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Preventive Improvement of Wastewater Treatment Efficiency

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Abstract. This paper focuses on studying the effect of electrolytic water on wastewater decontamination processes, using model solutions and wastewater from the food-processing plant. The aqueous solutions under study were obtained by changing the redox potential (ORP), and pH of ordinary tap water using a pH corrector, which is a flow-through electrolyzer with a membrane separating the cathode and anode zones, and the solutions were obtained by adding to tap water a solution containing products of electrokinetic synthesis. Parameters that changed as a result of the study: ORP, TDS, pH. Solutions capable of almost complete inhibition of the vital activity and growth of microorganisms were obtained. Also, solutions were obtained that promoted their development, and when seeding them on a dense nutrient medium, there was continuous growth. Further research is advisable to detail the technical and economic indicators of municipal and industrial facilities' water supply and sewerage schemes with preventive water treatment processes.

Keywords: wastewater, meat, methods of pretreatment, pH corrector, biostimulation, bioinhibition.

1 Introduction

Food products are a good breeding ground for microorganisms. Therefore, to preserve food quality, i.e., meat products, they are subjected to salting, refrigerated storage, and other types of preservation [1]. At the same time, during slaughtering, animal carcasses are constantly washed with water, which is subsequently discharged as effluent and sent to sewage treatment plants. Accordingly, the wastewater enterprises of the meat industry have a high degree of bacterial contamination. Particularly dangerous are pathogenic microorganisms in them by E. Coli, worm eggs, anthrax. In this connection, before discharging into water bodies or on the ground areas of sewage of enterprises of the meat industry, they should be subjected to effective cleaning and disinfection [2].

At the same time, it is essential to solving the problem of the contamination of the effluents from meat industry enterprises based on washing the carcasses of slaughtered animals with an aqueous solution with predetermined parameters.

2 Literature Review

Methods of wastewater treatment in the meat processing industry from pathogens and various pollutants can be divided into the following basic methods [3–5]: mechanical (physical), chemical, physicochemical, biological, and combined.

Examining the scientific periodicals indexed by the Scopus metric database, it was found that this topic was first covered in 1978. Since then we can see a sharp decrease in the study of this topic until 2006, with a further decrease in publication activity, with variable values over the years: 2009, 2019–2020. (Fig. 1). This trend is very popular in the countries with a high indicator of consumption of meat and milk products. Therefore, according to the results of the study of this topic, the first place for the number of publications is occupied by the United States of America - more than 100 scientific works, followed by Brazil – 61 papers, China and Canada – about 50 papers.

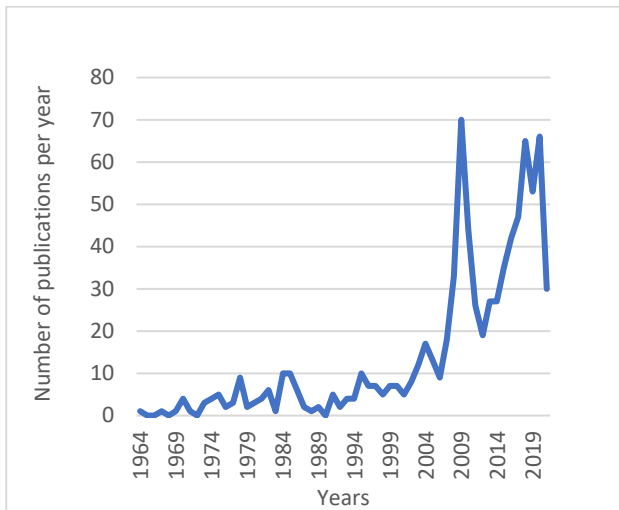


Figure 1 – Analysis of search results by years

The most significant number of scientific works is focused on improving ecological situation in regions and engineering sector, biofuel production, and chemical machine-building with the production of different kinds of chemical additives (Fig. 2). The most critical areas of research are actual for Ukraine.

Looking at the 2019–2021 years, we can see that the primary position of the majority of works reveals the solution of environmental problems of food enterprises. Such works can include the following topics [6–8]: assessment of toxicity of wastewater of the meat-processing industry, optimization of processing technology of liquid wastes from food processing plants, and processes of anaerobic pickling for purification of high-quality wastewater.

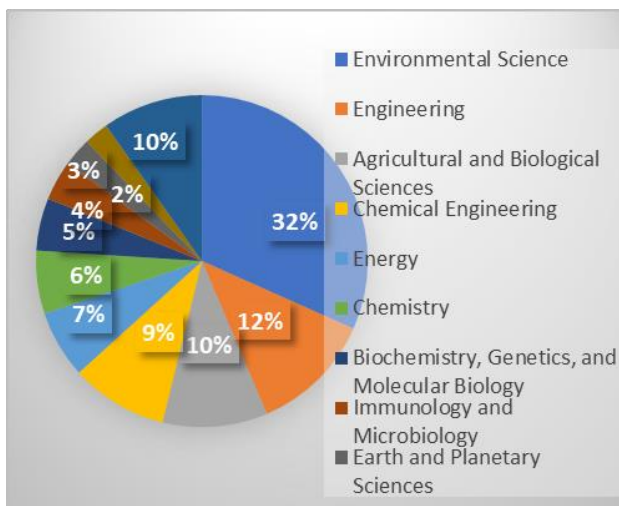


Figure 2 – Search results in the use of bioenergy technology

Ivanchenko et al. (2020) developed a quick analysis for an unbiased and accurate assessment of wastewater properties and its sediments. Biotests allow quick identification of integral toxicity and can be used for screening investigations. The optimal method for determining the overall toxicity of complex sums is to

evaluate the properties of the hydrogenous fraction since it is a real threat if it enters the human body. Biotests on the representatives of different trophic levels allowed one to assess the safety of the investigated wastewater in a short time. That is why they were recommended as test systems to control the environmental safety of wastewater to identify several specific chemical spores, integral toxic potential, and long-term consequences for natural and piece ecosystems [9].

In the process of research by Kulikova et al. (2019) special attention was paid to the study of the new combined unit - aerobic treatment reactor (FLOTEX - AERO) and anaerobic treatment reactor (FLOTEX - ARO). They were designed taking into account the main advantages and disadvantages of the used tanks for fat removal, brine collectors, floating and aerobic treatment plants intended for non-cleaning biologically, as well as the special features of wastewater from meat and dairy plants [10].

Harris and McCabe (2020) investigated improvements in anaerobic wastewater recycling in the Australian black-bean industry. Anaerobic lagoons are an economically efficient method of waste management when land availability is not an issue; however, high-fat loadings in wastewater can negatively impact the anaerobic lagoon system and fail anaerobic digestion characteristics. This work will discuss the importance of primary pretreatment and consider a low level of research aimed at optimizing the operation of the cooking apparatus and improving the biological composition of the fat. These studies include the following: influence of temperature and mixing; the influence of microelement composition and additives; potential benefits from the previous treatments such as chemical, thermobaric, thermochemical, and bi-PAR. Recommendations are given for the optimal operation of the cooking apparatus and future possibilities in adopting alternative variants of anaerobic digestion technology [11].

For disinfection, you can use the approaches described in paragraph 9.2.11.1 of SP 32.13330.2012 “Sewage. Outdoor networks and facilities” domestic wastewater and their mixtures with industrial wastewater discharged into water bodies or used for technical purposes should be subjected to disinfection. This is aimed at maintaining the environmental safety of the environment [12].

SanPiN 2.1.5.980-00 “Hygienic requirements for the protection of surface waters”, which regulates the disinfection of sewage, establishes the following requirement: “Wastewater hazardous by epidemiological criteria may be discharged into water bodies only after appropriate treatment and disinfection to the number of thermotolerant coliform bacteria CFU/100 ml \leq 100, the number of total coliform bacteria CFU/100 ml \leq 500 and the number of coliforms CFU/100 ml \leq 100”.

In this case, a sequential scheme of water treatment is classically used (Fig. 3).

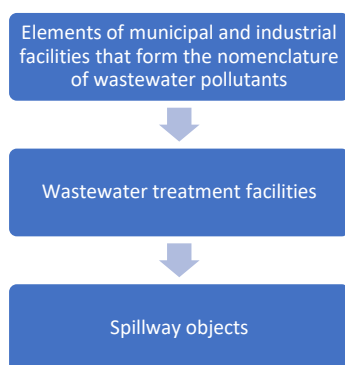


Figure 3 – Classical scheme of wastewater treatment by municipal and industrial facilities

This study aims to investigate the effect of electrolytic water on wastewater decontamination processes, using the example of model solutions and wastewater from meat-processing production.

3 Research Methodology

3.1 Methodology for the study of model aqueous solutions obtained from meat processing

The aqueous solutions under study were obtained by changing the redox potential (ORP), and pH of ordinary tap water using a pH corrector, which is a flow-through electrolyzer with a membrane separating the cathode and anode zones, and solutions were obtained by adding a solution containing electrokinetic synthesis products (ECO) to tap water (Table 1).

Table 1 – Composition of the solution

Component	Quantity, g/l
Pancreatic hydrolysate of fish meal dry (PGRM dry)	7.5
Peptone dry fermentative for bacteriological purposes	7.5
Pancreatic casein hydrolysate dry (PHC dry)	10.0
Yeast extract	2.0
Sodium chloride	3.5
D-Glucose	1.0

The anolyte was obtained by sampling the solution from the anodic zone of the pH corrector; the catholyte was sampled from the cathodic zone. The sampled solutions were used both separately and mixed to obtain a neutral solution.

For obtaining ECO-1 solutions, 15 ml of activated solution was added to 150 ml of tap water. For obtaining ECO-2 solutions, 30 ml of activated solution were added to 150 ml of tap water. After obtaining each of the solutions, fresh pig meat was soaked in them for 30 seconds to simulate the process of washing animal carcasses at meat processing plants. Six different solutions were obtained, the values of which are shown in Table 2.

Table 2 – Indicators of obtained aqueous solutions for meat treatment

Solution/indicators	ORP, mV	TDS	pH	t, °C
Tap water	-7.7	207	7.13	17
Anolyte	92.5	278	5.42	22.6
Catholyte	-129	220	9.18	22
Anolyte + catholyte (in equal proportions)	21	270	6.64	22.7
ECO-1 (ele-based solution)	-2	280	7.03	19.6
ECO-2	-1.6	380	7.03	20.5

Then, after soaking, all indicators of the solutions were measured again. We also measured the concentration of nitrogen compounds (ammonia/ammonium, nitrites, nitrates) in the solution. All measurements were repeated after 5 hours as well as one day after receiving solutions. Also, these solutions were plated on a dense agarized nutrient medium to determine the total microbial count and then compare the insemination of these solutions. It was also concluded that changes in the values of aqueous solutions for washing meat affect their subsequent infestation and the ability of microorganisms to live and multiply in these solutions.

A specific nutrient-dense medium for determining the number of mesophilic aerobic and facultative anaerobic microorganisms (CMAFANM) was used to assess the total insemination of various meat flushes.

Prepared nutrient medium, which is a hygroscopic fine-dispersed powder of beige color, was used for cultivation. The combination of components in the medium provides the nutrient requirements for visual growth detection and determination of mesophilic aerobic and facultative anaerobic microorganisms.

Preparation of the medium: (50±5) g of dry medium is introduced into (1±0.05) dm³ of cold water (both distilled and tap water, previously prepared, can be used). The mixture is thoroughly mixed, brought to a boil, and boiled for 3-5 minutes without allowing it to burn. If there is a precipitate, filter it through a cotton-gauze filter. The medium is heated to boiling again, poured into flasks or tubes, sealed with cotton plugs, and sterilized at (121 ± 2) °C for (15 ± 1) minutes. The prepared medium is transparent and has a yellowish-brown color. Immediately before use, the medium is melted by placing the container with the medium in a water bath. The molten medium is carefully cooled to a temperature of 40–45 °C without foaming. Nutrient medium is introduced into sterile Petri dishes in the amount necessary to create a layer of a medium of at least 2 mm (usually 12–15 cm³ of agar medium is required) growth is judged by the appearance of visible colonies of microorganisms on the nutrient medium.

A universal nutrient medium, meat-peptone agar, a natural nutrient medium, was used to determine the PMF. Composition of the nutrient medium: 1 l of meat broth, 10 g of peptone, 5 g of NaCl, 20 g of agar-agar.

Preparation: Mix meat broth with peptone and table salt, boil for 10 minutes, filter through a paper filter. Then the necessary amount of agar-agar is added. The pH is

adjusted to 7.2–7.4. Feeding tubes are sterilized by autoclaving at 121°C and 1 atm for 20 minutes.

GRM-agar nutrient medium is designed for the cultivation of a wide range of microorganisms. It can be used in sanitary research of water, sewage, and other materials. If necessary, it can be enriched with carbohydrates, blood, serum. It is a hygroscopic fine-dispersed powder of light yellow color.

Composition of the nutrient medium (in grams per liter of distilled water): pancreatic hydrolysate of fish meal – 24.0; sodium chloride – 4.0; agar-agar – 12.0 (± 2.0).

Preparation: a suspension of 39.0 g of the drug in the amount indicated on the label is stirred in 1 liter of distilled water and boiled for 1–2 min until the agar is completely melted, filtered through a cotton-gauze filter. The medium was poured into bottles and sterilized by autoclaving at 121 °C for 15 min. Sterile medium cooled to 45–50°C is poured into sterile Petri dishes with a 4–6 mm layer.

After preparation and sterilization, the prepared nutrient medium was poured into Petri dishes and waited for solidification. Then, all aqueous samples were diluted ten times in sterile tap water under a laminar flow box. The obtained solutions in the volume of 1 ml were placed on a solid nutrient medium and distributed on the nutrient medium using circular movements of the Petri dish and spatula. We placed the seeded microorganisms in a thermostat with a temperature of 37 °C.

3.2 Research methodology for wastewater from a meat processing plant

To assess the degree of contamination of wastewater, mineralization, TDS, and pH (Table 3).

Table 3 – Indicators of the main indicators in the composition of wastewater JSC “Pinsk meat processing plant”

Indicators	pH	TDS	ORP, mV	t, °C
Wastewater sample	6.44	1116	32.8	19.6
Anolyte	2.38	1600	270.0	22.2
Catholyte	11.46	1200	-237.0	21.3
ECO-2	6.48	1100	32.3	38.8

Different wastewater treatment methods from various organic and microbiological pollutants were also carried out by adding anolyte and catholyte solutions, treatment with hydrogen peroxide; exposure to ultraviolet radiation; dosing biocidal product (BP) (with a mass fraction of 5 % – 4 ml/l).

During the experiments, 5 containers with a volume of 5 liters were taken, adding 1 liter of wastewater to each. For treatment with anolyte, catholyte, and ECO-2, 1 liter of wastewater was taken into the tank. When BP was exposed, its concentrated solutions and liquid glass were diluted to obtain solutions with a mass fraction of the substance of 5 %. In the first tank, 2 ml of diluted liquid glass solution was introduced to alkalize the wastewater, and after 2 minutes, 4 ml of BP solution was introduced. Flakes began to form in 20 seconds after introducing the flocculant: flakes were formed quite large, in the form of a coarse curd mass, capturing all large particles in the

solution, indicating that BP, as a flocculant, not only catalyzes the process of coagulation but also enhances it by order.

100 ml each of the anolyte and catholyte solutions were added to the following two containers. After mixing thoroughly, let stand for the effective passage of all processes. We added 0.4 ml of hydrogen peroxide to 1 liter of wastewater, stirred thoroughly, and poured the solution into a unit containing two ultraviolet lamps. It was treated with ultraviolet radiation for 5 minutes.

4 Results and Discussion

4.1 Study of biostimulation and bioinhibition of model aqueous solutions

After treating the meat with ordinary tap water (control experiment) and bacteriological seeding of this water sample on the nutrient medium KMAFANM, the total insemination was no more than $4 \cdot 10^{10}$ CFU/ml (Fig. 4).



Figure 4 – The contamination of tap water 2 days after washing fresh pork meat with this water

There is also a colony of fungi on the medium. This colony-forming unit may have gotten into the solution during the preparation of dilutions.

As a result of washing meat with water sampled from the anodic zone (anolyte), no total insemination of the sample was planted on the nutrient medium KMAFANM. It can be concluded that high ORP values have a deleterious effect on the vital activity of microorganisms, and solutions having such ORP values can be used as disinfectants in the process of washing meat carcasses at meat processing plants without being toxic substances (Fig. 5).



Figure 5 – The contamination of water sampled from the anode zone 2 days after washing fresh pork meat with this water

After washing the meat with water sampled from the cathodic zone (catholyte), there was a solid overgrowth of the KMAFANM medium, counting colonies, in this case, is impossible in both replications, which indicates the positive effect of negative ORP values on the vital activity

of microorganisms, indicating that these solutions are not suitable for meat treatment to obtain an antibacterial effect (Fig. 6).



Figure 6 – The contamination of water sampled from the cathodic zone 2 days after washing fresh pork meat with this water

After treating the meat with a mixed solution consisting of equal proportions of catholyte and anolyte, there was uniform growth of microorganisms in both cups and amounted to about $9 \cdot 10^{11}$ COE/ml, which indicates that this solution is also not suitable for washing the meat to disinfect it and obtain an antibacterial effect (Fig. 7).



Figure 7 – The contamination of a mixed water sample from the cathodic and anodic zones, 2 days after washing fresh pork meat with this water

After introducing a certain amount of ECO-2 products into normal water, and as a result of subsequent soaking in this solution of meat, the sowing of this solution did not occur, and only on one of the cups can be seen a colony of fungus, presumably caught in the solution during the preparation of dilutions. This result may indicate that using these reagents in the process of washing animal carcasses at meat processing plants can serve as a good measure to prevent the contamination of wastewater with microorganisms (Fig. 8).



Figure 8 – The contamination of the solution containing ECO-2 products in the amount of 30 ml/150 ml of tap water 2 days after treatment of fresh pork meat with this solution

The results obtained after introducing a smaller amount of ECO-1 products are similar to those described above - there is no contamination of this solution, indicating an apparent bactericidal effect of electrokinetic oxidation products in lower concentrations as well (Fig. 9).



Figure 9 – The contamination of a solution containing IVF products in the amount of 15 ml/150 ml of tap water 2 days after treatment with this solution of fresh pork meat

4.2 Studies of the number of nitrogen compounds formed in the treated model solutions

In parallel with the infestation, we also measured the number of nitrogenous compounds formed in the solution, which allowed us to judge the preventive effect on microorganisms and various kinds of protein molecules, which also contaminate the wastewater. Initial values were measured immediately after soaking the meat in each of the solutions. Further measurements were made 8, 16, and 24 hours after soaking the meat, the values of nitrogen compounds in the solutions are shown in Fig. 10–12.

In all solutions, after some time, the values of acidity began to tend to neutral values, so the values of alkaline solutions shifted closer to 7, and acidic solutions - closer to 6, initially neutral solutions remained as such over time.

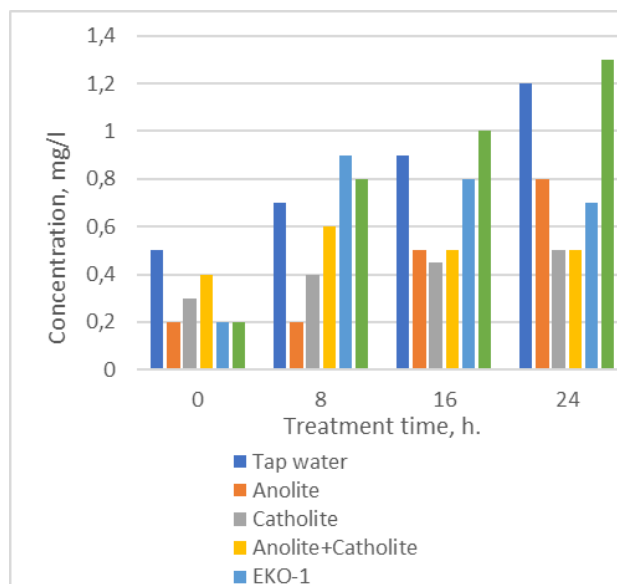


Figure 10 – Changes over time of NH_4^+ concentration, mg/L in the model solution at different treatment methods

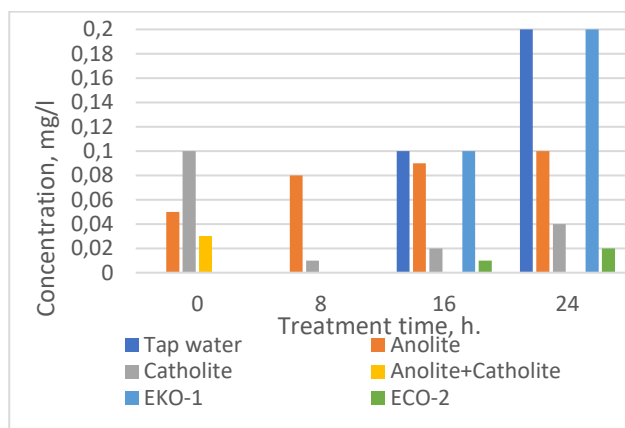


Figure 11 - Changes over time of NO₂⁻, mg/L concentration in the model solution at different treatment methods

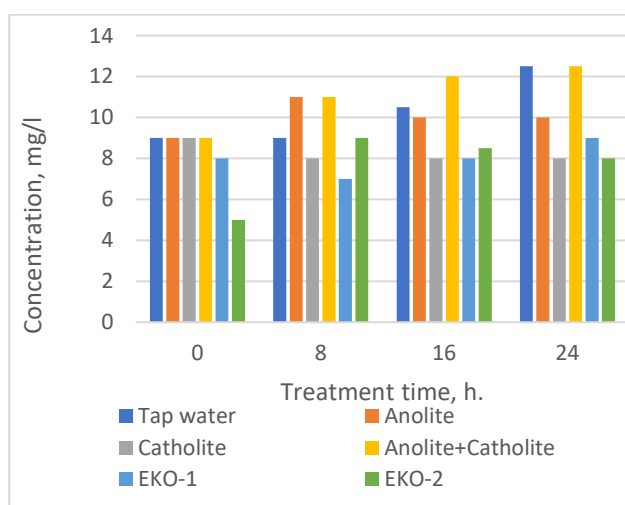


Figure 12 – Changes over time of NO₃⁻, mg/L concentration in the model solution at different treatment methods

Indicators of nitrogenous changes also underwent some changes, so the values of ammonium ion in almost all solutions increased, respectively. This led to a slight increase in other nitrogenous compounds, namely nitrites and nitrates, to which the ammonia/ammonium in the solution decomposes. This fact suggests that after 8 hours in the solutions began to decompose protein molecules into simpler mineral compounds, which indicates the effectiveness of the solutions shown not only as antibacterial agents but also as agents suitable for cleaning water from some organic pollutants. Solutions containing products of electrokinetic oxidation proved to be the most effective solutions at this time interval. Ammonia/ammonium values in each of these solutions increased 4-fold.

One day later, various changes also continued to occur in the solution. As for nitrogen compounds, active growth of ammonia/ammonium was observed in the solution, which contained more ECO-1 and ECO-2 products, and the amount of this ion in the anolyte solution increased 4-fold completely suppressed the development of microorganisms. Other indicators of nitrogenous compounds also began to increase. The amount of both

nitrite ion and nitrate ion increased, indicating that the toxic ammonia/ammonium ion is undergoing decomposition in these solutions.

4.3 Determining the effectiveness of wastewater treatment methods from microorganisms

After wastewater treatment, using the 5 different methods described above, all the indicators of the solutions were measured again. The measurements were repeated after 5 hours and one day after the wastewater treatment. Solutions were filtered, and 2 samples were taken for analysis to determine the effectiveness of wastewater treatment methods from microorganisms.

Six samples of previously prepared water were taken. Then, the first dilution was prepared with distilled water (10⁻¹). After that, a series of dilutions was prepared: 1 ml of the sample was taken from the first and diluted 1:10 with a physiological solution (second dilution (10⁻²)). The following dilutions were prepared in the same way up to the 10th dilution (10⁻¹⁰).

In all 6 samples, 0.5 ml of the last dilutions were inoculated on KMAFNM medium. The cultures were incubated in an incubator at 37°C for 2 days. A control was performed on the second day.

TDS, ORP, and pH values were taken one hour after purification, after 5 hours, and after 24 hours. The results are shown in Table 4.

Table 4 - Changes in the leading indicators of wastewater

Value	Catholyte	Anolyte	ECO	UV+H ₂ O ₂	BP
OVP1h	18.80	30.30	18.90	-23.80	-140.20
OVP5h	20.00	28.10	16.30	-23.00	-138.50
OVP24h	24.00	30.20	18.60	-17.20	-140.00
TDS1h	1080.00	1060.00	1090.00	1130.00	1250.00
TDS5h	1000.00	1020.00	1020.00	1077.00	1175.00
TDS24h	960.00	985.00	963.00	980.00	1120.00
pH1h	6.68	6.49	6.68	7.40	9.39
pH5h	6.65	6.52	6.72	7.39	9.39
pH24h	6.61	6.48	6.68	7.31	9.38

Before the experiment, conducted a control as a reference in all scientific laboratory experiments. The control cup did not germinate, indicating the experiment's validity and compliance with all rules of sterilization of laboratory utensils and media throughout the experiment.

In the cup in which the initial (waste) water was sown, solid growth was detected, indicating a high content of microorganisms (Fig. 13).

The number of colony-forming units exceeded 30 on plates on which water treated with anolyte and ultraviolet radiation with the addition of hydrogen peroxide was sown.

On the surface of the medium where the catholyte-treated sample was planted, 11 colony-forming units were counted, which is equal to 5.6 · 10¹¹ when converted to ml of water. This proves that the decomposition of chlorides in the pH-corrector (in wastewater, the chloride concentration is 1100 mg/l) with the formation of sodium hypochlorite.

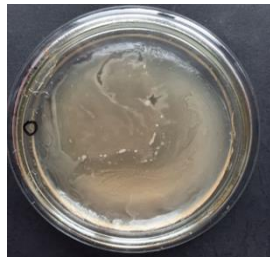


Figure 13 – Source wastewater discharged on KMAFANM medium

In a cup with a water sample treated with ECO-2, the number of colony-forming units was equal to 8, which in terms of 1 ml of water is $4 \cdot 10^{10}$. Since ECO-2 has pronounced coagulating properties, most of the microorganisms settled down together with large particles floating in the water column.

No colonies were found on a cup with a water sample treated with flocculant BP. This can be explained by the fact that the flocculant is not only a catalyst for coagulation but also enhances it many times (Fig. 14). In addition, it also has a high disinfecting effect.



Figure 14 – Sample treated with BP

The final results of wastewater treatment using 5 different treatment methods are shown in Table 5.

Table 5 – Number of CFU/ml when using different methods of meat-processing wastewater treatment

Cleaning methods	Total infestation, CFU/mL
Source water	Solid growth
Catholite	$5.6 \cdot 10^{11}$
Anolite	Less than $6 \cdot 10^{11}$
ECO-2	$4 \cdot 10^{10}$
UV+H ₂ O ₂	Less than $1.0 \cdot 10^{11}$
BP	0

Based on the results obtained, we can recommend a water supply and sewerage scheme with a preliminary impact on water solutions in places of formation of pollutants (Fig. 15) to preventively improve the effectiveness of wastewater treatment of municipal and industrial facilities.

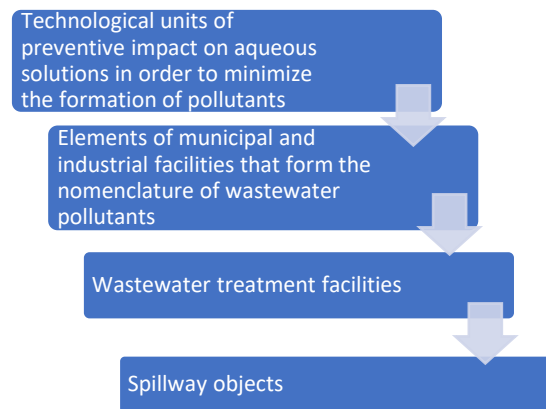


Figure 15 – Modernized scheme of water supply and sewerage of municipal and industrial facilities

The results of chemical and microbiological analysis of wastewater treated by 5 different methods show that flocculant BP is the most effective in wastewater treatment because it disinfects and catalyzes effect. Due to the complex action of different methods, it is possible to make a multistage treatment of wastewater, which will be much more effective than using each method separately.

The practical implementation of such a scheme (Fig. 15) will allow one to reduce the cost of creating (modernizing) sewage treatment plants, to reduce operating costs for wastewater treatment, and to increase the ability of water circulation systems to more flexibly counteract abnormal situations in the “spillway” channel: salvo emissions of pollutants, and breakdowns of individual components of such systems.

5 Conclusions

As a result of the studies, it was found that the change in the parameters of aqueous solutions during the treatment of the meat with these solutions directly affects the population of these solutions with microorganisms. Parameters that were changed as a result of the study: ORP, TDS, and pH.

Solutions capable of almost entirely inhibiting the activity and growth of microorganisms have been obtained, and solutions have also been obtained that, on the contrary, promoted their development and in which solid growth occurred when sown on a dense nutrient medium.

Based on the above, it can be concluded that to prevent pollution and contamination of wastewater at meat industry enterprises, instead of treating meat carcasses with ordinary tap water can be used solutions with modified parameters TDS, pH, and ORP, namely with a slight (acceptable) increase in total mineralization. Solutions containing biocidal products are also effective for this purpose since they also have antimicrobial properties and can decompose organic pollutants quickly.

Further research is advisable to focus on detailing the technical and economic indicators of water supply and sewerage schemes of municipal and industrial facilities with preventive improvement of water treatment processes.

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