

Note: No. 1 corresponds $r_a1$ and $h_1$, No. 2-5 corresponds $r_a2$ and $h_2$. 

However, with the distance between the anode and cathode equal to the thickness of the dielectric ring, that is, $\varepsilon = 5$ mm, and the gap between the adjacent anode and cathode equal to $\delta = 10$ mm, the current density at the ends of the electrodes will be 2 times the average current density in the gap and will be $j_a = 188$ A/m$^2$. This is 1.88 times the maximum permissible value. In this case, the ends of the anodes will dissolve, and the dissolution products will fall into the solution and onto the walls of the electrodes, increasing their electrical resistance and reducing the productivity of the liquid to be cleaned. In this regard, the considered solution to the problem of increasing the service life of electrodes is relevant and promising.

4. Conclusion
In the developed reactor design, the current density in the gap between the adjacent anode and cathode and at the ends of the electrodes is less than the maximum permissible due to the fact that the height of the dielectric ring from above and below is greater than the height of the adjacent anode and cathode by size $\delta$, that is, it corresponds to formula (2). Thus, with the difference in the heights $\Delta h$ of the rings and the anodes and cathodes fixed on them from above and below, corresponding to condition (2), provides an increase in the service life of anodes and a reduction in downtime in repairs, an increase in the productivity of a biological wastewater treatment reactor is achieved.

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