

5.4. ANOLYTE PEROX: A FUNDAMENTALLY NEW ANTIMICROBIAL AGENT

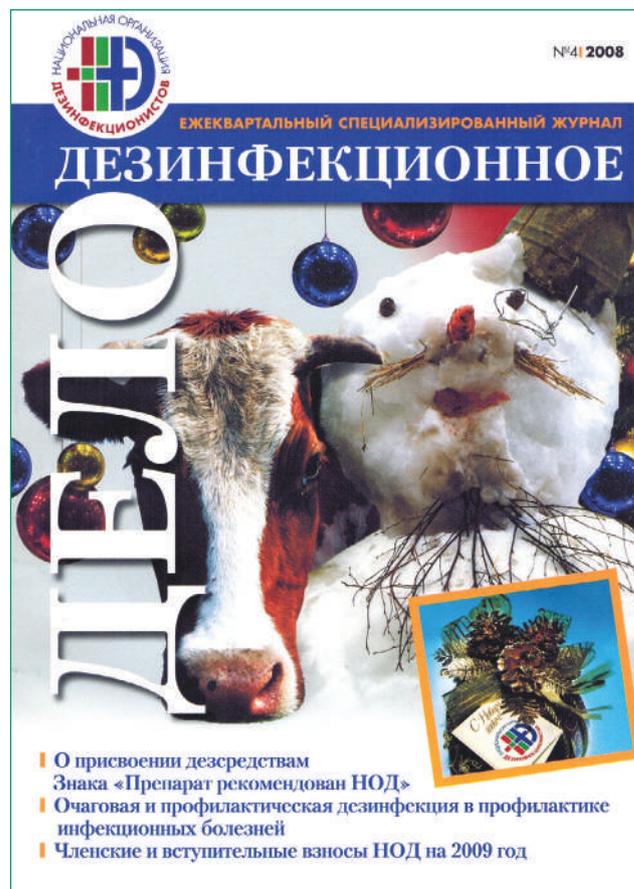
Creation of environmentally friendly, non-toxic antimicrobial solutions for versatile applications with a wide spectrum of action, corrosion safe, with active substances decomposing into harmless components at the end of a set period of functional activity, and to which microorganisms cannot develop resistance, regardless of the duration of the agent application, is an important task for medicine, food industry and a number of other areas. The ultimate task in this regard is to create an antimicrobial solution, which would correspond to fresh water in terms of toxicity and mineralization, and at the same time would be an effective detergent, disinfectant and rinse agent. A solution, which, being used for the disinfection of various objects, would not require their subsequent rinsing with sterile water, since the solution itself would be an analogue of fresh sterile water with antimicrobial properties. A solution with all its physicochemical parameters meeting the requirements for fresh drinking water, and at the same time, effective and safe for humans and warm-blooded animals, with some of its “magic” substance destroying pathogenic microorganisms both inside it and on the surface of everything it comes in contact with.

If we analyze the current situation in the field of human fight against microbes, we can find out the following.

Almost all modern liquid disinfectants are solutions of chemically stable substances and are approximately equally harmful to both microbes and humans. But, unlike humans, microorganisms very quickly adapt to stable chemicals due to their more effective adaptation mechanisms and rapid generational change.

Stable active substances (AS) of antimicrobial agents, with all their apparent market diversity, belong to only a few classes of compounds (alcohols, aldehydes, quaternary ammonium compounds, phenols, some others).

In fact, the whole variety of antimicrobial drugs is a combination of a small amount of stable chemical compounds. Manufacturers associate the functional effectiveness of such preparations-mixtures mainly with new proportions of substances. However, as a rule, each new drug created according to this principle loses its functional novelty for microorganisms much faster than for a human being using it. As a result, the number of strains of microorganisms resistant to whole classes



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Electrochemical synthesis and prospects for the use of a neutral peroxocarbonate detergent-disinfectant solution

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of chemical compounds increases over time. Periodic planned replacement of some antimicrobial drugs for others in the general set of disinfection measures of health care institutions (HCI) does not solve the problem of nosocomial (hospital-acquired) infections (HAI), since when new stable disinfectants are introduced into practice, there are still conditions for the emergence of strains of microorganisms resistant to both new and old disinfectants. As a result, the spectrum of microorganisms resistant to antimicrobial agents expands.

Analysis of the chemical composition of disinfectants shows that the overwhelming majority of modern chemicals contain xenobiotics (substances foreign to warm-blooded organisms). Consequently, to some extent, they possess

a sum of negative properties characteristic of substances incompatible with human and animal organisms.

There are non-toxic antimicrobial agents (factors of antimicrobial action) well known from the history of medicine, to which microorganisms in principle cannot develop adaptation reactions.

They are flame, sunlight (the ultraviolet component), ionized plasma of an electric discharge, i. e., substances that are either metastable in nature or induce a state of metastability in living cells of microorganisms they destroy. In this case, the metastable state of the microorganism ends with its irreversible denaturation or disintegration, while the metastable factor of antimicrobial effect itself ceases to exist. For example, being a metastable substance, flame plasma does not have a toxic aftereffect and, unlike most solutions of organic chemical disinfectants, does not leave a fundamental possibility for microorganisms to develop resistance.

The oldest liquid metastable environmentally friendly agent is hydrogen peroxide. But in concentrations from 3 to 6%, which are mainly recommended for disinfection in health care facilities and disinfection of medical products (MP), in terms of acute toxicity, hydrogen peroxide belongs to the 3rd class of moderately hazardous substances according to GOST 12.1.007—76 and is not recommended for processing of MP made of metals prone to corrosion. Contact of hydrogen peroxide with iron, chromium, lead, silver, manganese and their salts is not allowed in order to avoid rapid decomposition. Hydrogen peroxide is sensitive to mineral and organic contaminants and ultraviolet radiation. Hence, it is clear that a low concentration of hydrogen peroxide does not provide the proper disinfecting effect, and a high concentration is dangerous for humans and unacceptable for many objects. Hydrogen peroxide is also unacceptable for the processing of food itself due to its ability to decompose when interacting with organic substances.

Further search for a “magic” substance inevitably leads to technologies that are used by wildlife. The mechanism of antibacterial defence has been investigated in sufficient detail; it has been functioning in the internal environment of animal organisms — from single-celled organisms to humans for millions of years without any failures. It has been proven [1] that the leading role in the bactericidal effect of neutrophils belongs to hypochlorous acid (HClO) produced by phagocytic cells. HClO is formed in neutrophils from hydrogen peroxide and chloride ions. The catalyst in this reaction is myeloperoxidase (MPO):



The formation of H_2O_2 and HClO in a short period of time (fractions of a second) in a small volume of an aqueous medium (fractions of a microliter), i. e., in the volume of the active zone of phagocytosis, is accompanied by reactions of spontaneous decay and interaction of transformation products of these compounds with the formation of active particles, similar to those which are formed during electrolysis of fresh water.

Hypochlorous acid (Fig. 5.4.1) differs from hydrochloric acid (hydrogen chloride, Fig. 5.4.2) in the presence of an oxygen atom and is the strongest antimicrobial agent among inorganic chlorine-containing substances. Its salt, sodium hypochlorite (Fig. 5.4.3), has hundreds of times less antimicrobial activity, which is natural, since salt always has less physical and chemical activity than the acid and base forming it.

Hydrochloric acid itself is in fact a very weak bactericidal agent. Approximately the same ratio is characteristic of a weak bactericide — acetic acid (Fig. 5.4.4) and a very strong antimicrobial agent — peracetic acid (Fig. 5.4.5) containing just one more oxygen atom than acetic acid. Similar analogies are typical for phosphoric and supra-phosphoric, sulfuric and persulfuric acids and

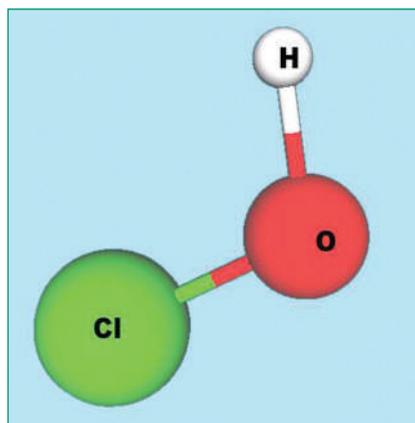


Fig. 5.4.1. Hypochlorous acid HClO.

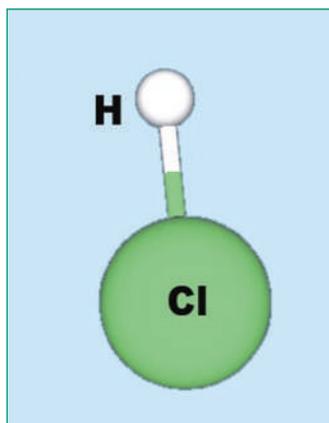


Fig. 5.4.2. Hydrochloric acid HCl.

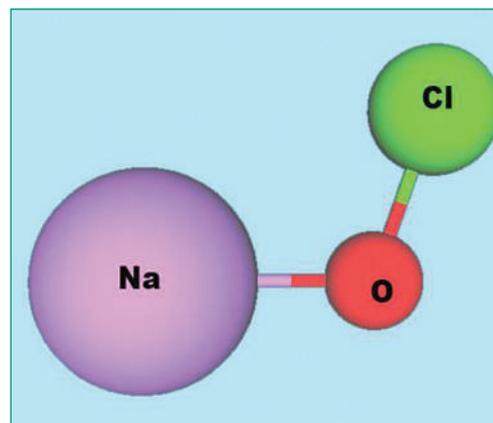


Fig. 5.4.3. Sodium hypochlorite NaClO.

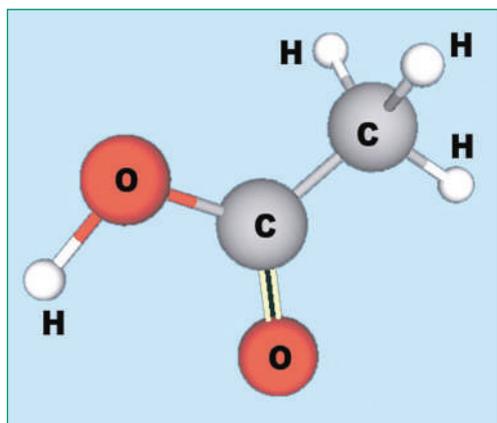


Fig. 5.4.4. Acetic acid CH_3COOH .

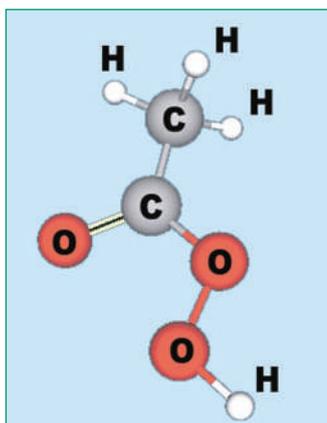


Fig. 5.4.5. Peracetic acid CH_3COOOH .

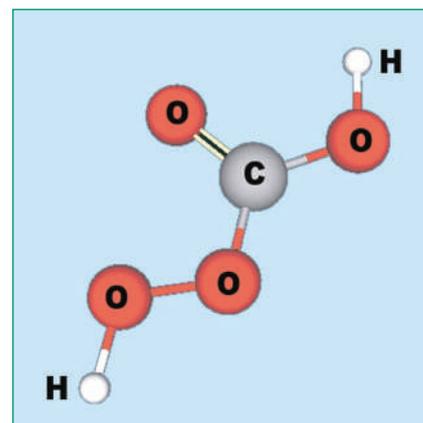


Fig. 5.4.6. Monopercarbonic acid H_2CO_4 .

the corresponding salts. It is obvious that the key element determining the antimicrobial activity of the analyzed compounds is oxygen in combination with hydrogen or alkali metals. In this regard, it is logical to assume that the described regularities are also characteristic of compounds formed of percarbonic acid (Fig. 5.4.6, 5.4.7), which contains more oxygen in its composition than carbonic acid (Fig. 5.4.8). Percarbonate salts — sodium and potassium peroxocarbonates (percarbonates) are effective antimicrobial agents and are widely used as bleaching agents and disinfectants of an extremely wide spectrum of action.

Percarbonates are produced industrially by electrochemical method: anodic oxidation of concentrated solutions of carbonates at low temperatures.

Percarbonates are colorless crystalline substances, extremely hygroscopic, but stable when dry. When heated, these salts transform into carbonates with the release of carbon dioxide and oxygen. A typical example of widely used percarbonates is sodium percarbonate with the commercial name of *Persol*.

As for percarbonic acid, which, in accordance with the above views, should be a much more biocidal product than its salts, then, in accordance with existing concepts [3], it is unknown in the free state. A note of historical interest makes it possible to believe that the first person who discovered the role of percarbonic acid in Nature was Academician Alexei Nikolaevich Bakh. In his works on the assimilation of carbon dioxide by green plants, A. N. Bakh explained the essence of the formation of sugar in the process of carbon dioxide assimilation. He considered the assimilation of carbon as a conjugate redox reaction occurring due to the elements of water (hydrogen and oxygen), and, based on this, he showed that the source of molecular oxygen released during assimilation was not carbon dioxide, as had been previously assumed, but water. Studying the participation of peroxides arising during assimilation, A. N. Bakh came to elucidating the essence

of oxidative processes (1893–1897) and formulated the peroxide theory of oxidation, according to which the energy required to activate molecular oxygen is supplied by the oxidized substance itself. Such properties are only characteristic of chemically unsaturated compounds, which, interacting with atmospheric oxygen, activate it. Activated oxygen, when interacting with an oxidizable substance, forms hydrogen peroxide.

Running carbon dioxide through a 1.5% solution of uranium acetate, A. N. Bakh noted the formation of hydrogen peroxide under the influence of sunlight, which

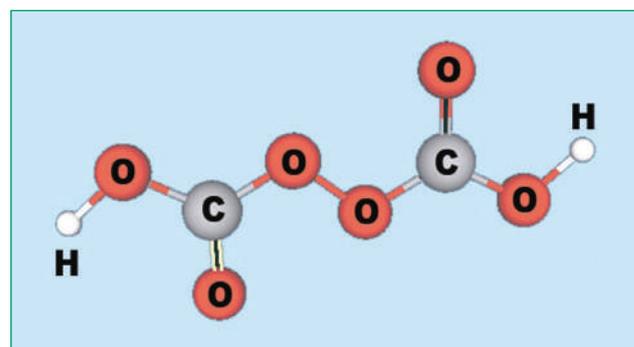


Fig. 5.4.7. Percarbonic acid $H_2C_2O_6$.

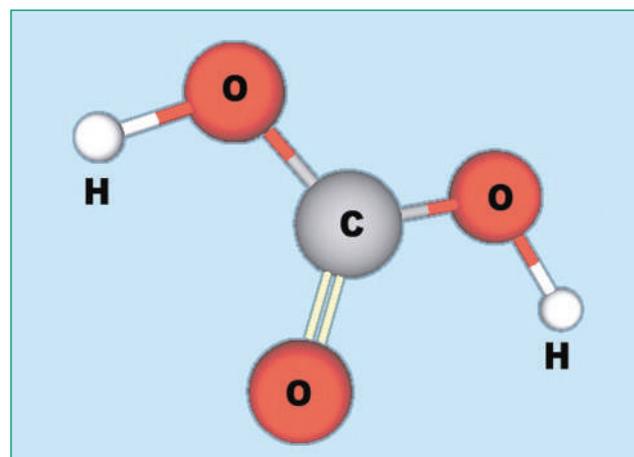


Fig. 5.4.8. Carbonic acid H_2CO_3 .

confirmed the existence of free form of peracetic acid. A. N. Bakh found out that in the process of photosynthesis, peroxide compounds (percarbonic acid, hydrogen peroxide) are formed, and they serve as a direct source of molecular oxygen released during the assimilation of carbon dioxide. In accordance with the experimentally substantiated concepts of A. N. Bakh, the hydrate of carbon dioxide H_2CO_3 decomposes according to the equation:



and then the monopercarbonic acid H_2CO_4 decomposes into carbon dioxide and hydrogen peroxide:



Sodium salt of percarbonic acid (sodium percarbonate) undergoes hydrolysis when interacting with water:



In solution pH less than 7, $Na_2C_2O_6$ decomposes into H_2O_2 and CO_2 . For monopercarbonic acid (HOOS-O-O-H), not only average (as for supracarbonic acid), but also acidic salts are known. Both can be obtained by interaction of carbon dioxide with alkali metal peroxides or hydroperoxides, which are also formed in the course of anode oxidation reactions according to the following schemes:



They are similar in properties to salts of percarbonic acid.

The authors carried out the analysis of possibilities of peracetic acid electrochemical synthesis based on the previously developed concepts of the kinetic stability of metastable compounds in aqueous solutions [4], and implemented the actual electrochemical synthesis using a system of universal modular flow-through electrochemical cells, known as FEM-3 [5].

Fig. 5.4.9 shows the general dependence of the electrical conductivity of aqueous solutions of various inorganic electrolytes — chlorides, sulfates, carbonates, nitrates of alkali metals, corresponding acids and bases, on their concentration in an aqueous solution (curve 1). In dilute electrolyte solutions (less than 0.1 mol/l), small changes in the concentration of solutes lead to significant shifts in the conductivity of the solution, which indicates the presence of a large number of water molecules taking no part in the formation of hydration shells around charged particles (ions). For more concentrated electrolyte solutions

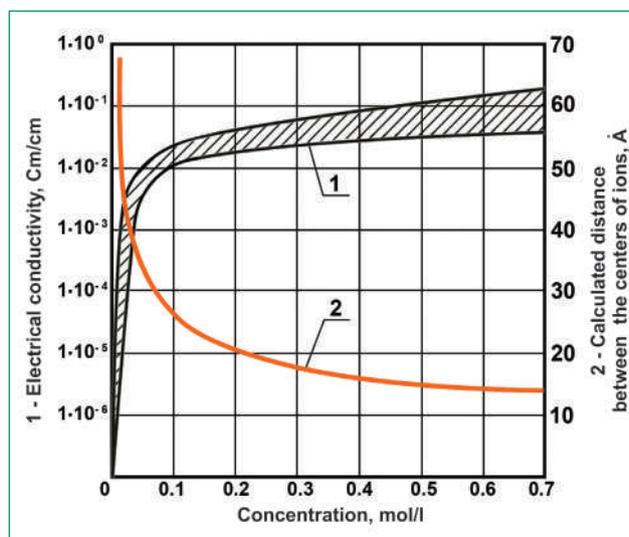


Fig. 5.4.9. Dependence of specific electrical conductivity and average distances between ions in electrolyte solutions on concentration.

(at a concentration of more than 0.1 mol/l), on the contrary, a very small change in electrical conductivity is observed with a significant change in concentration. This indicates that the hydration shells surrounding charged particles in the solution are in close interaction with each other, and the degree of their interpenetration increases with a growth of the concentration of electrolyte ions. These representations are illustrated by curve 2 in Fig. 5.4.9, which characterizes the theoretically calculated distances between the centers of electrolyte ions in a solution depending on their concentration. Curve 2 is a kind of indicator of the structural properties of the solutions.

The structure of a solution is understood to be a relatively stable in space and time arrangement of dissolved particles and water molecules interacting with each other relative to an arbitrarily chosen particle, corresponding to their most probable distribution. There is a well-known postulate of the electroneutrality of a hydrated ion, put forward by L. Pauling, one of the leading specialists in the theory of chemical bonding. According to this postulate, the ion charge is redistributed over the hydrogen atoms of the water molecules surrounding the ion. The concept of the donor-acceptor character of the interaction between an ion and water molecules is generally accepted. When an ion is hydrated, there is a kind of neutralization and redistribution of its charge over the water molecules surrounding the ion. The most important consequence of this is the ability to represent an ion as a kind of neutral particle, rather, a complex atom with filled electron orbitals. The analogy is so profound that, in fact, an ion in a solution can be likened to an atom of a noble gas, which has the same number of electrons and the same weight. Such a concept,

developed by G. A. Krestov, turned out to be fruitful, it has made it possible to understand a lot in the complex processes of transformation of substances when they transfer to a solution.

In the process of electrochemical synthesis of percarbonic acid from a strongly diluted solution of sodium or potassium carbonate or hydrogen carbonate, it is important to ensure the hydration of the newly formed associates of highly charged reagents (compounds) directly in the diffuse part of the double electric layer of the electrode, that is, in the zone where the electric field reaches several million volts per centimeter. In this case, as follows from many years of experience in the field of electrochemical transformation of dilute solutions [5], the greatest directional change in the structure of the solution is provided, which makes it possible to ensure the long-term existence of electrochemically synthesized products. The schematic diagram of the electrochemical synthesis of peracetic acid developed by the authors is shown in Fig. 5.4.10. In accordance with this diagram, a dilute solution of sodium or potassium carbonate or hydrogencarbonate is introduced into the anode chamber of the experimental electrochemical cell. Fresh water flows in a countercurrent flow in the cathode chamber, and the volumetric flow rate of water in the cathode chamber must exceed that of the carbonate solution in the anode chamber. This is necessary to create conditions under which the flow of current in the electrochemical circuit through the diaphragm of the reactor is ensured solely by the transfer of cations (sodium or potassium ions) from the anode chamber to the cathode one. An additional factor ensuring the transfer of current through the diaphragm only by metal cations and preventing the penetration of hydroxide ions from the cathode chamber into the anode one is the increased pressure in the anode chamber, which makes it possible to create a pressure gradient in the pore space of the diaphragm directed against the electrophoretic movement of free hydroxyl groups.

When the catholyte is fed in a countercurrent flow, a more complete removal of the alkali metal cations from the anolyte flow is achieved, which cannot be obtained when the catholyte is fed in a forward flow (parallel flows).

An aqueous solution of sodium carbonate with a concentration of 0.6–1.0 g/l was used as the initial solution in the studies. The process was carried out at an excess of pressure in the anode chamber in comparison with the cathode chamber by 0.1–0.5 atm. The optimal pressure difference was determined based on the concentration of the carbonate solution and the electrolysis parameters. At a pressure of less than 0.1 atm, it was not possible to suppress the backflow of hydroxide ions from the cathode chamber, which led to the termination

of the oxidation of carbonate ions. At a pressure of more than 0.5 atm, not only alkali metal cations, but also carbonate ions were removed from the anolyte flow through the diaphragm, which reduced the current efficiency of peroxy compounds.

Optimal for the process was the maintenance of the electrolyte flow rate in the cathode chamber 2–5 times higher than that in the anode chamber. At a flow rate lower than the lower limit of the specified ratio, it was not possible to ensure the transfer of current through the diaphragm mainly by sodium ions, and when the rate was exceeded by more than 5 times, the hydraulic pressure gradient in the cathode chambers increased significantly, which led to a violation of the regime of the same pressure difference across the diaphragm of the electrochemical cell.

Experiments have shown that the optimal electrochemical system for such a process is a chain of 8 hydraulically connected modular electrochemical cells FEM-3 (MB-11). The sequential hydraulic resistance of the anode chambers of various elements to each other allows for intensive anodic electrochemical

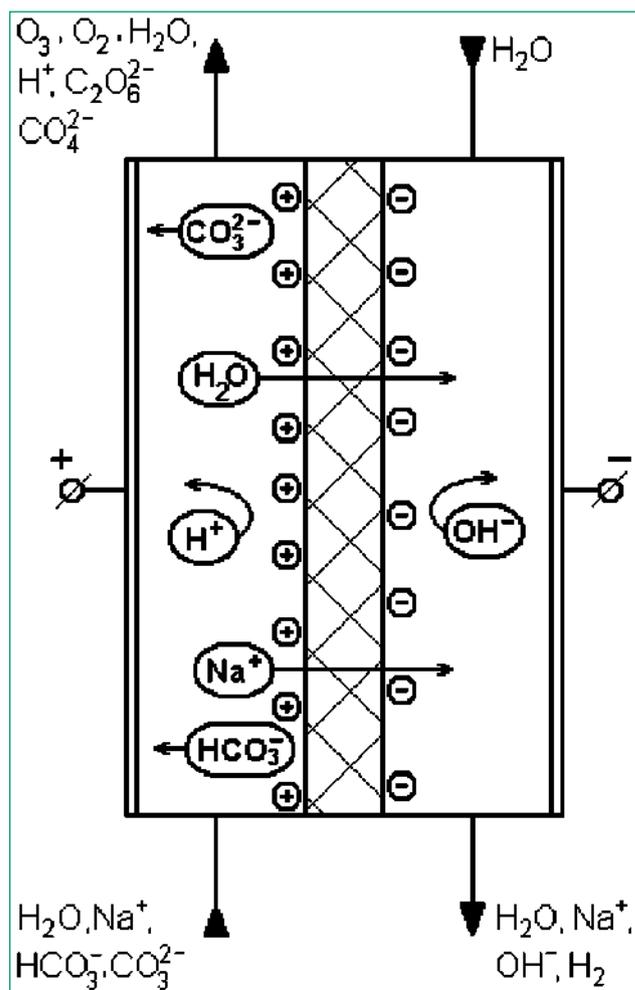


Fig. 5.4.10. Schematic diagram of the synthesis of peracetic acid solution.

treatment of the initial carbonate solution on a path of more than one and a half meters in the gap between the diaphragm and the electrode of about 1 mm. Serial connection of the cathode chambers of eight FEM-3 elements allows, at a water flow rate of 40–60 l/h, for effective removal of sodium ions from the anode chambers of the FEM-3 elements and, at the same time, to maintain the optimal value of electrical conductivity in all elements of the FEM-3 circuit due to the mutually opposite influence on the electrical conductivity of the gas filling of the cathode chambers and the increasing concentration of hydroxides as the water moves from the beginning of the chain of cathode chambers to the outlet of the catholyte flow.

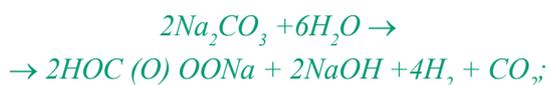
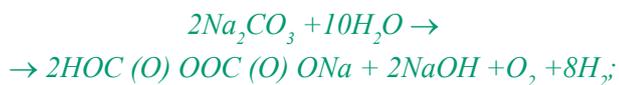
When more than 10 FEM-3 elements are used in the circuit, the complexity of determining and maintaining the optimal pressure difference between the anode and cathode chambers increases, since the hydraulic resistance of the cathode chamber of the cell, represented by several series-connected chambers of the FEM-3 electrochemical cells, increases significantly:

Chemical reactions that take place in process of the synthesis are as follows. At the cathode, the water reduction reaction mainly takes place:

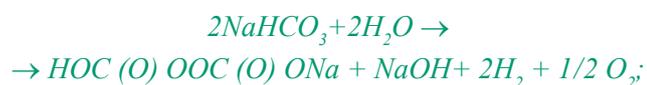


As the water moves through the cathode chambers chain of reactors, the concentration of sodium hydroxide in it increases as a result of electromigration of sodium ions from the anode chambers of the FEM-3 elements through the diaphragm into the cathode chambers.

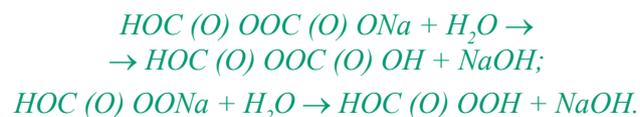
In the anode chambers, at the initial stage of the sodium carbonate solution flow, reactions of the formation of sodium peroxocarbonates take place in accordance with the total electrochemical reactions:



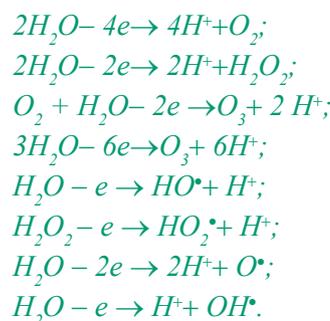
As the carbonate solution proceeds further through the hydraulically sequentially connected anode chambers and the pH of the medium decreases, it becomes depleted in sodium ions and carbonates turn into bicarbonates, which also undergo oxidation according to the following total reactions:



With a further decrease in pH in the anode chamber and its approach to pH = 7, the next stage of anode oxidation of sodium peroxocarbonate solutions is the conversion of peroxocarbonate salts into the corresponding acids — percarbonic (HOC(O)OOC(O)OH) and monopercarbonic (HOC(O)OOH):



In addition, in the anode chambers of the FEM-3 elements ending the chain (in the direction of movement of the anolyte), oxidation reactions of water and products of other electrochemical oxidation reactions take place:



Carbon dioxide synthesized during the process and dissolved in water also undergoes oxidation in the presence of catalysts, which are products of anodic electrochemical reactions, turning into percarbonic acid:



At slightly alkaline pH values, percarbonic acid (HOOC-O-O-COOH) forms salts as a result of the replacement of hydrogen ions by alkali metal ions.

The resulting solution, Anolyte PEROX, has the following characteristics: the content of monopercarbonic and percarbonic acids, as well as, possibly, a certain amount of sodium peroxocarbonates — from 20 to 50 mg/l in the equivalent of active chlorine (determined by iodometric titration), redox potential — within +500 to +800 mV relative to silver chloride reference electrode, total concentration of dissolved electrolytes is from 0.4 to 0.7 g/l.

It is possible to distinguish percarbonic acid in Anolyte PEROX from hydrogen peroxide as follows.

If you add 2–3 ml of Anolyte PEROX to a solution containing 10 grams of potassium iodide in 50 ml of water, iodine is released instantly:



A solution of hydrogen peroxide with a concentration of 40-50 mg/l releases iodine from a solution of potassium iodide much more slowly.

At the cathodes of the FEM-3 element chain, in addition to the above-mentioned water reduction reaction, accompanying electrochemical reactions also occur with the participation of reduction products:



The catholyte containing the above compounds has an increased extraction ability and high biological activity due to the low value of the redox potential.

Based on the experimental studies carried out, an experimental electrochemical device was developed and manufactured for the synthesis of Anolyte PEROX and catholyte in volumes sufficient for carrying out extensive practical tests (Fig. 5.4.11).

Productivity of the pilot system for Anolyte PEROX is 20 l/h, for catholyte — 60 l/h.

The conducted toxicological tests of Anolyte PEROX have shown its complete safety. Also, as a result of experimental studies, the complete absence of the damaging effect of Anolyte PEROX on metals subject to corrosion was confirmed.

The conducted tests of the antimicrobial effect of Anolyte PEROX on medical instruments and on a suspension test

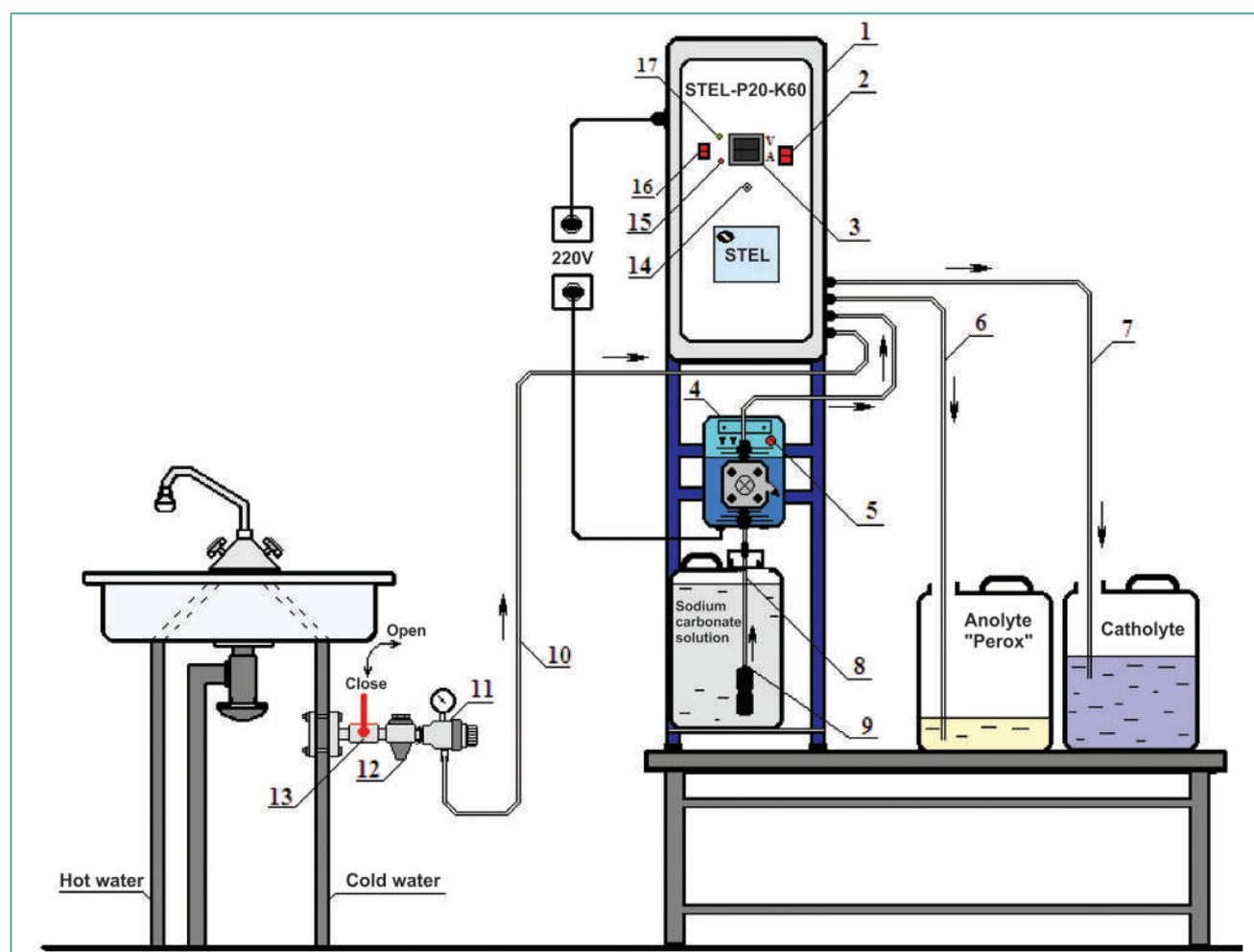


Fig. 5.4.11. Pilot system for electrochemical synthesis of Anolyte PEROX.

1 — STELP-20-K60 device; 2 — toggle switch to enable/disable the system; 3 — digital display of control of current A and voltage V; 4 — membrane dosing pump; 5 — pump performance regulator; 6 — Anolyte PEROX outlet hose; 7 — catholyte outlet hose; 8 — hose for supplying alkali metal carbonate solution to the system reactor; 9 — check valve; 10 — hose for supplying water to the system from the pressure water supply line; 11 — reducer; 12 — filter; 13 — ball valve; 14 — gear screw regulating the ratio of anolyte and catholyte flows through the reactor; 15 — overload light indicator; 16 — toggle switch for switching the modes of Anolyte PEROX obtaining; 17 — "reactor" light indicator of the system operating mode.

showed good results already after 10 minutes of treatment, with the concentration of active substances 40–50 mg/l in the active chlorine equivalent.

The tests of the virucidal properties of Anolyte PEROX showed its ability to inhibit the polio virus for 2–3,0 log₁₀ TCID₅₀ depending on the test object (dental instruments, rubber tubes, silicone tubes, etc.). Moreover, the optimal duration of treatment did not exceed 15 minutes.

Table 5.4.1 shows comparative data on the virucidal activity of Anolyte PEROX and known disinfectants.

From the data presented in Table 5.4.1, it can be seen that when the concentration of active substances is 50–75 times lower than that of AS for quaternary ammonium compounds in Diabac and Deseffect, Anolyte PEROX has a higher virological activity with complete toxicological safety.

As tests of the duration of preservation of active substances of Anolyte PEROX have shown, the decomposition of percarbonic acid and, accordingly, the loss of antimicrobial activity of Anolyte PEROX occurs rather slowly: within 3 days of storage, the antimicrobial activity of the agent decreases by no more than 20 percent. This is due to the extreme dilution of the solution and the strength of the structure of the ion-hydrate shells formed in a high-strength electrostatic field in the electric double layer on the surface of the electrodes of the FEM-3 elements.

Besides, there is no need of using stabilizers and other ballast ingredients, which are mandatory additives in the preparation of peroxocarbonate solutions.

Conclusion: A technology and technical means have been developed for the production of an all-purpose electrochemically activated antimicrobial solution Anolyte PEROX, which is produced in STEL-PEROX

devices by electrochemical synthesis from an aqueous solution of sodium carbonate or sodium bicarbonate. The active ingredients of Anolyte PEROX are sodium peroxocarbonates, percarbonic acid and hydroperoxide electron-acceptor compounds in a metastable state — oxidants. The salinity of the PEROX solution is in the range from 0.4 to 0.7 g/l, the concentration of oxidants, measured by iodometric titration in the equivalent of active chlorine compounds, is from 30 to 50 mg/l. The hydrogen index of Anolyte PEROX is in the range from 6 to 7. The solution is non-toxic, has no corrosive activity and is proposed for use not only as a disinfectant for medical devices and food products, but also as sterile water with antibacterial properties lasting for three days. In this capacity, Anolyte PEROX can be used for rinsing medical products in technological processes of preparing them for use.

In addition, in STEL-PEROX devices simultaneously with Anolyte PEROX, Catholyte PEROX is synthesized, which can be used as a washing solution, as well as a medium for preparing insecticide solutions. The mineralization of Catholyte PEROX does not exceed 1 g/l at a pH exceeding 10 and a redox potential of less than minus 500mV (relative to the silver chloride reference electrode). The active ingredients of Catholyte PEROX are sodium hydroxide, hydrogen peroxide and other metastable hydroperoxide electron donor compounds — antioxidants. As shown by preliminary experiments, the use of Catholyte PEROX as a medium for the dissolution of insecticidal agents allows increasing the functional properties of insecticide solutions while reducing the concentration of active substances by 50–70% due to the intensification of the processes of transfer of active substances through insect vestiture.

Table 5.4.1

Indicators	Anolyte PEROX	Deseffect	Diabac
AS Concentration	0.004–0.005 % %	0.2–0.3 % %	0.15–0.25 % %
AS Contents	percarbonic acid, sodium peroxocarbonates, hydrogen peroxide, singlet oxygen, ozone	n-alkyldimethylbenzyl ammonium chloride, n-alkyldimethyl (ethylbenzyl) ammonium chloride, etc.	alkyldimethylbenzyl ammonium chloride, formula activators, functional additives
Toxicity	IV class of toxicity when administered into the stomach and inhaled, no sensitizing effect on the skin	IV class of toxicity when administered into the stomach and inhaled	III class of toxicity when administered into the stomach, IV class of toxicity when applied to the skin, low hazard with inhalation
Antiviral activity (poliovirus)	inhibition by 2.0–3.0 log ₁₀ TCID ₅₀	inhibition by 2.0–2.5 log ₁₀ TCID ₅₀	inhibition by 2.0–2.5 log ₁₀ TCID ₅₀

Note: TCID₅₀ — tissue cytopathogenic infectious dose causing damage to 50% of the cell monolayer.

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Э45

Bakhir V.M., Panicheva S.A., Prilutsky V.I., Panichev V.G.

**Э45 ELECTROCHEMICAL ACTIVATION:
INVENTIONS, SYSTEMS, TECHNOLOGY**

The book considers theoretical concepts and hypotheses about the nature of the phenomenon of electrochemical activation of substances discovered by Vitold M. Bakhir in the seventies of the last century. It provides information on the most significant inventions in the field of electrochemical activation and the results of the practical implementation of inventions in various fields of science, engineering and technology. It describes various electrochemical systems for producing liquids with an abnormally high activity in oxidation-reduction, catalytic and biocatalytic processes.

Based on the experience of engineering and practical use of electrochemical systems for production environmentally friendly, safe for humans and animals electrochemically activated detergents, disinfectants and for production of the environmentally friendly sterilizing solutions, the authors predict further development of electrochemical activation technology. Various examples show that the role of electrochemical activation in the near future will steadily increase not only in the field of drinking water disinfection and purification, wastewater and swimming pool water treatment, food industry and agriculture, but also in chemical, petrochemical and mining industries to save raw materials, time and energy, while improving environmental safety and efficiency of the processes.

The book is intended for a wide range of specialists and students interested in the application of electrochemical technologies in various fields of human activity.

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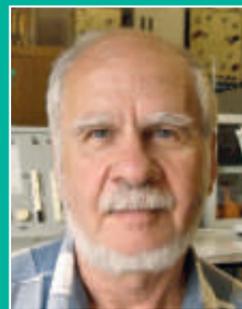
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VITOLD BAKHIR — the creator of new scientific and technical field — electrochemical activation (ECA). Doctor of Technical Sciences, Professor, Scientific Director at Electrochemical Systems and Technologies Institute. The author of more than 400 inventions with copyright certificates of the USSR and patents of the Russian Federation, USA, Canada, Great Britain, Germany, Switzerland, Italy, Japan, China, South Korea. The above-mentioned inventions are implemented in several hundred thousand various electrochemical devices in many countries. The author of 7 monographs and more than 300 scientific articles.



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