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EFFECT OF PLASMA-CHEMICALLY ACTIVATED AQUEOU SSOLUTIONS ON THE PROCESS OF DISINFECTION OF FOOD PRODUCTION EQUIPMENT

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Abstract. In food production, it is essential to implement preventive measures aimed at improvingthe qualityof products, namely decontaminating them of microorganisms causing food poisoning.Effective sanitisation of food production equipment allows preventing products' contamination by pathogenic microflora and by microorganisms that lead to spoilage of food. The paper presents a study of the effect of plasma-chemically activated aqueous solutions on the process of disinfection of food production equipment. Activated aqueous solutions have been characterised,and it has been shownhow theyaffect pathogenic microflora present on the surfaces of equipment involved in meat production and processing. Analysis of microbiological indicators (QMAFAnMand coliform bacteria) has shown that the number of pathogenic bacteria decreased by half on all surfaces of theprocessing roomeven at the peroxide concentration 100 mg/l, while at the concentration 500 mg/l, we observed complete destruction of pathogenic microflora both in the poultry slaughter room and in thediseased animal slaughterhouse. The disinfecting properties of plasma-chemically activated aqueous solutions in the process of production of chicken mincehave been analysed. After the surfaces of the cutterswere treated with the activated aqueous solutions having the peroxide concentration 500 mg/l,the equipment was found to be completely sterile:no microflora was detected in the wipe samples, andthis dynamics was observed for 7 days.The use of the disinfectant proposedstops thedevelopment of any microflora on the surface of technological equipment. The level of microbiological contamination of the finished meat product (chicken mince) after treating the equipment with plasma-chemically activated solutions has been studied,their peroxide concentrationsbeing 100 to 700 mg/l. No pathogenic microflora (in particular, nocoliform bacteria and mould) was detected in the finished meat products obtained after the equipment was treatedwith thedisinfectant solution at a concentration higher than 500 mg/l. Plasma-chemically activated aqueous solutions with the concentration of peroxides 500 mg/l are considered optimal for disinfection of the technological surfaces and equipment of meat processing enterprises, since they ensure complete removal of pathogenic microflora and allow obtaining a product free from pathogens.

Key words:plasma-chemical activation, aqueous solutions, hydrogen peroxide, microflora, contamination,disinfectant, equipment.

Introduction. Formulation of the problem

High-quality food products manufactured by the modern food industry should be maximally safe for the consumer. In food production, it is important to implement preventive measures aimed at improving products' quality, namely reducingmicroorganisms that may cause food poisoning.These preventive measures include the search for new chemical substances that, when usedin washing and disinfection of the equipment and production facilities, will allow producing goods with improvedsanitary safety. Thorough cleaning and disinfection of food production equipment allow preventing contamination of products by pathogenic microflora and microorganisms causing food spoilage [1-3].

Washing and disinfection of the process equipment are very important stages of food production, which largely influence the safety and quality of the manufactured food. Theyplay a key role in making food productslong-life, reducingtherisks associated with the production process, and securinga clean and comfortable working environment. Appropriate cleaning and disinfection and the use of high-quality detergents can effectively prevent microbial contamination, whichis particularly dangerous, as it can havesevere consequences:a decrease in the product's quality, harm to health, or even life-threatening situations [4-6].

Thorough and safe disinfection of food equipment is a matter of particular importance. The present-day world faces the acute problem of epidemiological safety. Thereare more than a thousand disinfectants in the modern chemical industry. However, not all of them meet the requirements of reliability, efficiency and safety for the use in the food industry [7]. Besides, most synthetic chemicals for disinfection are highly toxic. So, the search for an environmentally friendly, non-toxic, and widely available disinfectant for the food equipment is still underway, and its development is of great interest to food manufacturers.

Analysis of recent research and publications

In food production, disinfection of technological equipment, processing area, containers, and packaging is an obligatory procedure, yet one of the most time-consuming.It is important for the formation of a product's quality characteristics, biological value, shelf life, and safety. Hence the variety of disinfection methods and the keen interest of food industry researchers and experts in developing new, highly effective methods and means of disinfection of consumer products [8-10].

In hospitals and other public places, it has become more difficult to achieve adequate levels of disinfection regularly and continuously because of ever-increasing microbial resistance.To solve this problem, innovators developed new technologies thatallowed quickly and effectively removing various pathogens, including bacteria and viruses, and remained active on the surface longer than traditional disinfecting agents did [11]. Apart from solutions for disinfection of surfaces at medical institutions, there are new disinfection technologies that can be used to disinfect fresh products as well and thus extend their shelf life [12,13].

In recent years, the spread of COVID-19 has been a pressing issue in the food industry. Abattoirs and meat processing plants have beena major risk forCOVID-19 infection throughout the pandemic. These outbreaks were taking centre stage.They affectedwhole communities, had far-reaching implications, and required intensive interventionson the part of public health institutions. In Germany, public health authorities faced a huge COVID-19 outbreak in Gütersloh, North Rhine-Westphalia [14]. More than 1,500 of the 7,000 workers tested positive for COVID-19, and 640,000 residents of two affected counties were returned to lockdown conditions. At one of the largest poultry farms in Portugal, at least 129 out of 300 workers contracted COVID-19. The company was closed for a week, additional measures included screening all employees. Outbreaks in England and Wales, too, were associated with meat processing.

Quality of the manufactured products, their appearance and stability during storage depends on the sanitary and hygienic condition of the process equipment. An important factor determining the quality of cleaning of process equipment is the appropriate choice of detergents and disinfectants. This is due to a vast variety of technological operations [15-17] and availability of a large range of detergents and disinfecting agents. Besidesremovingdirt properly, they should effectively disinfect the equipment. There is a wide choice of traditional and new chemical sanitisers for enterprises, but most of them cannot be used on objects that directly contact food raw materials and products [18].

For foodborne and spoilage microorganisms, the modern environment of the food industry is favourable andenables them to form biofilms on various surfaces in contact with food products. It is widely recognised that biofilm has become a serious problem in the food industry: the mode of biofilm growth increases the resistance of microbes to chemical disinfection [19,20]. Retention of biofilms after cleaning and disinfection procedures may lead to foodborne diseases and food spoilage, which shows how importantit is to prevent biofilm formation at food production enterprises. Using only traditional disinfection technologiesmay prove insufficient in achieving the proper quality and safety offood manufactured.

Chemical agents for disinfection of process equipment and containers are quite effective bactericides if the concentration of disinfectants is strictly observed.Still, there is a danger that disinfectants may pass into food products, and that the equipment may corrode if these requirements are not met [21,22].

Equipment and containers are disinfectedwith the use of chemicals immediately after washing and rinsingthe detergent residues off the equipment. The disinfectantis a solution of the antiseptic agent selected.

Such chemical reagents as chlorine-containing agents, ammonium compounds, and peroxide substances are used as disinfectants in the food industry [23]. Disinfectants containing chlorine are widely used against a whole spectrum of microorganisms, but they are harmful to human health and, if ingested, may cause intoxication of the human body.

A wide use of agents based on hydrogen peroxide is a promising direction in the search for affordable antiseptics and disinfectants [24-26].A significant advantage of these agents is that their main active substance (hydrogen peroxide) decomposes into safe chemical compounds – oxygen and water.Hydrogen peroxide and agents based on it have a wide range of antimicrobial effects, for example, on coliform bacteria, staphylococci, streptococci, moulds, etc. It can be used to disinfect any equipment, pipelines, and containers made of stainless steel, aluminium, low-carbon steel, those with nickel and brass coating, and those made of plastic, galvanised and tin-plated iron. Neither does it cause any negative reaction when in contact with rubber, concrete, or wood. For disinfection, 0.05–3% solution of this agent is used at 40°C, thedisinfection time is 10–30 minutes. Hydrogen peroxide mixed with other substancesis used for sterilisation of the packaging material. Packaging materials for children'sfood products are disinfected with concentrated solutions of hydrogen peroxide (30–35%). In the food industry, disinfectants based on 20–60% hydrogen peroxide are used to disinfect equipment and containers.

Hydrogen peroxide can be usedto disinfect any raw materials [27]. Hydrogen peroxide mixed with other substances is usedto sterilise surfaces.Hydrogen peroxide-based disinfectants are widely used in the food industry for disinfection. However, hydrogen peroxide and agents based on it are rather expensive, so the cost of products increases significantly [28]. The antimicrobial action of hydrogen peroxide is due to its high oxidative activity. Decomposition of hydrogen peroxide by microbial and tissue proteases is accompanied by a release of oxygen, which oxidises the sulphhydryl and hydroxyl groups of proteins and lipids, thus causing the death of microbes.

Thereare a number of new environmentally friendly agents used for sanitary treatment of the equipment in the modern food industry. They feature novel properties and low corrosion activity. These agents are of great interest for food manufacturers [29].

Nevertheless, new high-quality and, most importantly, multi-purpose disinfectants based on hydrogen peroxide are still being searched for.

The scientists show interest in plasma-chemical treatment of process solutions, namely activation by non-equilibrium ("cold")plasma. Thus, activated water has a specific composition.The reaction products determining the reactivity of this water are the most detectable. Primarily, these are hydrogen peroxide and superoxide compounds, excited particles and radicals, which play an important role in redox processes [30-32]. It should be noted that these aqueous solutions,after plasma treatment,may exhibit new properties, previously little studied.The processes occurring in a liquid medium in contact with NCP are of interest from the point of view of studying the reactions under non-equilibrium conditions, involving electrons and excited particles, the average energy of which is slightly higher, compared with that in the "cold" state.Chemical transformations during the contact action of a plasma discharge on the liquid take place mainly at the gas/liquid interface. Therefore, it is important to determine the parameters of plasma, the surface and volume changes in the gaseous and liquid media, and the mechanism of chemical reactions in the reaction volume [33].

The NCP is implemented at the junction of high-energy chemistry and classical electrochemistry, with the chemical and physicochemical processes involving high-velocity, excited, or ionised particles, the energy of which often exceeds that of chemical bonds. This energy creates specific conditions in the reacting system, and they, in turn, cause the emergence of new types of processes, as compared with the traditional ones.

The processes under consideration can be conventionally classified into electrochemical processes (involving transformations on electrodes) and plasma-chemical ones (when ultraviolet radiation and ionisation of a gaseous medium with the formation of charged particlesproduce contact action on a liquid-phase system).

The major role in the description of these processes is played by non-equilibrium chemical kinetics, which is characterised by the violation or absence of someor all typical features of classical kinetics. Free electrons take a significant part in plasma-chemical reactions: in most cases, reactions under their impact are decisive in the initiation of complex multistage chemical processes [34,35]. Their collisions with the particles of the plasma-forming gas lead to ionisation (formation of an electron and a positive ion).A condition for the stationary existence of plasma is the equal rates with which charged particles are formed and die. The energy of ionisation of a molecule exceeds the excitation energy of any of its internal degrees of freedom, that is why rotationally, vibrationally, and electronically excited states of molecules (including the radiant ones) are formed and decompose (dissociate) in plasma simultaneously. The particles resulting from collision under the action of an electron impact can react both with each other and with the materials that are in contact with plasma.

A chemical reaction is one of the channels of energy redistribution in a system, which ultimately brings it to a state with minimal potential energy. Continuously gaining energy, electrons transfer it to atoms and molecules by collisions. However, because of the relatively low efficiency of this transfer, there is a large difference between the translational energy of electrons and that of heavy particles. The function of electron energy distribution is non-Maxwellian, i.e. it cannot be characterisedby the temperature parameter. It begins to depend on the composition of the gaseous phase and on the electric field strength. The specific energy density in plasma is so high that events in it cover a complex set of physical, physicochemical, and chemical processes [34,35], and the typical durations of all processes are close values. So, they influence each other.That is why describing plasma-chemical reactions and processes occurring during their interaction is a fundamental multi-channel problem, with channels interacting differently depending on the various periods of time and energies.When we convert the average energy of electrons into the corresponding thermal units, the typical values of electron "temperature" will be $3.0{\cdot}10^5$–$1.0{\cdot}10^6$ K. Non-equilibrium phase transitions can be observed in highly non-equilibrium plasma (average energy of electrons ~ 3–5 eV, temperature of heavy particles ~ 300–500°K). For non-equilibrium conditions, it is possible to direct selectively the energy flow to activate the required components of a chemically reacting system.Water and products of its dissociation, hydrogen and hydroxyl ions are the important factors determining the structure and biological properties of living organisms [36].

The strength of bonds between water molecules is determined by their electrical polarity and explains the specific arrangement of electrons in the oxygen and hydrogen atoms constituting the water molecule. The oxygen atom combines the pair of its electrons with the electrons of the hydrogen atoms by overlapping the *1s*-orbitals of the hydrogen atoms with hybrids of the sp^3-orbitals of the oxygen atom. Each bond formed as a result is by one-third an ionic and by two-thirds a covalent bond. The angles and lengths of bonds in a water molecule were precisely determined by optical spectroscopy and X-ray diffraction analysis.An average angle of the *H–O–H* bond is 104.5°, which is slightly different from the value 109.5º for the angle corresponding to the ideal tetrahedral arrangement of the four possible sp^3-orbitals of the oxygen atom. This deviation from the ideal angle results from the tendency of unpaired electrons of oxygen atoms to repel paired electrons (average interatomic distance of *H–O* is 0.965 Å). This configuration of electrons in a water molecule leads to its electronic asymmetry. The more electronegative oxygen atom tends to attract the electrons of hydrogen atoms, and hydrogen nuclei remain bare. As a result, each of two hydrogen atoms has the partial positive charge σ^+, while the oxygen atom carries the partial negative charge σ localised in the region of uncollectivised orbitals.Reactions in the liquid phase induced by low-temperature plasma at reduced pressure are described in[37,38].

The main feature of the systems considered is the appearance of a phase interface between plasma and liquid electrolyte solution, which leads to the emergence of new factors associated with the processes of charge transfer. The space near the solution/gas phase interface has properties similar to those of the cathode space when implementing the processes of the classical glow discharge.They also act asthe anode in the liquid phase. Based on this observation, it is concluded that the liquid acts as a bipolar electrode. While charged particles knock out electrons from the surface of a solid electrode, in case of a liquid electrode, charged particles penetrate the solution and interact with it, initiating various chemical reactions, which result in the release of electrons into the gaseous phase. Under these conditions, a limiting factor is not the processes occurring in the gaseous phase, but the concentrations of electrically conductive particles in the liquid phase. Ions induced from plasma into the solution recombine to form chemically active particles or accumulate in the solution, changing its electrical conductivity and other properties [39,40]. This complex physicochemical interaction results in obtaining activated solutions.

The use of plasma-chemically activated aqueous solutions is aimed at increasing the efficiency of disinfection, reducing antimicrobial treatment, and enhancing the toxicological safety, since their composition is rich in peroxides and superoxide compounds.

Thisis achieved by using plasma-chemically activated aqueous solutions containinghydrogen peroxide asthe active substance in the processes of disinfection. Hydrogen peroxide is a commonly used classical antiseptic agent.Getting into cells, under action of enzymes (peroxidase and catalase), it breaks down into water and oxygen, which has an antimicrobial effect. After its action, no harmful chemicals remain in the cells, so there is no chemical contamination of food raw materials. Plasma-chemically activated aqueous solutions do not result in unwanted odours and off-tastes and make it unnecessary to use chemical preservatives. These solutionscan be used as multi-purpose disinfecting, sterilising, and bactericidal agents.

The method of treatment of process equipment presented in this study is aimed at solving of the technical problem of increasing the efficiency of disinfection, reducingthe duration of treatment, and improving toxicological safety. Thismethodis based on the task of high-quality disinfection of the food equipment. The technical essence of the method is the use of plasma-chemically activated aqueous solutions containing hydrogen peroxide as an active agentto disinfect foodequipment.

The purpose of this study consists in increasingthe efficiency of disinfectingthe process equipment, reducingthe duration of treatment,and improvingthe toxicological safety of food production.

The objectives of the study:

1. Establishing the disinfecting properties of plasma-chemically activated aqueous solutions during treatment of the equipment and surfaces at a poultry slaughterhouse.

2. Analysingthe disinfecting properties of plasma-chemically activated aqueous solutions during processing of poultry (production of mince).

3. Investigating the microbiological contamination of finished products after disinfection of the equipment with the proposed disinfectant.

Research materials and methods

The objects of research were elements of equipment of a meat processing enterprise.They included the equipment and surfaces of a poultry slaughtering and processing room, poultry meat grinder (cutter), and mince produced usingthe equipment under study. Plasma-chemically activated aqueous solutions with different concentrations of peroxides were taken as disinfectants.

The water and aqueous process solutions wereactivated using the special laboratory plasma-chemical unit (Fig. 1) functioning on the basis of the research and production laboratory of the Dnipro State Agrarian and Economic University.

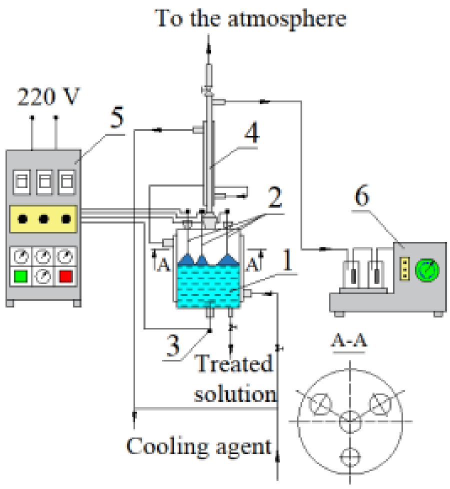

Fig. 1.Three-arc plasma-chemical laboratory unit:
1 – reactor; 2 –anodes; 3 –cathode; 4 – reflux condenser;
5 – power supply; 6 – vacuum pump.

The objects researchedwere chemically pure water and aqueous solutions of inorganic and organic composition. This allowed us to get a holistic view of the processes in liquid media during their treatment with plasma discharge.Tap water was activated in plasma discharges of reduced pressure with the voltage 1000–1200 V and current 30.0–200.0 mA, with the subsequent transition, as the electrical conductivity increased, to the mode of non-equilibrium plasma with the following parameters: voltage 400 to 600 V, current up to 150 mA. The content (concentration) of hydrogen peroxide in the activated water was determined by iodometry [33].

The unit operation is described as follows.The input voltage is supplied to step-up transformer. AC voltage from the secondary winding of the transformer is applied to the bridge rectifier, and pulsating DC voltage through the ballast resistor is further supplied to the electrodes of the reactor. Additionally, the reactor anode is connected to the ignition device, which generates pulses with the amplitude up to 15 kV and duration up to 1.5ms. The pulses are rigidly synchronised with the phase of the pulsating voltage.When the ignition pulse is formed, there is a breakdown of the vacuum space (created by pumping the gaseous phase out of the reactor using the vacuum pump) between the reactor electrodes. As a result of a sharp drop in the resistance, anode current begins flowing, thus creating a discharge. The voltage of the discharge burning is almost constant (750–900 V) and depends on how thin the gas is within the reactor. The magnitude of current of the discharge gap is determined by the plasma resistance and by the value of the voltage applied to the system “plasma discharge – ballast regulator.”The voltage is regulated under the principle of the phase method, i.e. the average value of the anode voltage supplied to the reactor depends on the phase of pulsating voltage at the anode and the time of the ignition pulse. Plasma appearsat the moment of ignition and goes out at the end of the anode voltage ripple. The process repetition frequency is 100 Hz. The discharge current is regulated in the device by changing the ignition moment in relation to the phase of the anode voltage ripple using a synchronising device. In this case, the reactor acts as a power-regulating unit. Plasma discharge parameters are recorded using the devices of the M4200 type, class 4.0. The operational parameters of the laboratory unit and the technical specification of the reactor are given in Tables 1, 2.

The characteristics of the activated water used as a disinfectant of the food equipment are given in Table 3.

Table 1 – Operational parameters of the laboratory test unit

Parameters	Power supply	Value
Input voltage	Single-phase alternating	~ 50 Hz – 220 V
Output voltage	DC pulsating, adjustable within the limits of	700–1500 V
Load current	Maximum value	0.3 A
Ignition load	Amplitude Pulse duration	12000–15000 V 1.0–1.5 ms

Table2 – Technical characteristic of the reactor

Reactor volume	**4 x 10^{-5}m^3**
Diameter	3.4 x 10^{-2}m
Height	0.2 m
Material	Molybdenum glass
Electrode	Stainless steel
Movable electrode	Refractory material

Table3 – Characteristics of water activated by non-equilibrium contact plasma

Expe-riment	Water	Activation time, minutes	Concentration of hydrogen peroxide, mg/l
1 (control)	Tap water	–	–
2	Activated water	5	100
3	Activated water	10	200
4	Activated water	15	300
5	Activated water	20	400
6	Activated water	25	500
7	Activated water	30	600
8	Activated water	60	700

The process equipment was disinfectedat an operating meat processing plant as follows.First, the process equipment was washed with hot water and detergent for 2–10 minutes at the temperature 70–90°C depending on the specific nature of the contamination, and then rinsed with clean water for 5 minutes(65–70°C) to remove the detergent residues. Disinfection was carried out by washing the equipment with the disinfectant solution (plasma-chemically activated aqueous solutionswith the given concentrations of peroxides 100–700 mg/l) for 2–10 minutes.Further,the equipmentwas washed with clean water, which was thenexamined for the presence of microflora. After that, the equipment was used to make afood product (mince), which wasexamined for the presence of microflora, including pathogens [41].

The sampling, preparation of thesample for analysis, and determination of the parameters of wipe samples from the equipment complied with standard methods of microbiological analysis.

The indicator determined was the quantity of aerobic and facultative anaerobic microorganisms (QMAFAnM), or total microbial count. This parameter includes various taxonomic groups of microorganisms: bacteria, yeast, and mould fungi. Their total number indicates the sanitary and hygienic condition of the equipment and finished product. This parameter, when checkedat all process stages, allows monitoring the changes in the cleanness of the equipment and of the food raw materials processed. The QMAFAnM indicator was determined using the classic method [41]: by inoculatingagarisedgrowth media, incubatingthe cultures, and counting the resulting colonies.

Besides, the assessment of the microbiological condition of the equipment involveddetermining the presence of *Escherichia coli* bacteria (coliform bacteria). Detection of *E. coli*on the process surfaces is a negative characteristic of any food production, yet they can enter from water, the personnel's hands, and other sources. This parameter was also determined with the use of the classic method: by inoculation on the growth medium followed by incubation and counting of colonies.

Themicrobiological indicators obtained were compared with the control where the disinfectant was not used. All experiments were conducted in quintuplicate.

Results of the research and their discussion

It has been studied what disinfecting properties plasma-chemically activated aqueous solutions show during treatment of the equipment and surfaces of a slaughterhouse. Table 4 presents the results of testingthe disinfecting properties of plasma-chemically activated aqueous solutions in a production environment during treatment of the premises and surfaces of the poultry slaughtering and processing room.

Analysis of the findings allows concluding that plasma-chemically activated aqueous solutions have a pronounced disinfecting action. The effect of their active substance (hydrogen peroxide) on the pathogenic microflora is observed even at the minimum concentration of peroxides (100 mg/l).The number of microflora decreased on all surfaces, as evidenced by the data in Table 4, and this testifiesto the effectiveness of the antiseptic proposed.

With the increase in the concentration of peroxides, unwanted microflora is gradually destroyed, and when the peroxide concentration reaches 500 mg/l, all surfaces are completelydecontaminatedof pathogensby both indicators:QMAFAnM and coliform bacteria. Identical results were obtained in the course of researchin the poultry slaughter room and the diseased animal slaughterhouse: contamination of the latter with specific pathogenic microflora always poses a danger of the staff's infection. The data obtained show the efficiency of plasma-chemically activated aqueous solutions as disinfectants of process equipment and premises at the stage of poultry slaughtering, both under ordinary conditions and in an industrial environment.

Table 4 – Results of treatment of the equipment and surfaces in the poultry slaughtering and processing room using plasma-chemically activated aqueous solutions

Object of research	Control		Concentration of peroxides in the plasma-chemically activated solution, mg/l							
			100		300		500		700	
	QMAFAnM	Coliform bacteria	QMAFAnM	Coliform bacteria	QMAFAnM	Coliform bacteria	QMAFAnM	Coliform bacteria	QMAFAnM	Coliform bacteria
Diseased animal slaughterhouse										
Centrifuge	$(1.3±0.17)·10^6$	+	$(9.3±0.77)·10^2$	–	$(1.1±0.17)·10^2$	–	–	–	–	–
Scalding tank	$(5.3±0.37)·10^5$	+	$(5.7±0.56)·10^2$	–	$(2.3±0.11)·10^2$	–	–	–	–	–
Gutting table	$(4.1±0.21)·10^7$	+	$(5.3±0.47)·10^3$	–	$(7.2±0.97)·10^2$	–	–	–	–	–
Wall	$(3.3±0.43)·10^7$	+	$(2.8±0.55)·10^3$	–	$(2.3±0.15)·10^2$	–	–	–	–	–
Floor	$(1.7±0.19)·10^8$	+	$(8.3±0.27)·10^4$	–	$(1.8±0.19)·10^2$	–	–	–	–	–
Poultry slaughterhouse										
Transporter	$(9.5±0.45)·10^4$	–	$(8.3±0.17)·10^2$	–	90±6	–	–	–	–	–
Trough	$(8.3±0.47)·10^4$	–	$(3.1±0.21)·10^2$	–	50±2	–	–	–	–	–
Packing table	$(7.4±0.58)·10^3$	–	$(1.1±0.18)·10^2$	–	20±3	–	–	–	–	–
Wall	$(9.3±0.67)·10^4$	–	$(1.2±0.27)·10^2$	–	30±7	–	–	–	–	–

The disinfecting properties of plasma-chemically activated aqueous solutions were studied during poultry processing. The microbiological indicators of poultry processing equipment (cutter) are presented in Table 5.

Besides immediate decontamination,an important aspect of disinfection of the surfaces of the process equipment is maintenance of the relative sterility of the process surfaces. The data obtained during microbiological analysis of contamination of the cutter surfaces used in making chicken mince showthat disinfection with the agent proposed resulted in a sustainable antimicrobial action(Table 5) that lasted for 1 week. It should also be noted that the disinfecting effect on the surfaces did notchange for a long time (7 days), which indicated a pronounced detrimental effect of the plasma-chemically activated aqueous solutions on microbial cells. That is, the disinfectant not only causes complete decontamination, but also stops the reproduction and development of pathogenic microflora on the surfaces of process equipment.

It can be explained by the specific composition of plasma-chemically activated aqueous solutions: hydrogen peroxide and superoxide compounds, excited particles and radicals, which play an important role in redox processes. Hydrogen peroxide is an antiseptic.On getting into the cells, it breaks down into water and oxygen under the action of enzymes andhasanantimicrobial effect, but leaves no harmful chemicals in the cells. That is, the products of redox reactions, upon contact with food products,are transformed into the substances that once wereconstituents of aqueous solutions before their plasma-chemical activation. As mentioned above, the activated aqueous solutions contain hydrogen peroxide and superoxide compounds.

One of the possible mechanisms of the action of activated water on bacteria isthe change in the outer layers of a cell, which makes receptors accessible toreactogenic enzymes, for example, lysozyme. Free radicals mayform a gap in the cell wall, which leads to the loss of selective permeability [42,43]. Peroxideas a component of activated water causes the destruction of surface structures and internal membranes in microorganisms [43]. The integrity of the cytoplasmic membrane disrupts the work of a number of membrane-related enzymes, such as dehydrogenases, and reduces the DNA repair system efficiency.

The bactericidal activity of hydrogen peroxide and activated water is primarily due to their high oxidative capacity, as well as to the action of toxic products, which are produced during lipid peroxidation [44]. Peroxidation affects ribosome proteins and causes their destruction. The superoxidesthat are formed,too,play a role in the destruction of membrane structures [45]. The action of hydrogen peroxide or activated water causes the local destruction of the integral cell wall and disruption of bacterial cell permeability even in the first minutes of contact. Selective ability to destroy pathogenic microflora directly is also a special feature of activated water [46]. Therefore, the result of using plasma-chemically activated aqueous solutions is the microbiological cleanness of process surfaces [47], which will allow making food products of higher quality. It is necessary to note the stable and long-lasting effect of disinfection of the surfaces of process equipment, namely complete destruction of microflora and prevention of its reappearance on the equipment surfaces.

The direct result of any technological process is a product.That is why the most important stage of research is the determination of microbial purity of chicken mince obtained on the equipment under study. The results of analysing the finished products are shown in Table 6.

Meat and meat products are a source of nutrition necessary for the normal human activity. However, they often become a source of pathogenic microorganisms, so they should meet the requirements of veterinary and sanitary safety. Obtaining high-quality meat products is only possible with effective disinfection of the equipment and premises at a poultry processing enterprise.

Table5 – Microbiological indicators of the surfaces of the process equipment (cutter) treated withplasma-chemically activated aqueous solutions

Concentration of peroxides, mg/l	Number of microorganisms in 1 ml of washing water, indiv. organisms							
	After treatment	After 10 min	After 30 min	After 60 min	24 hours	72 hours	120 hours	1week
0	170	171	178	193	$(1.3\pm0.77)\cdot10^2$	$(7.4\pm0.12)\cdot10^3$	$1.4\pm0.52)\cdot10^4$	$5.4\pm0,51)\cdot10^5$
100	102	103	103	104	104	105	105	105
200	91	90	90	90	90	91	91	91
300	50	50	50	49	50	50	50	50
400	15	12	12	12	12	12	12	12
500	0	0	0	0	0	0	0	0
600	0	0	0	0	0	0	0	0
700	0	0	0	0	0	0	0	0

Table 6 – Microbiological indicators after the use of plasma-chemically activated aqueous solutions

Peroxide concentration, mg/l	Microbiological indicators of the finished products		
	Total number of microorganisms in 1 g of the product	Coliform bacteria	Mould microflora
0 (control)	$3.8 \cdot 10^2$	Found	Found
100	$0.7 \cdot 10^2$	Not found	Not found
200	$0.3 \cdot 10^2$	Not found	Not found
300	$0.2 \cdot 10^2$	Not found	Not found
400	$0.1 \cdot 10^2$	Not found	Not found
500	0	Not found	Not found
600	0	Not found	Not found
700	0	Not found	Not found

That is why, after analysis of the obtained data, it should be noted that the use of plasma-chemically activated aqueous solutions todisinfect equipment allowed manufacturingmince with far fewer microorganisms, and at the concentration of peroxides 500 mg/l, no pathogenic microflora was detected. Coliform bacteria and mould were not found either, which is indisputable evidence of high-quality food obtained.

The main achievement of our study should be considered the sustainable complete absence of pathogenic microflora in chicken mince, which allows manufacturinghigh-quality and safe food.

The shelf life of the plasma-chemically activated aqueous working solution is 6 months from the date of its manufacture, provided it is stored in a closed container. It is an extremely important aspect, since chemically unstable hydrogen peroxide solutions do not last long, which constrains their use in the processing industry.

In an industrial environment,activated aqueous solutions are obtained usingexperimental industrial plasma-chemical units. Therefore, the disinfectantpresented can be applied inindustrial production and may be of interest to the processing industry. Plasma-chemically activated aqueous solutionscan be used as a multi-purpose disinfecting, sterilising, and bactericidal agents. The phenomenon of activation of the aqueous solutions causes a number of specific physical and chemical effects, which can be a starting point for new advanced technologies.The use of plasma-chemical activation can make the production process easier and cheaper in many cases, taking into account the costs of energy and the time for activation.

In comparison with disinfectants used now at processing enterprises, the activated aqueous solutions under study feature high antimicrobial and sporicidal activity, are inexpensive, highly effective, and low-toxic. This agent has no irritating properties, which greatly simplifies the work with it. These solutions can be widely used for the disinfection of the equipment, fixtures, containers, working surfaces, and warehouses at processing plants.The shelf life of the plasma-chemically activated aqueous working solution is 6 months from the date of its manufacture, provided it is stored in a closed container [7].

Conclusions

1. Disinfecting properties of plasma-chemically activated aqueous solutions used to treat the equipment and surfaces of a poultry slaughterhouse have been investigated. The inhibitory effect on microorganisms was observed even at the 100 mg/l concentration of peroxides in plasma-chemically activated solution. By such indicators asQMAFAnM and coliform bacteria, the quantities of pathogenic microflora decreased by half on all surfaces of the poultry slaughterhouse. At the concentration 500 mg/l,complete destruction of pathogenic microflora was recordedboth in the poultry slaughter room and in thediseased animal slaughterhouse. This indicates the indisputable disinfecting ability of the aqueous solutions proposed.

2. It has been determined how the disinfecting properties of the plasma-chemically activated aqueous solutions reveal themselves during poultry processing (production of mince). After treatment of the cutter with the plasma-chemically activated aqueous solutions at the concentration of peroxides 500 mg/l, the equipment was recorded to be completely sterile: no microflora was found in the wipe samples, and this dynamics was observed for 1 hour.

3. Microbiological decontamination of the finished products during disinfection of the equipment with the proposed disinfectant (at the concentration of peroxides 500 mg/l) has been studied. No microflora, including coliform bacteria and mould, was detected in the finished meat products obtained after treatment of the equipment with the disinfectant solutions.

4. Thus, at high concentration of peroxides in the solutions, pathogenic microflora (even *E. coli* and mould) is destroyed completely.This makes it possibleto sterilise the equipment if necessary. The period of the disinfectant action has been studied: it lasts for up to 7 days, so during this time,the microflora is not reproduced on the surface, which is sufficient for the food production.

Therefore, disinfecting food equipment bymeans of plasma-chemically activated aqueous solutions allows increasing the quality of disinfection, sterilising the equipment if necessary, prolonging the disinfectant effect, eliminating surface corrosion, and improving the toxicological safety of finished products.

Plasma-chemically activated aqueous solutions with the concentration of peroxides 500 mg/l are optimal for disinfection of process surfaces and equipment, since they ensure complete decontamination destroying all pathogenic microflora and allow obtaining a product free from pathogenic microorganisms.

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ВПЛИВ ПЛАЗМОХІМІЧНО АКТИВОВАНИХ ВОДНИХ РОЗЧИНІВ НА ПРОЦЕС ДЕЗІНФЕКЦІЇ ОБЛАДНАННЯ ХАРЧОВИХ ВИРОБНИЦТВ

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Анотація. У процесі виробництва харчових продуктів важливим є провадження профілактичних прийомів, направлених на підвищення якості продукції, а саме, деконтамінацію мікроорганізмів, здатних викликати харчові отруєння. Ефективна дезінфекція обладнання харчових виробництв дозволяє попередити забруднення продукції патогенною мікрофлорою і мікроорганізмами, що призводять до псування харчових продуктів. Досліджено вплив плазмохімічно активованих водних розчинів на процес дезінфекції обладнання харчових виробництв. Представлено характеристику активованих водних розчинів, їхній вплив на патогенну мікрофлору, що присутня на поверхнях обладнання, задіяного в процесі переробки м'яса та виробництва м'ясопродуктів.При аналізі мікробіологічних показників (КМАФАнМ і БГКП) кількість патогенної мікрофлори знизилась в два рази на всіх поверхнях цеху вже при концентрації пероксидів 100 мг/л. А при концентрації 500 мг/л, спостерігалось повне знищення патогенної мікрофлори як в цеху по забою птиці, так і на санітарній бійні. Проаналізовано дезінфікуючі властивості плазмохімічно активованих водних розчинів в процесі виробництво курячого фаршу. При обробці поверхонь кутерів активованими водними розчинами з концентрацією пероксидів 500 мг/л відмічено повну стерильність обладнання, оскільки в змивах взагалі не виявлено мікрофлору, така динаміка зберігається протягом 7 діб. Припиняється розвиток будь-якої мікрофлори на поверхні технологічного обладнання після використання запропонованого дезінфектанту. Досліджено мікробіологічне забруднення готової м'ясної продукції (курячого фаршу) при обробці обладнання плазмохімічно активованими розчинами з концентрацією пероксидів від 100 до 700 мг/л. Так в готовій м'ясній продукції, отриманій після обробки обладнання дезінфікуючими розчинами концентрацією більше 500 мг/л, не виявлено патогенну мікрофлору, в тому числі, бактерії групи кишкової палички та плісняву. Плазмохімічно активовані водні розчини з концентрацією пероксидів 500 мг/л є оптимальними для використання в процесі дезінфекції технологічних поверхонь і обладнання м'ясопереробних підприємств, оскільки викликають повну деконтамінацію патогенної мікрофлори і дозволяють отримати продукт не заражений патогенами.

Ключові слова: плазмохімічна активація, водні розчини, пероксид водню, мікрофлора, контамінація,дезінфектор, обладнання.