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Electrochemical and Electrostatic Decomposition Technologies As A Means of Improving the Efficiency and Safety of Agricultural and Water Technologies

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ABSTRACT

At present, in the conditions of a tense ecological situation connected with the growth of industrial enterprises and their sewage, technogenic accidents and catastrophes, as well as various natural anomalies, modern methods of water treatment are among the priority areas. Particular attention is paid to cleaning heavily polluted sewage by using modern technological innovations and technical solutions. In the work presented, research is given in the field of disinfection and wastewater treatment of agro-industries using "green" technologies - electrochemical activation and electrostatic treatment. The technology of obtaining activated solutions in the electrochemical form, created by special installations, the use of which is possible at the place of consumption in the required quantity is popular in the world. As a result of electrochemical activation, aqueous solutions transform into a metastable (activated) state, while exhibiting increased reactivity in various physicochemical processes. Energy characteristics of the electrostatic field (ESF), allow to carry out activation processes at an $\vec{E}$ ESF intensity of 6-50 kV / m and inhibition of microorganisms at an $\vec{E}$ ESF intensity of more than 75-120 kV / m. In general, electrostatic treatment of sewage will be able to improve the efficiency of treatment in terms of: chemical oxygen demand (COD) – 15%, biochemical oxygen consumption for 5 days (BOD5) – 21%, nitrogen-containing compounds (N total) – 8%; phosphate (P total) – 11%.
Thus, the development of "green" technologies will solve many environmental problems, preserve water resources and achieve consistently high water quality with lower costs.

Keywords: *Food Industry, "Green" Technologies, Electrochemical Activation, Electrostatic Treatment, Wastewater Treatment, Environmental Safety*

INTRODUCTION

In the course of a long evolution, all living organisms on the Earth have fully adapted to their natural conditions and to a natural dependence on fresh water. During the relatively short historical period of human existence, the increase in its anthropogenic pressure on the environment led to a disturbance to the ecological situation and caused degradation of the environment and human health. The biosphere loses its originally dominant importance for living organisms and in the populated regions, it gradually turns into the technosphere. Uncontrolled and rapidly developing man's technogenic activities lead to many irreparable consequences: to the extinction of certain species of plants and animals, to numerous and annually emerging new diseases and to a reduction of the average life expectancy. Drawing attention to the higher problems, politicians and scientists began to support and conduct scientific research aimed at studying the influence of natural and anthropogenic factors on humans and other living organisms. But even up to now, despite the growing interest in this problem, the influence of electrostatic fields and electrochemical processes on living organisms remains an unexplored area.

Clean water resources are limited. Currently, more than 780 million people do not have access to them. About 85% of global waste water from industrial and settlement plants are not cleaned, thereby polluting them [1]. A large amount of sewage containing organic substances in high concentrations, suspended solids and cleaning agents is formed in the food industry and the agro-industrial complex (AIC). Wastewater treatment at the enterprises of the agro-industrial complexes producing fruit and vegetable products is connected to the sewerage system (indirect discharge of waste water), because they are often located on the territory of the settlements, and their wastewater is sent to urban sewerage or directly to natural water bodies. The level of pollutants of sewage at their discharge into water bodies should be below the maximum permissible concentration (RUS, SanPiN 2.1.5.980-00), which requires preliminary purification to bring these waters to the necessary ecological parameters.

Cleaning highly polluted wastewater attracts special attention in connection with the development of technological innovations, which in turn makes it possible to purify water only from anthropogenic pollution. However, to solve such problems as the negative impact of climate change on water resources, the increase of water stress problems, and the depletion of groundwater, the technological base is still lacking [2].

In general, food industry enterprises have similar treatment systems, usually including biological treatments. Since sewage treatment is not a tool for increasing the profit of an enterprise, the main direction of its improvement is aimed at reducing costs. At small concentrations of pollutants, enterprises dilute the effluents to the standard values. However, for most of the process of water generation, expensive cleaning is required.

According to the "Water Strategy of the Russian Federation for the Period to 2020" (approved by the Decree of the Government of the Russian Federation No. 1235-r of August 27, 2009), the specific water intensity of the Russian Federation's GDP is expected to decrease by 42% and 2.5 times, which requires a comprehensive approach when creating new technologies and ways to conserve natural water resources [3].

Of great interest for disinfection of water are non-reagent methods based on the use of various physical fields. These include electrical discharges, ultraviolet rays, ultrasound, laser, etc. The main advantage of physical methods is that they directly affect microorganisms, practically without changing the chemical composition of water [4].

At present, the attention of many researchers is attracted by methods of electrotechnology that can overcome the high cost and generation of toxic by-products based on the use of diaphragm electrolysis for decontamination and improvement of the quality of sewage. These methods combine electrooxidation with coagulation, active chlorine, UV irradiation and other techniques to increase the rate of wastewater treatment from toxic and difficult-to-oxidize organic substances [5-7].

At the same time, electricity consumption can be reduced by a factor of 2 using the oxidizing methods, which will entail a reduction in the costs of wastewater treatment. The method is based on the catalytic decomposition of hydrogen peroxide in an aqueous medium [8].

Many of the above physical methods are in the development stage of industrial designs. Comparing the application of ultraviolet radiation with electrochemical activation (hereinafter ECA), it should be taken into account that for effectively disinfecting water by ultraviolet radiation, practically all suspended particles and organic compounds absorbing radiation with a wavelength of about 254 nm should be removed [4]. When using ECA, these actions are not applied, which leads to a simpler and more profitable use.

Well known world companies for the purification of industrial waters by physical and chemical methods are Viqua (Canada) [9], Ecowater Systems (USA) [10], "Vontron Technology" (China) [11] and others. Among the Russian research and production companies, one of the most effective and environmentally sound technical and technological methods is the solution of Delfin Aqua LLC, which realizes the disinfection of water for various sectors of the food industry, agro-industrial complex, medical and pharmaceutical industry, sewage and circulating water, drinking water, as well as social facilities and housing and communal services [12].

2. MATERIALS AND METHODS

The technology of waste water treatment of food industry enterprises depends on the volume and nature of the pollution of effluents. For example, for bakeries, the volume and quality of sewage during the year will be in a limited range with a tolerance of 5-10 %.

Among the other types of sewage, transporter-washing waters are allocated. Transporter-washing waters are formed during washing and hydro-transport of fruit and vegetable products, while the volume is 1300-1400% of the weight of the processed raw materials. In relation to the total discharge of enterprises, these waters constitute 55% [13].

The amount of contamination of conveyor-washing water, mg / l:
1. Inorganic suspensions (ground) – 750;
2. Organic – 230;
3. Inorganic soluble – 200;
4. Organic soluble – 190;
5. Nitrogenous substances – 150;
6. BOD_5 – 152.

However, for enterprises in the processing sector, significant seasonal and production fluctuations in the concentration and composition of the effluents will be recorded. For the treatment facilities of each food industry enterprise, a certain composition of sewage with the content of various organic substances (COD and BOD), fats, mechanical impurities, proteins, product residues, etc., is characteristic.

Any changes in the technological processes require high flexibility of the equipment. The minimum requirements for the discharge of waste water from enterprises and the regulatory indicators are presented in Table 1.

Table 1: Standard and averaged indicators of sewage pollution

№	Index	Average values of waste water	Municipal Unitary Enterprise "Vodokanal"	Maximum allowable concentration cultural-domestic
1	BOD_5, mg / l	350-390	300	4
2	COD, mg / l	560-600	500	30
3	NH_4–N, mg / l	11-13	27	1,93
4	N_{total}, mg / l	22-25	50	1,5
5	P_{total}, mg / l	3-8	12	3,5

Note: BOD_5 – biological oxygen demand (5 days), COD – chemical oxygen demand

Since the 1970s, the method of electrochemical activation of water (ECA) has been actively studied in the USSR and abroad. Scientific researches and works in the field of application of ECA technologies were confirmed and led to positive practical application in medicine, agriculture, food industry, etc.

This scientific and technical direction is focused on ensuring the safety and health of the population and preserving the clean environment. It is known that ECA solutions have antimicrobial properties against facultative anaerobic and mesophilic aerobic microorganisms, E. coli bacteria, bacteria of the genus Proteus, genus Salmonella, Staphylococcus Aureus [14].

In the studies Filonenko V.B. et al. [15], modifications of electroactivated water for the disinfection of equipment were studied. As a result of the conducted experiments, it was proved that this treatment method contributes to the almost complete removal of the sanitary-indicative (Escherichia Coli) and specific (Salmonella) microflora from the surface of the equipment.

Multiple studies around the world also confirm the fact that the ECA aqueous solution has antimicrobial, antiviral and antibacterial properties [16-18].

Methods of electrochemical activation and electrostatic treatment (EST) of wastewater are widely and successfully used in various industries.

2.1. Electrochemical activation

At the moment, the technology of electrochemically activated solutions is very popular in the world. It is considered as one of the best options to use in the food industry to protect consumers from bacteria such as E. Coli and Salmonella, excluding the risk of toxic chemicals.

ECA technology replaces bulky chemical production with compact modular electrochemical systems. The production and use of metastable substances instead of traditional chemical reagents allow reducing the consumption of chemical reagents tenfold or completely eliminating their use.

Electrochemical activation changes the composition of dissolved gases, acid-base and oxidation-reduction properties of water in a range much larger than under equivalent chemical regulation, synthesizes chemical reagents from water and dissolved substances.

Widely known in Russia and abroad, there are ECA installations that provide environmentally friendly sterilizing and disinfecting solutions (anolyte type ANK), medical and children's institutions, utilities, food industry, swimming pools and agro-industrial enterprises.

Table 2 shows the comparative characteristics of electrochemically activated anolyte ANK, obtained in ECA plants, and traditional chemical preparations for disinfection and sterilization [12,19].

Table 2: Comparison of the ANK anolyte characteristics obtained in the ECA plants and various disinfectant solutions

№	Name, country of manufacture	Concentration of working solution,% (concentration ratio)	Characteristic of antimicrobial action					Allergenicity and toxicity (GOST 12.1.007-76)	Combination of disinfecting properties and detergency	Adaptation of microorganisms
			Bacteria	Mycobacteria	Viruses	Mushrooms	Disputes			
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
1	Anolyte ANK (Russia)	0,01-0,05	+	+	+	+	-	IV	+	–
2	Hypochlorite of sodium (Russia, USA, etc.)	0,1-0,5	+	+	+	+	-	IV	–	+
3	Presept (USA)	0,5	+	+	+	-	-	III	–	+
4	Chloramine (Russia)	1,0-3,0	+	+	+	+	-	IV	–	+
5	Chlorhexidine Bigluconate (Russia)	0,5-4,0	+	+	+	-	-	IV	–	+
6	Lysoformin-Special (Switzerland)	0,5-4,0	+	-	+	-	-	III	–	+
7	Virkon KRKA (Slovenia)	0,5-2,0	+	-	+	-	-	III	–	+
8	Lisetol-AF (Germany)	2,0-5,0	+	+	+	+	-	III	–	+
9	Sydex (USA)	2,0	+	+	+	+	-	III	–	+
10	Cold Sore (USA)	2,0	+	+	+	+	-	IV	–	+
11	Deconex 50FF (Switzerland)	0,5-4,0	+	+	+	-	-	III	–	+

As a physico-chemical process, ECA is a combination of electrochemical and electrophysical effects on a liquid with the ions and molecules of solute contained in it, in the space charge region near the electrode surface of the electrochemical system under conditions of minimal heat release in the case of nonequilibrium charge transfer across the "electrode-electrolyte" boundary electrons.

To synthesize the disinfecting solution, special installations are produced in which diaphragm electrolysis of the saline solution is realized. These units are designed to produce a disinfectant aqueous solution of a mixture of oxidants (hypochlorous acid, hypochlorite ions, chlorine dioxide, ozone, hydroperoxide compounds) by electrochemical decomposition of a solution of sodium chloride. The advantage of the plants is the production of a disinfecting solution at the place of consumption in the required quantity. So, to get a disinfecting solution, only water (SanPin 2.1.4.1-74-01), edible non-iodized salt of the 1st grade or salt of the brand "Extra", and power supply (50 Hz and 220 V) are required.
The use of disinfecting solution produced by the plants provides a prolonged effect, eliminates the risk of secondary water contamination, and guarantees a stable quality of water disinfection belonging to the 4th class of low-hazardous substances (GOST 12.1.007-76). After using the solution, it does not accumulate in the external environment, does not create films on the surfaces, does not require flushing and deactivation after application. Schematic diagram of the device ECA is shown in Figure 1 [12,19].

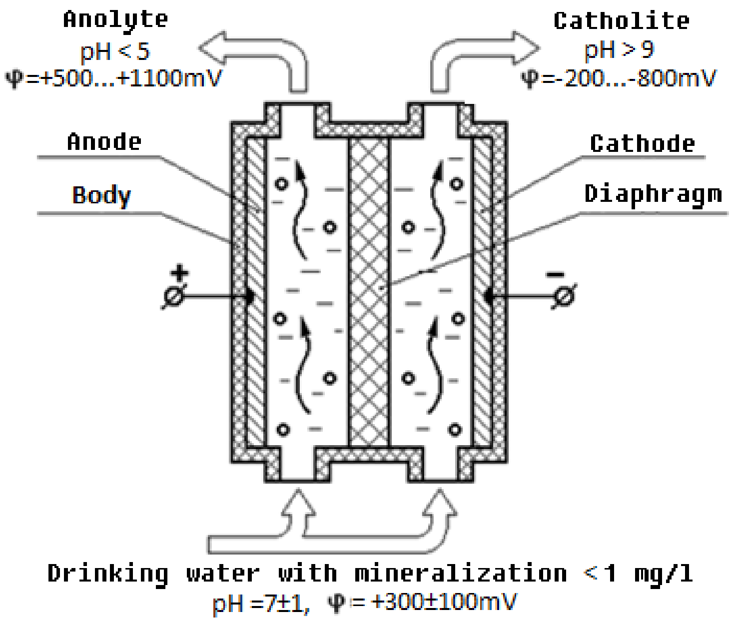

Figure 1: Schematic diagram of the device unit ECA

The basis of this approach is the scientific understanding of the environmental and economic benefits of the practical use of activated substances, including activated by the electrochemical action of water, over traditional chemical reagents, in industry, agriculture, medicine and other fields of activity. These representations fully correspond to the principled positions of "green" technologies - the creation of new ones and the transformation of existing chemical industries and chemical technological processes with a view of ensuring their ecological purity and safety.
It is important to note separately that the anolytes have long been certified under various trademarks all over the world, and are included in the European List of Endoscopic Endoscopy Products (ESDS Guideliness Committee) for disinfecting drinking water in the Netherlands, and for enhancing safety of food products (greens on the shelves of shops, meat, fish, seafood) in the USA. ECA-solutions are used in dental practice in Switzerland and Belgium for disinfection of root canals. In Turkey, USA, Korea, Japan and many other countries, the anolyte is used to treat purulent wounds, pressure sores and other skin diseases [19, 20].

2.2. Electrostatic treatment

Also worth considering is the method based on the use of electrostatic field (ESF), which creates the conditions for rapid growth of biomass, which helps to reduce the time of operation of treatment plants in the enterprise. Processes using high-voltage processing are widely used in various fields of technology, including: for gas cleaning, for electric smoking, for electric separation, etc. These processes combine the essence of the applied method, which consists in the movement of an ionized gas in the electric field, which informs the charge of finely dispersed particles of matter (dust, smoke smoke, etc.), while the particles perform ordered directional motions between unlike charged electrodes,

in a number of technological processes [21].
The influence of the electrostatic field can lead to profound structural changes, and, consequently, to a higher efficiency of nutrient biomass use [22]. Recirculated water passes through a fast, usually at the majority of APC enterprises, only mechanical cleaning, while a large number of bacteria and spores remain in the water, but the electrostatic treatment (EST) allows slowing down the processes and preventing the development of microorganisms in the water. The basic scheme of the device of the EST block is shown in Fig. 2, the circuits of the EST device, unlike the ECA, do not have a separating diaphragm; the anode and cathode contact with the aqueous medium, the thickness and material of the casing, which must be a dielectric with a wall thickness of 1-2 mm, while increasing the wall thickness decreases the intensity of the action on the boundary layer of the dielectric-aqueous solution [23, 24].

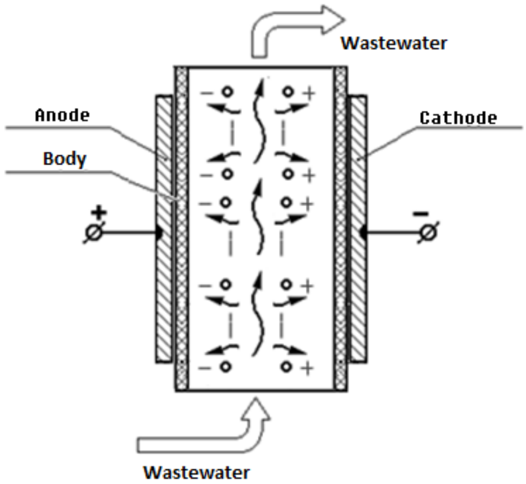

Figure 2: Schematic block diagram of the device EST

Electrostatic treatment of aerobic microorganisms allows increasing biomass faster and reducing the number of free elements in water. Water molecules do not have a dipole moment, they practically do not ionize; therefore, in the presence of microorganisms in an aqueous medium, the potential energy of the electrostatic field is assimilated by microorganisms, and if the aqueous medium is not mobile, orientational ordering of molecules and particles in the electrostatic field takes place. This phenomenon makes it possible to use the technology in treatment plants and in microbiological industries. For each type of microorganism, there are optimal processing parameters, but the intensity of the ESF over 55 kV / m leads to disruption of metabolic metabolism and cell death. Thus, it was found that with increasing duration and intensity of the EST, the process of inhibiting the growth of microorganisms was initialized, and with the decrease in the parameters of the EST – the growth of clusters of microorganisms (activated sludge) in wastewater was intensified.

3. RESULTS AND DISCUSSION

In recent decades, the use of the electrostatic field in the production of foodstuffs has been gradually tested. The greatest number of studies is related to biotechnological processes, among which a special place is occupied by technologies for intensification of ethanol production, activation of baker's yeast. In the field of agriculture, ESF has found application in the processes of cultivation of biologically valuable microscopic algae, chlorella [25]. Studies have shown the general patterns of the effect of ESF on microorganisms in the water and air environments, which opened the way to the creation of innovative technologies for activation and deactivation of microorganisms.
It is worth noting that the energy characteristics of the ESF allow activation processes with an $\vec{E}$ ESF of 6-50 kV m^{-1} and an inhibition of microorganisms with an $\vec{E}$ ESF strength of more than 75-120 kV m^{-1}. Investigations in the field of electrostatic field influence revealed a number of regularities in the influence of salt composition, temperature regime, and the presence of organic and inorganic impurities on the efficiency of ESF.
Unlike ECA, the technology of EST has a number of limitations, for example, the presence of coarse unfiltered impurities can drastically reduce the effectiveness of EST. The significant influence of the presence of various impurities on the efficiency of the ESP is due to the dispersion of the ESP and the start-up of physical and chemical processes around the largest particles.

The nature of the EST is related to electromagnetic fields, but ESF does not have a penetrating effect. The maximum allowable voltage of ESF at work stations is regulated and should not exceed the following values: when exposed to 1 hour – 60 kV $m^{-1}$and when exposed more than 1 hour to 9 hours, the value is determined by the calculation method. For today, the EST has already been tested for waste water treatment of vegetable processing enterprises, peasant farms, but has not been used on an industrial scale. The dynamics of the reduction in COD values for EST, $\vec{E}$ ESF 15-25 kV m^{-1} are shown in Figure 3.

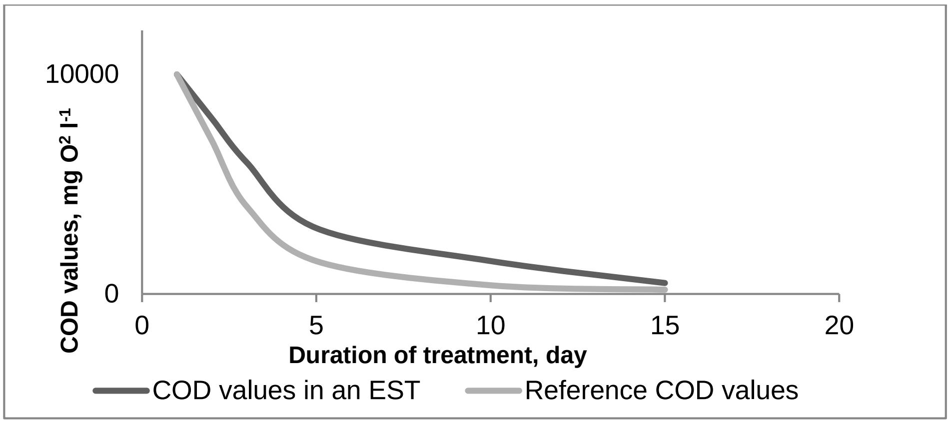

Figure 3: Regularity in the change in COD values in an EST

Sewage and circulating water produced in the process of washing fruits and vegetables usually undergo rapid mechanical cleaning, while a large number of suspended particles, bacteria and spores remain in the water, repeatedly contaminating fruit and vegetable products. In the process of approbation of the technology, the design of a pilot plant was simulated, allowing to ensure stable processing of ESF. It was noted that with an $\vec{E}$ ESF intensity of 6-50 kV / m, an increase in the number of microorganisms of at least 10% was observed in the volume of the storage reservoir from the baseline values, when compared with the control sample. However, with an ESF intensity of 100-110 kV / m, the microbiological contamination of the water decreased by 15-20% at 30 seconds of treatment.

Unlike EST, when passing through a reactor, ECA allows lowering the COD values from 6000-1000 mg O^2 / L to the standard values of the discharge for a period of time equal to a single treatment, depending on the capacity of the reactors.

With the additional saturation of the aqueous medium with oxygen, ECA has a beneficial effect on aerobic microorganisms, with endogenous respiration of cells increasing by 10-15% (Figure 4).

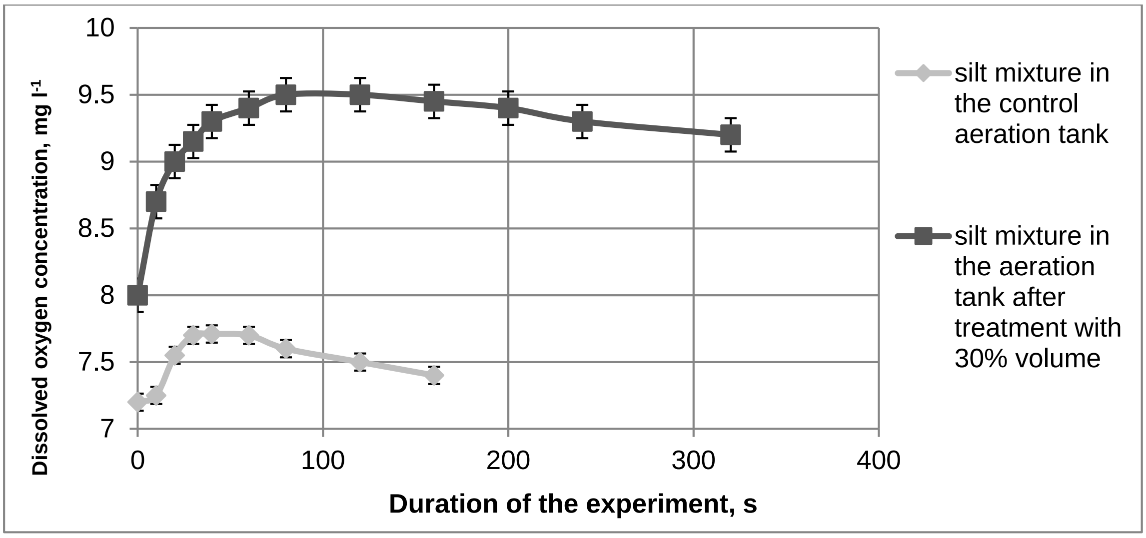

Figure 4: The change in the oxygen concentration in water that has undergone electrostatic treatment $\vec{E}$ = 41,6 kV m^{-1}, T = 25˚C

This phenomenon can be explained by increasing the distance between the cells of the surface of the membrane, which increases the throughput and oxygen consumption. The change in oxygen consumption is also associated with an increase in the expenditure of nutrients necessary for the development of cells. In food enterprises, for example, in the processing of fruit and vegetable products, circulating and waste water are usually formed, containing microorganisms washed off from the fruit and particles of damaged products. The process of purification of circulating and waste water is characterized by changes in the parameters COD, BOD_5 (Figure 5), N_{total} and P_{total} (Figure 6).

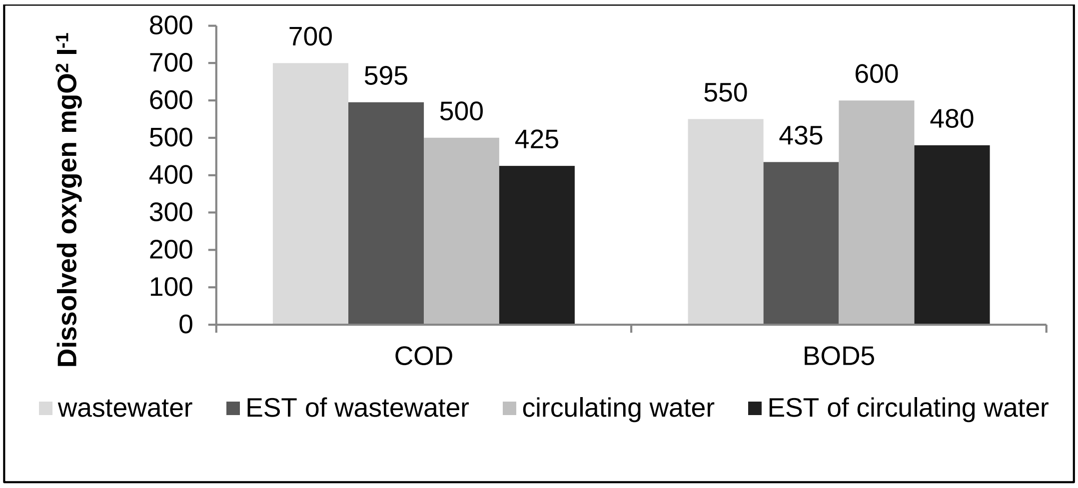

Figure 5: Characteristics of indicators COD and BOD5 of purification of circulating and waste water

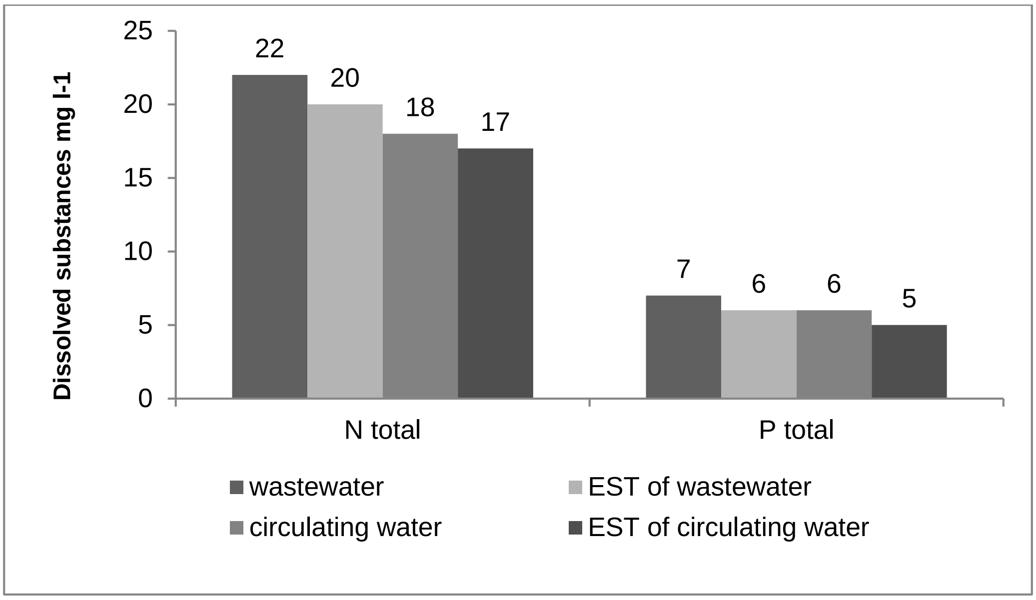

Figure 6: Characteristics of indicators N_{total} and P_{total} of purification of circulating and waste water

The dependencies shown in Fig. 6 show that for given processing parameters, the content of nutrients decreases, regardless of the presence of circulation in the purification system, while the circulation ensures a more intensive course of purification processes.

Electrostatic treatment of waste water can improve the efficiency of cleaning: COD – 15 %, BOD_5 – 21 %, N_{total} – 8 %; P_{total} – 11 %. Microscopy showed that the EST of waste water contributed to a sharp increase in filamentous bacteria in the aquatic environment. The appearance of bacteria such as Beggiatoa and Thiothrix occurs only at low concentrations of organic pollutants, which confirms the effectiveness of purification in the EST.

4. CONCLUSION

As a result of the experimental work, a positive effect of electrochemical solutions and electrostatic fields was established as a disinfection of water. The study of EST showed that for processing, it is not necessary to create a permanent ESP, short enough, of the order of 30-60 s. pass through the electrostatic activator to maintain the specified characteristics. When comparing the methods of EST and ECA, it is established that the ECA reactor reduces the COD values from 6000-1000 mg O^2 / l to the standard discharge values over a period of time equal to a single treatment, taking into account the productivity of the facilities.

Treatment of industrial wastewater including purification from coarse impurities [26] and disinfection of treated sewage [19,23] has been studied. The development and introduction of "green" nature-like technologies used in the principles of electrochemical activation are a priority of domestic science [27], and also contribute to the overall reduction of global polluting emissions and discharges [28].

The academic and expert community of the BRICS countries strengthen cooperation in the areas of activity related to the non-reagent regulation of the physicochemical properties of water and aqueous solutions through the use of electrochemical activation in technological processes. Summarizing the above, it is important to emphasize that the future behind the "green" technologies is the electrochemical activation of water and aqueous solutions because of its environmental friendliness, efficiency and economy. The urgency of introducing safe physico-chemical methods for purification of industrial wastewater at industrial enterprises, technical and technological solutions for disinfecting both technological processes and products in agriculture and public catering is emphasized [29, 30].

In conclusion, it is important to note the importance of improving the "green" physicochemical techniques and technologies aimed at increasing the efficiency of use, environmental friendliness, economy and resource saving in technologies for storage and processing of food's raw materials and food products while minimizing chemical risks in the food industry. Improvement of existing technologies is impossible without taking into account the state of the environment, the complex solution of existing problems with the use of highly efficient technologies will solve many environmental problems and preserve water resources. The developed complex technical and technological solutions for the use of EST and ECA for increasing the efficiency of use, quality and safety of food's raw materials and food products of vegetable and animal origin on the basis of the use of physical and chemical processing methods will contribute to the obtaining scientific, theoretical and applied knowledge, the development and improvement of physico-chemical engineering and technology, the accumulation of practical experiences, as well as the development of scientific, technical and technological The direction in the food industry and agriculture.

5. ACKNOWLEDGEMENT

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