Electrochemical Water Treatment for the Suppression of the Development of Microbiological Contamination in Technical Water Systems

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Abstract. The paper presents the results of integrated water treatment with an electric field and hydrogen peroxide, which makes it possible to suppress the development of microbiological pollutants in technical water systems. The combined effect provides a significant reduction in the content of microalgae and bacteria. Thus, treated water can maintain the achieved quality of neutralization, which makes possible its safe transportation and long-term use in water circulation systems.

1. Introduction

In many technological processes that use water, especially those that have contact with the environment (water intake from natural and artificial open water bodies, contact with atmospheric air, aeration), problems arise in the water colonization by various forms of microorganisms, multicellular organisms, animals and plants. Microbiological contamination and especially the growth of biofilms can seriously affect the quality of treated water and cause significant operational damage during the operation of water treatment plants [1]. Organisms that enter the water supply system from the outside are divided into allochthonous and autochthonous ones. Allochthonous organisms are not capable of normal life in the water supply system. Allochthonous organisms include filamentous bacteria, fungi, algae and various plankton. Sphaerolitus natans often serves as a hindrance among filamentous bacteria. Leptomitus lascheus is the most dangerous among fungi. Algae that impede water supply belong to various types. In the northern regions, the operation of water supply systems is hindered mainly by diatoms; in the south – blue-green and green algae. Autochthonous microorganisms also enter the water supply systems mainly with the flow of source water, but unlike allochthonous microorganisms, they take roots in water supply systems and are able to reproduce there.

Autochthonous microorganisms. Many of them develop on pipes and channels more intensively than in water bodies, since there are no their natural enemies there. Among autochthonous microorganisms there are bacteria, fungi, mollusks, arthropods, worms, bryozoans, sponges, protozoa and other lower animals. Algae usually do not belong to autochthonous organisms, since the absence of light interferes with their vital functions. Autochthonous microorganisms are capable of attaching themselves to the surfaces of walls and pipes and thereby withstand the flow of water. The internal fouling in the pipes is very resistant and often located in hard-to-reach places. Therefore, it is much more difficult to fight autochthonous fouling than with allochthonous fouling, and the damage caused by it is very great. Allochthonous microorganisms interfere mainly with the operation of filters, while autochthonous microorganisms in the entire water supply system [2].

The removal of microorganisms is not always a high-priority task for water treatment, water purification and reverse water supply systems. However, all water treatment systems face the effects of microbiological growth. The presence in the water of various kinds of biological objects leads to malfunctioning of calculated operating modes of the equipment caused by an increase in hydraulic and
thermal resistance and can provoke biological corrosion of surfaces [3].

2. The relevance of research
Currently, the problem of increasing biomass in process water is being solved in the following areas: water treatment (preventing the formation of bioobjects) and impacts that impede the attachment of bioobjects to equipment surfaces. Water treatment processes, as a rule, are carried out using strong oxidizing agents (chlorine, chloramines) and other reagents that can cause corrosion of equipment elements, as well as create difficulties when it is necessary to purify recycled water by the most common biological methods [4].

There are two main approaches for regulating bacterial growth in the water supply system. The first is to provide a sufficient level of biocidal agent within the water supply system (continuous dosing). This is usually used when a large amount of chlorine or chloramines is added to the source water to ensure its residual content in the distribution system, up to the points of consumption. Chlorine is the most common biocide used (minimum residual content is 0.3 mg/l). Ozonation is also often used in water treatment systems, although in this case, maintaining the residual ozone content in water is difficult due to its rapid decomposition. The second approach is to periodically disinfect the system. Options for using biocides in batch or continuous treatment will depend on the required water quality [5, 6].

The search for technological modes of water treatment to prevent the development of microbiological pollutants in water purification and transportation systems in order to ensure the normal operation of the equipment, and at the same time maintain its quality characteristics while minimizing energy and reagent costs, is an urgent issue. Treatment of process water using the effects of an electric field, with minimal or complete absence of chemical reagents, allows solving the problems of fight against biological fouling. This method can be effectively used in any technical water systems.

3. Problem formulation
The objectives of the paper were the selection of modes of electrochemical water treatment in order to inhibit the growth of biocultures and their destruction, providing high quality treatment with minimal energy consumption, and also the possibility of intensifying the process with the introduction of a chemical disinfecting agent – hydrogen peroxide, both in order to achieve optimal parameters for the neutralization of microbiological contamination, and in order to maintain the quality of the treated water for a long time.

At the same time, the possibility of carrying out the process outside the technological equipment is being considered.

4. Theoretical background and experimental studies
Experimental studies to evaluate the quality of electrochemical water neutralization were carried out in order to identify the possibility of treatment with minimal electricity consumption, and in order to evaluate the effectiveness and feasibility of using this method. There exist some known methods of preventing biological fouling of heat exchange equipment by electrically processing the coolant, which allows to suppress the vital activity of microorganisms in water and prevent the formation of biofilms on the heat transfer surfaces of equipment. But at the same time, the technological equipment itself requires structural alterations and is exposed to the impact of the electric field, which can cause difficulties in its operation.

The selection of modes of electrochemical water treatment in order to inhibit the growth of biocultures and their inactivation is a promising direction [7].

Experimental studies aimed at evaluating the quality of electrochemical water neutralization were carried out in order to identify the possibility of treatment with minimal power consumption, and in order to evaluate the effectiveness and feasibility of using this method. As the model environment river water was used which is used as an industrial coolant. The biomass and its increase and decrease in water were estimated using the membrane method using an ultrafiltration equipment with membranes Vladipor of the MFAS type - X-1.

Membranes Vladipor of the MFAS – X – 1 type are microporous film material made on the basis of a mixture of cellulose acetate with a pore size of 0.9 μm. Contaminants of this size are mainly microalgae cultures. Field of use: to determine the mass concentration of suspended solids in natural water and treated wastewater. Technical features: non-toxic. Water treatment was carried out in a stationary non-flowing mode in an electrolyzer with a capacity of 5 liters with an electrode system of titanium insoluble electrodes. The total volume of the studied water was divided into two samples, one of which was subjected to periodic
exposure to an electric field, the second was under the same conditions (open tank, temperature within 20-24 °C, in the light) without treatment.

Experimentally the minimum current parameters were selected allowing to achieve acceptable results in processing quality. When working with the studied model water, from a series of experiments indicators of a direct current with a force of I = 0.5 A were selected, while the voltage was U = 18 V. Treatment parameters were chosen based on the lowest possible power consumption. The duration of the experiment was 14 days; the electrolytic cell was switched on for 1 hour each day. The results are presented in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Kinetics of the electrical process: 1 - sample without working out, 2 - sample with processing.

Experimental studies have shown a significant decrease in the content of biocultures in water, the degree of neutralization was about 70% of the initial amount of pollutants. At the same time, a growth of biomass was observed in the control water sample, almost twice the initial pollutant content. The experimental data allow concluding about the effectiveness of this type of processing and carrying out further research in order to determine the optimal technological parameters.

![Figure 2](image2.png)

**Figure 2.** Evaluation of the effect of "aftereffect" of electric processing: 1 - sample without working out, 2 - sample with processing.

To evaluate the possibility of using the electric water treatment in industrial water circulation, studies were conducted estimating the effect of the “afteraction”, that is, the duration of maintaining water with
the achieved neutralization quality. For this, the experiment with electric field treatment was suspended in order to determine the time of preservation of the results obtained. Figure 2 shows the results of biomass growth in the sample without treatment and subjected to electrochemical effects. From the presented dependencies, it can be seen that the growth of biomass began 10 days after the experiment was stopped; this makes it possible to minimize the time of water treatment and reduce power costs. According to experiments, to achieve and maintain a minimum content of pollutants at the level of 20 mg / l, it is sufficient to carry out the treatment for 1 hour once a week. For specific process conditions, appropriate effective and economical treatment modes can be selected.

An obvious drawback of electrical processing is the short duration of the effect of maintaining water quality. That is why additional agents are necessary to support the effect of neutralization in technological systems with reverse water supply, systems with pauses in the technological process, with an extended water supply system. In the presence of a wide variety of chemicals for the treatment of water, hydrogen peroxide was chosen – a reagent with minimal negative effects, both for technological equipment and for the environment [8].

Oxygen-containing preparations, in particular hydrogen peroxide, are strong oxidizing agents that form free radicals that damage the lipids of the cell membrane, DNA and other important components of the microbial cell [9].

Although many microorganisms produce catalase, which protects cells against hydrogen peroxide by decomposing it into water and oxygen, the concentration of H₂O₂ used in disinfection allows in most cases to overcome this resistance mechanism. However, in its high concentrations and in the presence of such positive qualities as a wide spectrum of activity, including bacterial spores, lack of smell, rapid decomposition in the environment into non-toxic products, there are negative qualities – high tissue toxicity with significant locally irritating and resorptive effect. It is necessary to follow the instructions strictly when using peroxide products, as at high concentrations they are very aggressive. That is why minimizing the dosage of the reagent while simultaneously exposing the water to an electric field will eliminate possible negative effects of the use of H₂O₂ without loss of water treatment quality [10].

Experimental studies were carried out under the same current conditions, but with the addition of hydrogen peroxide 1% - 38% aqueous solutions of hydrogen peroxide stabilized by the addition of sodium phosphates. A series of experiments made it possible to determine that the boundary minimum concentration providing high treatment indices is 10 ml / l of a 19% solution. Treatment results are shown in Figure 3.

![Figure 3](image-url)  
**Figure 3.** Kinetics of combined electrochemical treatment: 1 - sample without working out, 2 - sample with processing.
Figure 4. Evaluation of the "aftereffect" of combined electrochemical processing: 1 - sample without working out, 2 - sample with processing.

Treatment results show approximately the same efficiency of neutralization by electrical treatment without the use of reagents (about 70%) and combined exposure (80%). And experimental studies of the “afteraction” indicate a significant extension of the time for maintaining the quality of treated water. The data are presented in Figure 4. As the graph shows, a noticeable growth of biocultures begins only on 30-40 days after the complete termination of impacts on water. These results allow you to choose technological treatment modes for various water types with different quality requirements.

To test the effectiveness of processing on smaller objects, bacterial inoculation of water samples was carried out to determine the number of CFU (colony forming units) – this is an indicator of the number of viable microorganisms in a unit volume (1 cm$^3$) in a liquid (1 ml).

The water disinfection experiment was carried out under the same conditions and under the same treatment conditions. In the first part of the study, the effectiveness of disinfection in an electric field without adding chemical reagents was evaluated, and in the second part, the quality of the integrated treatment was evaluated. The data are shown in Figure 5 and Figure 6.

Figure 5. The effect of "aftereffect" for disinfection of water by electric treatment
The treatment results indicate a high efficiency of the disinfecting effect (about 99%) with direct exposure to an electric field (100%), and a significant increase in the effect of "afteraction", which reaches 20-25 days with combined treatment.

![Graph](Image)

**Figure 6.** The effect of "aftereffect" for disinfection of water by combined electrochemical treatment.

To confirm the reliability of the results, the experiments were carried out with fivefold repetition at different times of the year, with similar conditions; the reliability coefficient is 2.5%, which shows sufficient accuracy of the experimental results.

The data obtained as a result of experimental studies indicate the prospects of the proposed integrated water treatment and, after additional studies, can be implemented in the design of electrolytic neutralization plants (flow-type electrolyzers) and reagents dosing and mixing systems (peroxide compounds). Such plants are affordable and can be integrated into existing technological systems of stages of water treatment, water recycling systems, water treatment, water transportation, etc. and to implement the proposed method of fighting against microbiological pollution.

5. Conclusion
1. The obtained results revealed the prospect of finding optimal technological parameters for complex electrochemical and reagent water treatment to fight against microbiological pollutants that can affect the quality of purified water and cause significant operational damage during the operation of technical water systems.

2. The research results allow to draw conclusions about the prospects of the use of electric treatment of process water to ensure minimization of the growth of biocultures. Treatment can significantly reduce the content of various types of pollutants – from 70% for microalgae and up to 99% for CFU. At the same time, treated water maintains the achieved quality of neutralization, at least for 7-10 days, which can significantly reduce the cost of electricity to maintain the specified requirements for water quality, ensure its long-term use in water circulation and transportation systems without the risk of biofouling of technological equipment elements.

3. When treating water with a complex of electrochemical effects and hydrogen peroxide, the neutralization efficiency gives slightly better results from 80% for microalgae and up to 100% for CFU. But at the same time, experimental studies of the “afteraction” effect indicate a significant extension of the time for maintaining the quality of treated water. The growth of biocultures begins only 30-40 days after the complete termination of impacts on water, according to CFU after 20-25 days.

4. The implementation of integrated water treatment is possible in various technical water systems using industrial electrolysis plants with an insoluble electrode module and a reagent dosing unit. Water neutralization in the technological scheme will allow not only to maintain the set parameters of water
quality and maintain them for a long time, but also to reduce the number of disinfection treatment cycles of system components, as without them the growth of microorganisms is inevitable.

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