6.2. REAGENT-FREE PURIFICATION OF FRESH WATER

Fragments of scientific research and completed projects

Discovered in the seventies of the last century, the phenomenon of electrochemical activation of fluids [1–31] is widely used in various electrochemical devices and technologies for reagent-free purification and disinfection of natural fresh water. The essence of electrochemical activation consists in the effect of temporary preservation by the near-electrode medium of the anomalous activity of electrons and all components of the medium (molecules, ions) participating in physicochemical processes in the area of the double electric layer (DEL) of the polarized electrode of the electrochemical system. In fact, this means that the physicochemical parameters of the near-electrode medium as a result of electrochemical action deviate extremely strongly from the equilibrium values, which under normal conditions correspond to the chemical composition of the liquid at a given temperature. The relatively slow relaxation of the anomalous properties of an electrochemically activated medium, including anomalous reactivity, catalytic activity in chemical and biochemical reactions, makes it possible to use such media, represented mainly by aqueous solutions of various substances, in technological processes without the consumption of chemical reagents and often with a much more significant positive effect in comparison with traditional methods of chemical regulation.

There is a well-known property of long-term coexistence (up to 6 months) of hydrogen peroxide and hypochlorous acid in a low-concentration (0.001–0.01%) sodium chloride solution, previously subjected to anode electrochemical action with a depth of 1600–1700 C/l at a current density of over 1000 A/m2 without temperature rise [1–8]. When simulating this process chemically — by mixing solutions of hydrogen peroxide and hypochlorous acid, there occurs mutual neutralization in accordance with the following reaction:

$$HClO + H_2O_2 \rightarrow O_2\uparrow + H_2O + HCl$$

This fundamental difference between the properties of an electrochemically obtained solution and its chemical model becomes understandable if we take into account that during the formation of antagonistic substances in the double electric layer (DEL) of the electrode, in its diffuse and dense parts with the electric field strength varying from several hundred thousand to several tens of millions of volts per centimeter — they are instantly hydrated in an electric field, simultaneously forming structural and energy complexes of protection against mutual destruction. Dense ionic-hydration shells retaining the structural organization acquired at the time of their formation in a high-intensity electric field, prevent the interaction of antagonistic active substances (AS) during storage of the solution.

The relaxation time for this property is calculated in hours and days, depending on the conditions of synthesis and subsequent storage.

Long-term preservation of anomalous activity by the near-electrode medium manifested in various physicochemical parameters and reactivity as applied to various technological processes, was studied in years 1982 to 1999 on various liquids and gases: distilled water, mineral oil, straight-run gasoline, aqueous and non-aqueous solutions of organic and inorganic compounds, gaseous chlorine, oxygen, hydrogen, helium [1–6, 13, 14]. At the same time, the ways of practical application of the discovered effects in various technologies were determined, including in the petrochemical industry (pyrolysis of straight-run gasoline, purification of oil and oil products from sulfur), in metallurgy and mining-chemical industry (hardening of steels, extraction of metals from ores and slags), in mechanical engineering (preparation and regeneration of cutting fluids, creation of drainless galvanic plants with the regeneration of chemical agents), etc. However, one of the main topics of research activity has always been water — from double-distilled water (DDW) to natural fresh and mineralized.

As part of the work on devices for obtaining antimicrobial double-distilled water, in 2019 a laboratory device AQUATRON-15–200L [30] was developed for the synthesis of electrochemically activated anolyte and catholyte of distilled water, with the electrochemical reactor made by 12 new generation MB elements (Fig. 6.2.1).

Along with biological experiments based on the use of electrochemically activated substances, there were studies of the actual process of synthesis of anolyte and catholyte of distilled water with an attempt to transfer the results obtained to a wider range of phenomena related to the creation of artificially induced ionic selectivity in inactive ceramic ultrafiltration diaphragms from alpha-alumina. The above diaphragms are the main part of the MB-11T flow-through electrochemical modular cells of 2016 generation.

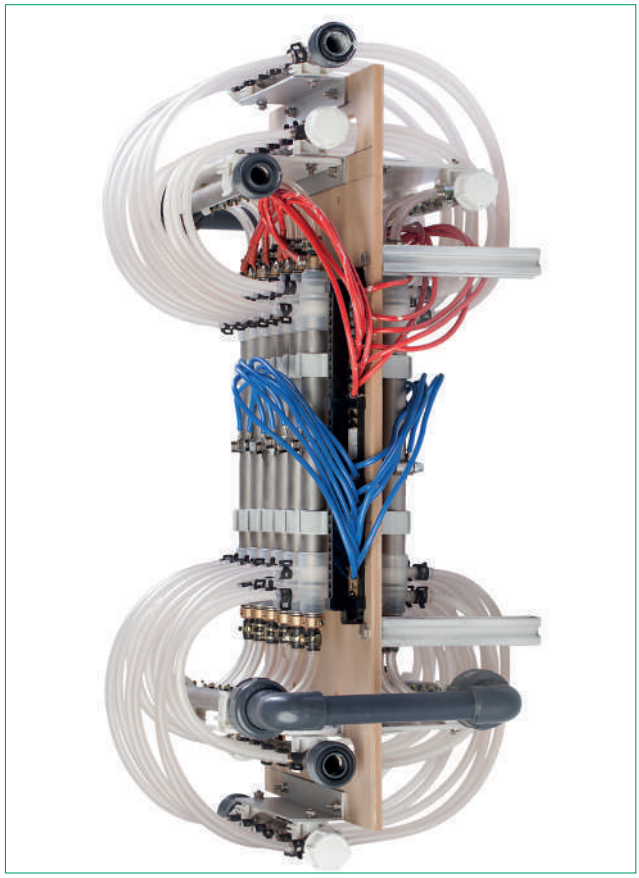

Fig. 6.2.1. *Reactor RPE-12MB-11T-300L*

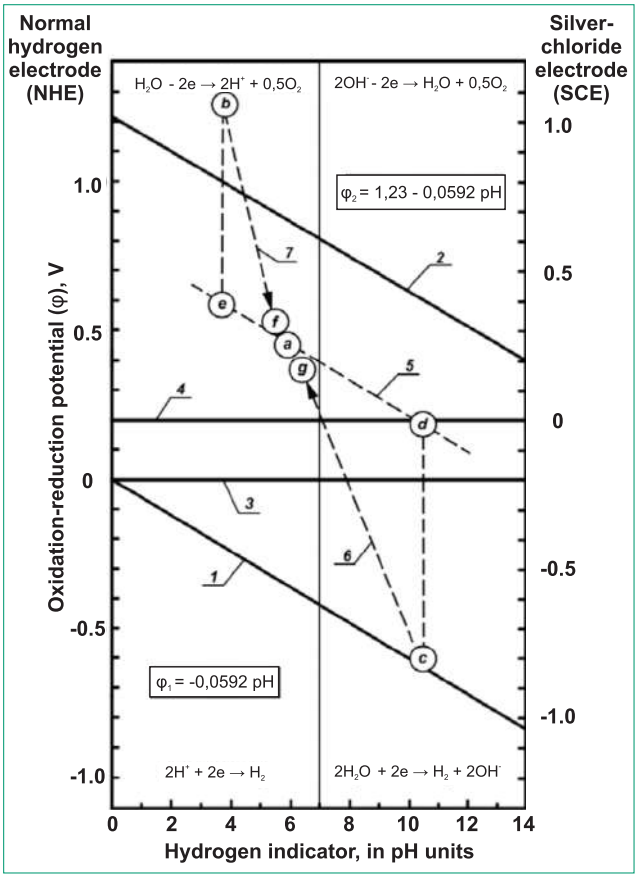

Fig. 6.2.2. *Ratio of pH and ORP for electrochemical and chemical regulation of distilled water parameters. Legend: 1 and 2 — potentials of water reduction on an inert cathode (φ_1 = –0.0592 pH) and oxidation on an inert anode (φ_2 = 1,23–0.0592 pH) respectively; 3 and 4 — zero lines of the scales of hydrogen (NHE) and silver chloride (SCE) reference electrodes; 5 — direction of pH and ORP change during chemical regulation of water parameters; a — initial values of parameters of distilled water; b and c — parameters of anolyte and catholyte, respectively; d and e — parameters of chemical models of catholyte and anolyte, respectively; f and g — parameters of anolyte and catholyte after the end of relaxation, respectively.*

Experiments on the study of pH and redox potential (ORP) of distilled water subjected to electrochemical action at the surface of the positive and negative electrodes of the electrochemical system carried out for many years [1–14], have shown that the pH and ORP of anolyte and catholyte of distilled water acquire abnormal values in comparison with those calculated based on the laws of electrolysis, as well as those obtained by modeling the acid-base properties of anolyte and catholyte by introducing acid and alkali into the original distilled water. Fig. 6.2.2 shows the results of experiments studying the parameters of electrochemically activated distilled water obtained using the AQUATRON-15–200L device. Distilled water in accordance with GOST 6709–72 was used as the starting one in all experiments with the following parameters: mass concentration of the residue after evaporation of the studied water samples obtained in three different laboratories, mg/dm^3 — in the range from 3.5 to 4.8 mg/dm^3; specific electrical conductivity at 25 °C — from 3.8 to 4.6 μS/cm; pH 5.8 to 6.2; redox potential measured with a platinum electrode relative to a silver chloride reference electrode +215 to + 340 mV.

The pH and ORP were measured with a PH FE20 pH meter (METTLER-TOLEDO), the specific electrical conductivity of water — with an FP-30 — STANDARD conductometer (METTLER-TOLEDO).

In the AQUATRON-15–200L system, in contrast to the known electrochemical systems for the production of anolyte and catholyte of distilled water [1], a flow-through electrochemical modular cell MB-11T-07 was used, with the ultrafiltration diaphragm made of chemically pure alpha-alumina. The uniformity of the structure and physicochemical properties of the diaphragm made it possible to exclude the electromigration of the products of electrochemical reactions from the auxiliary to the working electrode chamber of the MB elements due to the same filtration rate for each microsection of the filtering surface under the action of a pressure drop across the diaphragm (from 0.5 to 1.8 bar) and the electric field that regulates the chemical components of the filtration flow in the diaphragm.

The cooled electrodes of the MB-11T-07 elements ensured the temperature constancy of the water flowing through the electrode chambers within 22, plus or minus 3°C. The current through one element of the MB was maintained in the range from 0.12 to 0.23 A at a voltage of 450–850 volts in various experiments. The specific amount of electricity consumed for the electrical treatment of water in the cathode or anode chambers of the MB elements ranged from 40 to 45 C/L, that is, based on the laws of electrolysis, more than ten times higher than the theoretical one, required for the complete electrochemical conversion of substances dissolved in water — electrolytes.

Measurements of pH, ORP and electrical conductivity were carried out within 2 or 3 minutes after the termination of the electrochemical treatment process. The time of each measurement did not exceed 5 minutes.

As a result, the parameters of the catholyte are: pH = 10.3–10.5, ORP = –795 — –800 at a temperature of 20–25°C. Specific electrical conductivity 4.8–5.6 μS/cm.

Anolyte parameters are: pH = 3.8–4.0; ORP immediately after obtaining — from plus 350 to plus 400 mV; after weak stirring in the flask for 10–15 minutes — from plus 1050 to plus 1100 mV at a temperature of 20–25°C. Specific conductivity is 3.2 to 3.5 μS/cm.

These results are shown in Fig. 6.2.2, where the pH — ORP coordinates show both the initial values of these parameters and those obtained as a result of cathode and anode treatments. The upper and lower parts of the graph show the chemical reactions of water decomposition characteristic of oxidation and reduction processes on inert electrodes (exchanging only electrons with the near-electrode medium), depending on pH. Also shown are the parameters of anolyte and catholyte after the end of the relaxation period (about 72 hours in closed vessels). The letters «e» and «d» mark the areas of chemical modeling of the pH of the freshly obtained catholyte and anolyte, respectively. The modeling of the catholyte was carried out by introducing microadditives of sodium hydroxide into the original distilled water in an amount from 6.0 to 6.5 mg/l. To simulate the anolyte, microadditives of hydrochloric acid were used in an amount from 3.9 to 4.2 mg/l. The replacement of hydrochloric acid with sulfuric acid did not lead to significant deviations. It is necessary to note a significant excess of the electrical conductivity of the model solutions in comparison with their «analogs»: 36–40 μS/cm for the chemical model of the anolyte versus 3.2–3.5 μS/cm for the real anolyte and 34–36 μS/cm for the chemical model of the catholyte against 4.8–5.6 μS/cm for a real catholyte, respectively.

The explanation of this fact is related to a change in the forces of interionic interaction as a result of a nonequilibrium electrochemical unipolar effect. It is known that the magnitude of the forces of interionic interaction in aqueous solutions of electrolytes is characterized by the coefficient γ in the equation relating the activity of ions α in a solution with their concentration c: $\alpha = \gamma \cdot c$. Ion activity α Is the effective concentration of the ion, according to which it participates in all chemical reactions in the solution. Activity coefficient γ shows how many times the activity of an ion differs from its true concentration in a strong electrolyte solution. In dilute solutions ($c < 10–4$ mol/L), which include distilled water, ion concentrations are low and there is practically no interionic interaction, therefore $\gamma = 1$ and the activities of ions are very close to their molar concentrations: $\alpha = c$.

An insignificant amount of stable electrolysis products in distilled water makes it possible to study relaxation processes without their interfering effect, but requires special conditions of electrochemical action, ensuring the contact of the largest possible number of the water flow microvolumes with the electrode surface, and the absence of the products of electrochemical reactions from the counter electrode chamber getting into the water being treated due to electromigration. An increase in the concentration of electrolyte ions in the source water from several tens to several hundred milligrams per liter greatly enhances the «activation» component of the reactivity of the anolyte and catholyte by varying the activity coefficient within the limits close to unity, thus increasing the technological value of the activated water.

An analysis of the theoretical data presented and the results of a practical experiment shows that an electrochemical nonequilibrium effect is capable of changing the reactivity (activity) of ions in solutions by tens of times without changing their concentration.

The pH values reached in the course of electrochemical action correspond to equilibrium concentrations of alkali and acid, many times higher than the content of salts in water, from which these alkalis and acids could be obtained. The ORP values go beyond the capabilities of chemical modeling for a given electrical conductivity and therefore are unique. Analyzing these results, which demonstrate the long-term abnormally high and abnormally low activity of electrons in water in contact with the surface of the cathode or anode, it is safe to assume for this case, too, the validity of Le Chatelier principle, according to which, during the electrochemical action, the near-electrode medium counteracts physicochemical transformations, but when they are completed, it retains the achieved metastable state for a long time, counteracting the transition to a state of thermodynamic equilibrium with the environment.

The results obtained in a laboratory device equipped with a new type electrochemical reactor are much higher than those previously achieved in the mid-1980s — early 2000s, and this makes the effects obtained much more promising

for the industrial application. Below are three examples from the first practical experiments using electrochemical activation for the treatment of distilled water and low-mineralized aqueous solutions. Based on the previously achieved results we can make extrapolative prediction of the qualitative and quantitative improvement of processes when using new electrochemical systems.

Example 1. In 1983, at the Tasma Company Pseudomonas aeruginosa (blue pus bacillus) bacteria were found in a 2000-liter titanium container with distilled water. Periodic treatment of water with hydrogen peroxide and ozone had no effect. The anode chamber of an electrochemical reactor with glassy carbon electrodes and an alundum diaphragm was included in a circulation loop closed to the container with distilled water. Distilled water flowed in the auxiliary (cathode) chamber at a flow rate of about 1.5 liters per hour and was discharged into the drain. Electrochemically activated anolyte with a maximum ORP value of +870 mV (SCE) in the flow was synthesized in the anode chamber of the reactor under a pressure of 0.3 atmosphere and mixed with the volume of water in the vessel. Turning on the electrochemical reactor for 1 hour per day in circulation mode ensured sterility of water from the second day of use.

Example 2. In 1986, at the P.O. box -7220 Company in Tashkent, one of the authors proposed a method for polishing silicon monocrystals with replacing the potassium hydroxide solution in deionized water with pH = 8.5 for a catholyte of deionized water with pH = 9.3. At the time, this was the maximum pH reached by treating water in the cathode chamber of a flow-through reactor with glassy carbon electrodes and an alundum diaphragm with pore sizes ranging from 1 to 10 microns. The result exceeded expectations: the speed of polishing to one monoatomic layer tripled with a simultaneous increase in the adhesion of the chemically deposited copper layer on the polished silicon surface by eliminating the possibility of adsorption of potassium ions on silicon.

Example 3. The work that opened the way to the creation of EMERALD electrochemical systems for drinking water purification was the BAZEKS device designed for electrochemical disinfection and conditioning of purified water for hemodialysis, i. e. water containing no more than 0.07 g/l of dissolved salts [31]. Before being fed to the hemodialysis device and mixing with the concentrate, the water was supplied under pressure to the BAZEKS device, where it was subjected to anodic electrochemical treatment in a reactor of ten flow-through electrochemical modular elements with ceramic (zirconium oxide) diaphragms in a mode of 150–200 C/l for the purpose of disinfecting and oxidizing organic impurities (pyrogens). After the separation of the coagulated organic compounds on a five-micron filter made of porous titanium, water entered the cathode chamber of the other reactor. Cathode electrochemical action was carried out in the mode of 250–500 C/l to change the redox potential and to make the water closer in this parameter to the internal environment of the human body, that is, to the patient's blood purified in the dialyzer (from minus 100 to minus 170 mV, SCE). The dialysis solution, prepared on this water with optimal pH and redox potential, entered the artificial kidney dialyzer. Clinical trials of the device on the instructions of the USSR Ministry of Health were carried out in the hemodialysis center of the Moscow City Clinical Hospital (GKB No. 50). The BAZEKS device was tested during hemodialysis on five patients. The test duration was 3 months. Due to the complete biocompatibility of the dialysis solution with the patient's blood and the acceleration of the transmembrane transfer of creatinine and urea through the dialyzer membranes (the effect of preliminary electrochemical treatment), the duration of the dialysis process based on the analysis of the biochemical parameters of the patient's blood was reduced by 1–2 hours (in accordance with individual data) for each of the five patients. During the tests, it was noted that the use of the BAZEKS device normalized the high blood pressure (BP) of patients and did not affect their BP if it was not beyond the normal range. Also, the disappearance of characteristic dermatoses and a general subjective feeling of «soft» dialysis were noted in all patients. The BAZEKS device for the first time used a flow-through electrochemical RPE reactor consisting of ten FEM-1 elements. The BAZEKS device was a prototype, on the basis of which several technological processes for water purification were developed in 1990–1991, which later received the names EMERALD, CRYSTAL and SAPPHIRE. In the same years, based on the BAZEKS device, experimental devices were made to produce a highly effective antimicrobial solution from water without addition of any chemical reagents; the solution was practically tested as a means to combat blue-green algae in fountains, as well as to combat Legionnaires' disease pathogens in the air conditioning systems [1].

In the studies carried out in 2018 using the AQUATRON-15–200L devices and those described above, much higher pH and ORP values were achieved due to the improved design of the main instrument for the synthesis of electrochemically activated anolyte and catholyte — an electrochemical reactor represented by the MB element. Therefore, it is safe to conclude that much better results should be expected from the use of such reactors in technologies using demineralized or low-mineralized water.

Also, the new generation electrochemical cells can be used with much greater efficiency in the well-known EMERALD devices for purification and conditioning of drinking water [20, 21], the salinity of which is usually in the range of 0.1–1 g/l. The processes of electrochemical

oxidation and reduction in MB elements during the treatment of drinking water occur at a voltage of 12 to 24 volts. EMERALD devices were developed in the early nineties. They ensure the destruction of all types of microorganisms and microbial toxins in water, oxidative destruction of organic compounds, including hormones, antibiotics, antidepressants, eliminate the color of water due to the presence of humic acids, organic and bacterial iron, remove heavy metal ions by converting them into insoluble hydroxides with further extraction on filters, oxidation of ferrous iron and manganese. There are about a hundred different flow charts for water purification in EMERALD devices. The purification principles consist in an optimal for each type of water combination of oxidation and reduction processes taking place in active electrode chambers, that is, in elements (electrochemical, flotation, electrosorption reactors) with passive elements (filters, sorption, catalytic reactors). A typical purification scheme was the primary treatment of the water flow at a specific consumption of the quantity of electricity from 150 to 350 C/l in the anode chamber of the MB flow-through electrochemical cell responsible for the destruction of microflora, the oxidation of organic compounds, the oxidation of divalent iron and manganese ions, and flotation separation using ozone bubbles and oxygen of coagulated organic compounds, filtration, catalytic elimination of excess chlorine-oxygen oxidants on carbon granules, and water treatment in the cathode chamber in order to convert heavy metal ions into hydroxides, with subsequent filtration.

In total, over the period 1991–2020, more than 300,000 original EMERALD household devices were manufactured with a capacity of 40–60 liters per hour.

Fig. 6.2.3 and 6.2.4 show the original EMERALD devices of various capacities and years of manufacture.

Fig. 6.2.3. *Emerald devices for water purification and conditioning, from left to right: Emerald model with built-in high-voltage power supply, 50 liters per hour, 1993; Emerald model with external low-voltage power supply, 50 liters per hour, 2006; EMERALD-EXTREM system for water purification in emergency situations, 500 liters per hour, 2009; Emerald system for water purification in a country cottage, 500 liters per hour, 2012.*

Fig. 6.2.4. *EMERALD HOME devices based on MB-11 elements of the latest generation, manufactured under license by EMERALD ECOTECHNOLOGIES LLC. EMERAD devices of HOME series are used in flats, offices, cottages and various public places, providing the best achieved degree of water purification and conditioning. On the left is EMERALD HOME 40 device, productivity — 40 l/h, power consumption — no more than 30 W, 2018. On the right is EMERALD HOME 60 device, productivity — 60 l/h, power consumption — no more than 60 W, 2019.*

The word «original» is not used by accident. In the latest 15 years, the number of counterfeit EMERALD devices has sharply increased and keeps increasing. A lot of devices have appeared for the production of so-called «ionized», «hydrogen», «alkaline», «living» water for regular drinking and treatment. The benefits of the commercial use of counterfeits will support their proliferation until consumers acquire the knowledge and ability to navigate the technical and engineering features of the products. One of the most difficult aspects in the technology of synthesis of electrochemically activated waters and solutions is to ensure the processing of each conditionally isolated microvolume of liquid in the double electric layer (DEL) and to prevent premature neutralization of the most active products of electrochemical reactions by equally active ones from the opposite polarity electrode chamber.

Almost all devices — industrial, laboratory, household ones, made by unauthorized manufacturers allow obtaining only small or trace quantitative and qualitative effects associated with the metastable state of the near-electrode environment. All the more significant — in demonstrating the possibilities of the technology of using electrochemically activated water and solutions — are the results of many foreign researchers who have used the simplest and far from perfect technical electrochemical systems [32–84]. It should be noted that foreign scientific publications in the field of electrochemical activation appeared approximately 10 years after the works published in the Soviet Union, that is, at the end of the eighties. At present, due to the rapid spread of information, the rate and number of various applications of electrochemical activation in foreign scientific publications are growing like an avalanche, although the technical means used for the synthesis of electrochemically activated substances remain mostly at a low level. The experience and practice of designing electrochemical systems are very difficult objects to transfer in the form of printed texts, drawings, instructions or by mechanical copying of finished products. Special knowledge of the workers of the receiving party is needed, which can be acquired as a result of their independent mastering of the theoretical foundations of the electrochemical kinetics of water and dilute solutions, as well as the thermodynamics of nonequilibrium electrochemical processes with the simultaneous accumulation of practical experience in this area. Therefore, from the beginning of the seventies of the last century to the present time, a group of scientists and specialists under the scientific leadership of V. M. Bakhir has been and remains the world's leading group. Fundamentally, electrochemical activation manifests itself in any electrochemical system consisting of inert (exchanging only electrons with liquid) electrodes immersed in water, through which the electric current flows. Any non-equilibrium electrochemical process generates

conversion products of the solvent and electrolyte, which have an excess of kinetic (thermal) and potential (structural) energy. The main task of designing technical electrochemical systems and technologies for electrochemical activation of liquids is to create conditions for minimizing heat release in the electrode chambers of the reactor and to ensure the conditions for the transfer of the potential energy of oxidative processes at the anode and (or) the potential energy of reduction processes at the cathode to as many microvolumes of the processed liquid as possible. A clear idea of the structural differences between a typical analogue (two electrodes with a baffle) and a prototype (a flow-through electrochemical reactor for electrochemical activation of distilled or ultra-fresh water), which is the closest in the mechanism of manifestation of potential excitation energy, lies in the field of laser technology. A chemical laser, like a wax candle, is a light source. The difference in design leads to the respective areas of application. A chemical laser directly converts chemical energy into coherent light energy, bypassing other forms of energy. In the working medium of a laser, consisting, for example, of molecular chlorine and hydrogen [85], as a result of energy input from the outside (pumping energy), reactions occur that generate molecules, radicals, and atoms in excited energy states, which ultimately makes it possible to extract energy from the working the medium of the laser in the form of a beam of light.

The similarity of the processes lies in the fact that during electrochemical activation, like in a chemical laser, it is necessary to impart excess potential energy to the molecules of the treated medium and prevent its dissipation as a result of various dissipative processes in the reactor itself.

The influence of the design of an electrochemical reactor on the result is illustrated by the following abstract analogy: the combustion of hydrocarbons in a candle flame and in a jet engine is described by very similar chemical equations. However, the difference in the design of these, in the chemical aspect, analogue and prototype, provides completely different results of combustion processes.

The problem of effective (ion-selective) chemical isolation of the working chamber of an electrochemical reactor from the auxiliary one is solved by a combination of the optimal design of the reactor and the corresponding mode of its operation in each separate flow chart. Another successful step in solving this problem was made by the creation in 2016 of a new generation of electrochemical reactors in accordance with [30].

The effect of intensifying the electrochemical action on water due to the electric field regulating the chemical components of the filtration flow in a porous medium, used in electrochemical cells of the 2016 generation in experiments with distilled water, is universal, since it turns an inactive ceramic ultrafiltration diaphragm into an ion-selective membrane, regardless of the electrolyte ion concentration.

The continuation of the above studies on the production of anolyte and catholyte of double-distilled water was carried out in 2020 on the AQUATRON-15–1500E device, equipped with two RPE-6 reactors made of MB-26T flow-through modular electrochemical cells, each of which being actually an independent compact diaphragm electrochemical reactor. The aim of the research was to study the range of values of the activity of electrons during the electrochemical treatment of fresh water with a total mineralization of less than 0.3 g/l in the new generation electrochemical reactors. The properties and parameters of the anolyte and catholyte of Moscow tap water were investigated in various modes of flow through narrow annular elongated gaps between the electrode (anode, cathode) and a ceramic ultrafiltration diaphragm made of aluminum oxide in the alpha form.

It was necessary to obtain quantitative estimates of the intensification degree of the processes of electrochemical action on dilute electrolyte solutions due to the stable physicochemical and physicomechanical properties of the diaphragms and the possibility of the formation of self-organizing vortex flow structures in an operating electrochemical reactor at relatively high speeds of liquid movement in each of its elements.

The result of the research was the achievement of previously obtained experimental data on the change in pH and redox potential of fresh water subjected to electrochemical action at the surface of the positive and negative electrodes of a single MB element at more than half the power consumption. Due to the parallel operation of the reactors of the electrochemical system in the mode of self-organizing structures of energy and mass transfer with a total consumption of fresh water through the cathode and anode chambers of the reactors at a rate of 1500 liters per hour (12 anode chambers and 12 cathode chambers of MB-26T elements), approximately 6–12 W x h/l of electricity consumption were required to achieve the limiting parameters of deviation of pH and ORP from the equilibrium state. Fig. 6.2.5 shows the results of experiments on studying the parameters of electrochemically activated fresh water obtained using the AQUATRON-15–1500E device. As a starting point in all experiments, we used drinking water from the north-western region of Moscow with the following parameters: total mineralization — 0.25 g/l; hardness — 3.6 mg-eq/l; pH — 7.1 ÷ 7.2; redox potential measured with a platinum electrode relative to a silver chloride reference electrode — from +250 to + 350 mV; specific electrical conductivity — on average 0.00031 cm/cm.

The pH and ORP were measured with a PH FE20 pH meter (METTLER-TOLEDO), the specific electrical

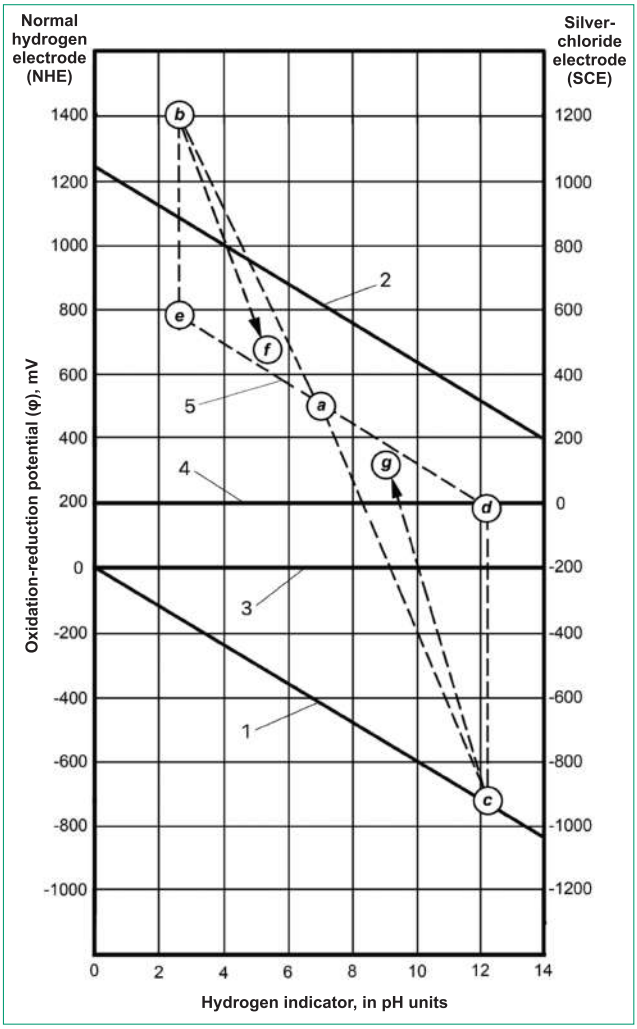

Fig. 6.2.5. *Ratio of pH and ORP in electrochemical and chemical regulation of fresh water parameters. Legend: 1 and 2 — potentials of water reduction on an inert cathode (φ_1 = –0.0592 pH) and oxidation on an inert anode (φ_2 = 1.23–0.0592 pH) respectively; 3 and 4 — zero lines of the scales of hydrogen (NHE) and silver chloride (SCE) reference electrodes; 5 — direction of pH and ORP change during chemical regulation of water parameters; a — initial values of fresh water parameters: pH = 7.0; ORP = +320 mV (SCE); b and c — parameters of anolyte and catholyte, respectively: pH = 2.7; ORP = +1200 mV (SCE), pH = 12.3; ORP = –920 mV (SCE); d and e — parameters of chemical models of catholyte and anolyte, respectively: pH = 12.3; ORP = 0 mV (SCE), pH = 2.7; ORP = + 780 mV (SCE); f and g — parameters of anolyte and catholyte after the end of relaxation, respectively: pH = 5.7; ORP = + 400 mV (SCE), pH = 9.0; ORP = + 120 mV (SCE).*

Fig. 6.2.6. *AQUATRON-15–1500E device. The reactor of the device is made of twelve flow-through electrochemical modular elements MB-26T of a new generation with the use of ultrafiltration diaphragms made of chemically pure alumina in the alpha form.*

conductivity of water — with a conductometer FP-30 — STANDARD (METTLER-TOLEDO).

The AQUATRON-15–1500E device (Fig. 6.2.6) used a reactor of twelve MB-26T flow-through electrochemical modular elements, with the ultrafiltration diaphragms made of chemically pure alumina in the alpha form. The uniformity of the structure and physicochemical properties of the diaphragms made it possible to ensure an almost complete separation of ions into cations and anions with the formation of the corresponding electrochemically activated products of anode and cathode reactions.

The cooled electrodes of the MB elements ensured the constancy of the temperature of the water flowing through the electrode chambers within 15 plus or minus 1°C with a flow rate from 1300 to 1500 l/h. The current strength was maintained in the range from 180–200 A at a voltage of 40–45 volts. The specific quantity of electricity consumed for the electrical treatment of water in the cathode or anode chambers of the MB elements averaged 100 C/l.

Measurements of pH, ORP and electrical conductivity were carried out within 2–3 minutes after the termination of the electrochemical treatment process. The time of each measurement did not exceed 5 minutes.

The research results are shown in Fig. 6.2.5, where both the initial values of these parameters and those obtained as a result of cathode and anode treatments are shown in the pH — ORP coordinates. Also shown are the parameters of anolyte and catholyte after the end of the relaxation period (about 72 hours in closed vessels). The letters e and d mark the areas of chemical modeling of pH of freshly obtained catholyte and anolyte, respectively.

The modeling of the catholyte was carried out by introducing microadditives of sodium hydroxide into the starting water. Microadditives of hydrochloric acid were used to model the anolyte. Replacing hydrochloric acid with sulfuric acid did not lead to significant deviations.

In comparison with the above data of studies on double-distilled water, an increase in the concentration of electrolyte ions in the original fresh water from several tens to several hundred milligrams per liter greatly enhances the «activation» component of the reactivity of anolyte and catholyte due to a synergistic change in the activity coefficient of ions contained in water and, accordingly, increases the role and technological value of activated water. In this case, it is important that the coefficient of activity of ions in the starting water is close to unity.

As the analysis of the practical experiment results has confirmed, **the electrochemical nonequilibrium effect can change the reactivity (activity) of ions in solutions by tens of times without changing their concentration.**

The pH values reached in the course of electrochemical action correspond to equilibrium concentrations of alkali and acid that are many times higher than the content of salts in water, from which these alkalis and acids could be obtained. The ORP values go beyond the capabilities of chemical modeling for this electrical conductivity, which makes them unique.

Based on the results of the first stage of the study, the following conclusions were made:

1. Electrochemical reagent-free control of the properties and parameters of water allows for the oxidation or reduction of almost any substances contained in water.
2. The most economical method of electrochemical regulation of the properties and parameters of fresh water is to use flow-through electrochemical modular MB elements with diaphragms based on alumina in the alpha form.

The second stage of the study consisted in determining the principle of constructing an electrochemical system for the purification of natural fresh water, in obtaining the resulting purified water and its comparative analysis for the main chemical and microbiological indicators.

The mechanism of fresh water purification processes in nature is represented by two main processes: redox reactions and filtration. Other processes — sorption, ion exchange, coagulation, flocculation, coalescence and sedimentation are supplementary and usually occur during the filtration of purified water through soil layers, sedimentary and rock massifs. Based on this concept, and also taking into account the need to create an effective technical system for water purification, with maximum simplicity and the minimum number of elements, the concept of hardware design of the purification process included the following stages: 1) oxidation and disinfection; 2) filtration; 3) recovery, coagulation; 4) filtration; 5) additional oxidation, water protection; 6) filtration. This concept is graphically presented in Fig. 6.2.7.

The constructive and technological solutions based on the concepts of modeling the main natural processes of water purification were developed and implemented in the EMERALD — UNIVERSAL devices of high productivity (from several hundred to several thousand liters per hour).

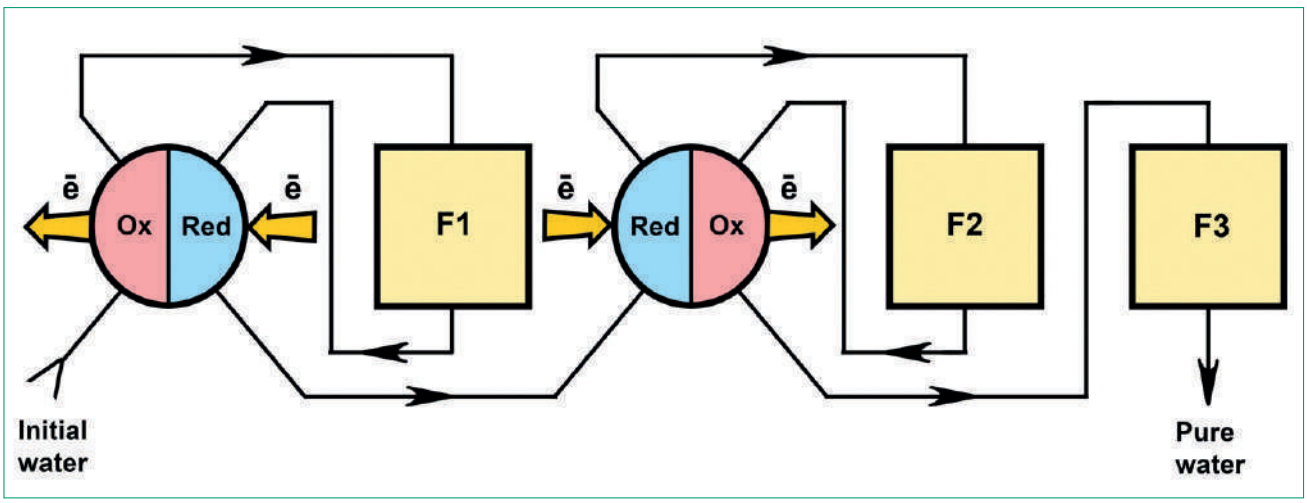

Fig. 6.2.7. *Flow chart of water purification with active electrochemical and passive filtration elements. The diagram conventionally shows the work of active electrochemical elements, which consists in removing electrons from water in the anode chambers and injecting them into water in the cathode chambers.*

A schematic diagram of the electrochemical water purification process shown in Fig. 6.2.8, has made it possible to take into account the main stages of treatment technology, which actually repeat the traditional schemes for purifying drinking water at water treatment plants. At the beginning of the purification process, it is necessary to

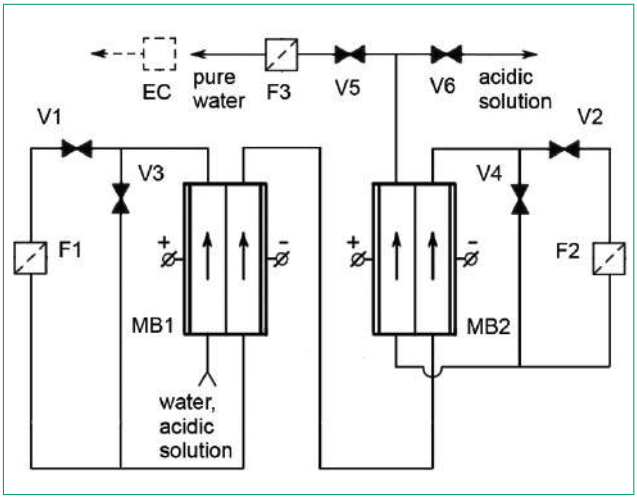

Fig. 6.2.8. *Basic hydraulic diagram of the water purification process in the EMERALD-UNIVERSAL device. Electrochemical reactors in the diagram are represented by single MB elements, but for high-capacity systems (from 100 to 1000 liters per hour), RPE reactors are used in the form of MB element blocks.*

destroy all microflora so that in the future all filter elements are completely free of biofilms. Typically, biofilms are formed in almost all filtration systems, where preliminary disinfection and protection of water by introducing chemical reagents is not performed. The primary stage of processing is realized when processing water in the anode chamber of the MB1 element. Then, after leaving the anode chamber of the MB1 element and separating the coagulated particles on the F1 filter, it is necessary to ensure that metal ions with a low pH of hydrate formation are removed from the water. This category includes almost all heavy metals, as well as iron, copper, zinc, magnesium, aluminum and some others. The process of transformation of ions of polyvalent metals into hydroxides occurs during double sequential treatment of water in the cathode chambers of elements MB-1 and MB-2. After removing the hydroxides on the F2 filter, it is necessary to protect the water once more by synthesizing oxidants in it, which is carried out by treating the water flow in the anode chamber of the MB2 element. After the flow of water through the final filter F3, the water enters the consumer network. All electrochemical transformations — cathode and anode ones in this scheme are symmetric in the specific quantity of electricity to maintain the pH of the purified water at the same level.

The device diagram, made in accordance with the accepted concept, corresponds to that shown in Fig. 6.2.8. Tests of the prototype on fresh water and saline aqueous solutions have confirmed the validity of the chosen concept of constructing a water purification system.

Fig. 6.2.9 shows a prototype of the EMERALD-UNIVERSAL-500 device mounted in a cottage and designed to study the process of purifying fresh water from a well.

Each of the two reactors of the RPE device consists of one MB-26T element. The device operates in automatic mode: it turns on when the level in the storage tank connected to the pressure boosting station drops. Replacement of filter cartridges is done manually once every two months with a water consumption of about 15 cubic meters per month.

The results of a comparative analysis of the quality of water from a well with a depth of 120 meters in the Istra district of the Moscow region are shown in Table 6.2.1. Water with a total mineralization of 0.3 g/l hydrocarbonate-sulphate-calcium-magnesium from sediments of the Carboniferous period of the Paleocene was subjected to electrochemical treatment in the EMERALD-UNIVERSAL-500 device. The water consumption averaged 450 l/h, the pressure at the inlet to the device was 1.6 bar, the current strength was 12 amperes, the voltage was 50 volts. **The test was carried out for 6 months.**

Fig. 6.2.9. *EMERALD-UNIVERSAL-500 device as the main universal system for water purification and conditioning in a cottage. When the sensor of the lower level of purified water in the storage tank is triggered, water from the well with a constant flow rate of 500 liters per hour enters the storage tank, having previously passed all the stages of purification in the EMERALD-UNIVERSAL-500 device. When the upper level in the storage tank is reached, the EMERALD-UNIVERSAL device turns off. A pressure boosting station connected to a storage tank and connected to an in-house water distribution system provides the entire cottage with clean water at any time and in any required amount.*

The initial choice of operating parameters was carried out on the basis of practical assessments of the water purification efficiency. We used an express method for assessing the water treatment quality by monitoring the rate of change in the color of the filter, through which the water flowed at a constant flow rate after passing one of the stages of electrochemical treatment; the water initially contained iron and/or manganese ions. The faster the color of the filter changed, the better the cleaning, all other things being equal, that is, the more efficient the electrochemical transformations in the liquid. Typically, the color change of the filter occurs within 30–40 minutes, even when working with ordinary Moscow tap water. Control measurements of the water purification from iron efficiency were carried out by the colorimetric method with sulfosalicylic acid in accordance with GOST 4011–72. Earlier it was found that when processing fresh water in the anode chamber of the MB element, the quantity of electricity 30–40 C/l is guaranteed to destroy all microorganisms, including in the form of biofilm, and microbial toxins are destroyed. Therefore, studies of the efficiency of iron and manganese extraction from water were carried out at obviously high values of the specific quantity of electricity consumed for water treatment. It was taken into account that there were practically no chlorides in the water purified. Table 6.2.1 shows the results of chemical and microbiological analyzes of water before and after the EMERALD-UNIVERSAL-500 device.

Table 6.2.1

Comparative results of the analysis of the purification quality of natural fresh water from a well in the EMERALD-UNIVERSAL-500 device

Indicator Units of measurement Result of measurement	Indicator Units of measurement Result of measurement	Indicator Units of measurement Result of measurement		Indicator Units of measurement Result of measurement
		Source water Purified water	Source water Purified water	
Organoleptic indicators				
Turbidity	FTU	1.6	0	2.6
Chromaticity	degree	4.6	0	20
Smell	score	2	0	2
General indicators				
General hardness	meq/l	6.38	5.92	7
Permanganate oxidizability	mg/l	1.3	0.9	5
Total chlorine	mg/l	0.0	0.6	1.2
Residual free chlorine	mg/l	0.0	0.5	0.5
Dry residue	mg/l	321	295	1000
Specific electrical conductivity	μS/cm	630	650	–
Total alkalinity	mmol-eq/l	6.1	6.2	–
Free alkalinity	mmol-eq/l	0.0		–
Cations				
Iron	mg/l	3.1	0	0.3
Strontium	mg/l	0.8	0	7
Manganese	mg/l	0.04	0	1
Calcium	mg/l	92.0	90.8	25–130
Magnesium	mg/l	25.6	22.5	5–65
Silicon	mg/l	6.5	6.4	10
Anions				
Hydrocarbonates	mg/l	370	380	–
Carbonates	mg/l	5.0	6.0	–
Fluorides	mg/l	0.4	0.5	1.5
Chlorides	mg/l	2.0	3.0	350
Nitrates	mg/l	4.3	4.5	45
Sulphates	mg/l	10.1	11.2	500
Microbiological indicators				
Total microbial count (TMC)	CFU/ml	450	0	50
Common coliform bacteria (CGB coliforms)	The number of bacteria in 100 cm^3	Found	Not found	0
Thermotolerant coliform bacteria	The number of bacteria in 100 cm^3	Found	Not found	0

In the EMERALD-UNIVERSAL device, the following processes are carried out sequentially: water treatment in the anode chamber of the first electrochemical reactor with subsequent filtration, water treatment after passing the first filter sequentially in two cathode chambers (in the first and second electrochemical reactors) with subsequent filtration, water treatment after passing the second filter in the anode chamber of the second reactor, followed by filtration. Analysis of the sediment from each of the three filters (Fig. 6.2.10) of the EMERALD-UNIVERSAL experimental device has made it possible to construct an approximate chemical flow chart of the processes that occur in a device with four active and three passive purification stages.

Fig. 6.2.10. *Appearance of ten-micron filters of the EMERALD-UNIVERSAL-500 experimental device after 4 hours of operation on fresh artesian water with a content of ferrous iron ions of about 3 mg/l. From left to right, filters numbered F1, F2, and F3 shown in Fig. 6.2.7 and 6.2.8.*

Water first enters the anode chamber of the flow-through diaphragm electrochemical reactor, represented by the MB-26T electrochemical modular cell (designation MB1 in the diagram, Fig. 6.2.8). The pressure in the anode chamber MB1 is higher than in the cathode chamber. Under the action of the flowing electric current, electromigration removal of a part of metal cations from water takes place through an ultrafiltration diaphragm into the cathode chamber.

The first active stage of water purification is the primary anode electrochemical treatment:

$2H_2O - 4e \rightarrow 4H^+ + O_2$; $O_2 + H_2O - 2e \rightarrow O_3 + 2\,H^+$;

$2H_2O - 2e \rightarrow 2H^+ + H_2O_2$;

$3H_2O - 6e \rightarrow O_3 + 6H^+$; $H_2O - 2e \rightarrow 2H^+ + O^{\bullet}$;

$H_2O - e \rightarrow H^+ + OH^{\bullet}$;

$Cl^- + H_2O - 2e \rightarrow HClO + H^+$; $Cl^- + 2H_2O - 5e \rightarrow ClO_2 + 4H^+$;

$2SO_4^{2-} - 2e \rightarrow S_2O_8^{2-}$;

$2FeSO_4 + H_2SO_4 - 2e \rightarrow Fe_2(SO_4)_3 + 2H^+$; $Fe^{2+} - e \rightarrow Fe^{3+}$.

Natural fresh water also almost always contains carbonic acid and its salts. Most of the carbon dioxide is present in the form of a free molecularly dissolved CO_2 gas and bicarbonate ions HCO_3^-. When treating water in the anode chamber, the water is enriched with free carbon dioxide as a result of reactions:

$Ca(HCO_3)_2 + 2H^+ + 2SO_4^{2-} - 2e \rightarrow CaSO_4 + 2H_2O + 2CO_2$;

$Ca(HCO_3)_2 + 2H^+ + 2Cl^- - 2e \rightarrow CaCl_2 + 2H_2O + 2CO_2$;

$Mg(HCO_3)_2 + 2H^+ + 2SO_4^{2-} - 2e \rightarrow MgSO_4 + 2H_2O + 2CO_2$;

$Mg(HCO_3)_2 + 2H^+ + 2Cl^- - 2e \rightarrow MgCl_2 + 2H_2O + 2CO_2$.

With traditional methods of removing ferrous iron and manganese ions, aeration (oxidation by air sparging) is most often used; chlorine, ozone, and potassium permanganate are also used as oxidants in the process of mechanical filtration of water on sandy or anthracite loads. However, the efficiency of these technologies is low, since the process of oxidation and formation of flakes takes quite long.

In the anode chamber of the MB element, the oxidation process is almost instant due to its combined properties of a perfect mixing and a plug-flow reactor. Also, the anode chamber destroys microbial microflora of all types and forms, microbial toxins, other organic compounds, including herbicides, pesticides, pharmaceuticals. The destruction of living and inanimate organic matter occurs as a result of oxidation by the products of anode electrochemical reactions, as well as due to direct oxidation in the double electric layer (DEL) at the anode surface. The process of direct oxidative destruction of organic compounds embraces a significant part of the flowing water volume due to the special nature of the flow of water in the gap between the coaxially located cylindrical electrode (anode) and the diaphragm. The superposition of hydrodynamic and electrostatic interaction in the moving core of the flow between the electrically charged electrode surface generating microbubbles of gases (ozone, oxygen) and the electrically charged surface of the ceramic ultrafiltration diaphragm (due to the adsorption layer of electrically active particles formed as a result of processes on the electrode) forms the flow structure in the form of a lot of microtoroidal jets interacting with the main flow core and translationally moving in the annular gap in the electrode chamber.

Thus, in the operating MB element, with the flow of an electric current and the corresponding flow rate of water, which during its stay in the anode chamber and after leaving it is collectively referred to as anolyte, the anode chamber turns into a double-acting reactor: a perfect mixing and, at the same time, a plug-flow one. Similar processes

of transformation of the electrode chamber into a perfect mixing and a plug-flow reactor also take place in the cathode chamber of each of the MB elements when the current flows with the release of hydrogen on the cathode surface and the corresponding water flow rate, also generally referred to as catholytes in the annular gap in the electrode chamber.

Compounds of divalent manganese in the anode chamber are converted into tetravalent ones, those of ferrous iron — into trivalent ones.

If the pH of the initial water was about 7, then after the first stage of anode treatment, the pH of the water decreases by about 1.0 pH unit.

All insoluble compounds — coagulated organic compounds, iron and manganese oxides — are retained by the F1 filter, which performs the function of the first passive stage of water purification.

The second active stage of water purification is cathode electrochemical treatment in the first reactor.

$2H_2O + 2e \rightarrow H_2 + 2OH^-$; $O_2 + e \rightarrow O_2^-$; $O_2 + H_2O + 2e \rightarrow$
$\rightarrow HO_2^- + OH^-$;
$Fe(OH)_2 + 2H^+ + 2e \rightarrow Fe + 2H_2O$; $Fe(OH)_2 + 2e \rightarrow Fe + 2OH^-$;
$FeCO_3 + 2e \rightarrow Fe + CO_3^{2-}$;

As a result of the cathode treatment of water in the first MB element, the pH of the water at the outlet reaches the values 7.5 ÷ 8.2.

The third active stage of water purification is secondary cathode electrochemical treatment.

$e_{cathode} + H_2O \rightarrow e_{aq}$; $H^+ + e_{aq} \rightarrow H^{\bullet}$; $H_2O + e_{aq} \rightarrow H^{\bullet} + OH^-$;
$HO_2^- + H_2O + e \rightarrow HO^{\bullet} + 2OH^-$; $O_2 + 2H^+ + 2e \rightarrow H_2O_2$;
$Fe^{2+} + 2e \rightarrow Fe$;

After leaving the cathode chamber of the second MB element, the water acquires a pH within about 9.

Ions of heavy metals, as well as of iron, copper, zinc, aluminum are converted into insoluble hydroxides and separated on the F2 filter (the second passive stage of water purification). The water is saturated with hydrogen and becomes suitable for the introduction of the last portion of oxidants in the anode chamber of the MB2 element.

The fourth active stage of water purification is secondary anode electrochemical treatment.

$OH^- - e \rightarrow HO^{\bullet}$; $O_2 + 2OH^- - 3e \rightarrow O_3 + H_2O$; $3OH^- - 2e \rightarrow$
$\rightarrow HO_2^- + H_2O$;
$H_2O_2 - e \rightarrow HO_2^{\bullet} + H^+$; $H_2O - e \rightarrow HO^{\bullet} + H^+$; $H_2O_2 - e \rightarrow$
$\rightarrow HO_2^{\bullet} + H^+$;
$Cl^- + 4OH^- - 5e \rightarrow ClO_2 + 2H_2O$;

Organic manganese and iron:

$Fe(OH)_2 + OH^- - e \rightarrow Fe(OH)_3$; $2Fe(OH)_2 - 2e \rightarrow Fe_2O_3 +$
$+ H_2O + H^+$;
$Mn^{2+} + 3H_2O - 2e \rightarrow Mn_2O_3 + 6H^+$; $Fe(OH)_2 + H_2O - e \rightarrow$
$\rightarrow Fe(OH)_3 + H^+$;
$Mn^{2+} + 2H_2O - 2e \rightarrow MnO_2 + 4H^+$.

In the anode chamber of MB2 element, organic ferrous iron and manganese are oxidized, additional oxidation with simultaneous enlargement of particles of all those impurities that have passed the previous stages. The coagulated particles are separated on the F3 filter, which is the third passive stage of water purification.

Comparison of the parameters of starting and purified water obtained during test studies (Table 6.2.1), which are benchmarks for assessing the effectiveness of technology and technical system, indicates the promising and high efficiency of water purification technology in electrochemical systems such as EMERALD-UNIVERSAL.

Fresh water is a poor conductor of electricity, which is due to the low concentration of charged particles — ions that have formed during the dissolution of various salts representing the mineral composition of water. Fig. 6.2.11 shows a generalized dependence of the electrical conductivity of water depending on the concentration of dissolved electrolytes, including not only various salts, but also the corresponding acids and bases. Fresh drinking water in most cases has a specific electrical conductivity in the range of 0.0001–0.001 S/cm, that is, about a thousand times less than electrolyte solutions in traditional electrochemical production. That is why, until the end of the eighties, it was believed that electrolysis of fresh, and even more so distilled water, was impossible.

Another factor hindering the development of electrochemical technologies for fresh and brackish waters is the complexity of the instrumentation of the process. During the operation of any electrochemical system on a dilute solution of a mixture of various electrolytes with a spontaneously changing chemical composition, constant and often unpredictable changes in the conditions of electrochemical action occur, associated with the formation of precipitation, the release of corrosive gases that damage structural elements, chemically active electrolysis products that react with the initial substances with the formation of solid particles and non-conductive films. Blocking of electrodes and a diaphragm with hardly dissolving inorganic and organic products of physicochemical reactions in electrode chambers is very often observed. Traditionally, these difficulties are eliminated either by using initial solutions with a strictly defined chemical composition, free from interfering impurities (production of hydrogen, oxygen, chlorine and alkalis, galvanic production), or by creating rough, massive and low maintenance structures (refining of non-ferrous and precious metals, obtaining non-ferrous metals from ores).

In both cases, water is used, but either in the form of an extremely purified concentrated solution of electrolytes of a strictly constant composition, or an unpurified, but also concentrated solution of electrolytes.

The advent of flow-through electrochemical modular FEM (MB) elements has made it possible to carry out water purification processes in a flow-through mode, at low power consumption, by direct only oxidizing processes in the anode chamber or only reducing processes in the cathode chamber, which, moreover, can be separated in time and space. For example, a portion of water subjected to anode electrochemical treatment in a diaphragm electrochemical reactor can be sent to a pressure flotation reactor to remove particles adhered to oxygen bubbles, then to a pressure filter to remove the residual amount of coagulated oxidized particles of organic compounds, after which this portion of water can be subjected to cathode treatment in the same reactor with subsequent treatments in auxiliary elements of the system. Thus, each portion of water in a continuous flow in the system from pressure diaphragm electrochemical reactors (active elements of the system) and intermediate auxiliary passive elements (flotation and catalytic reactors, filters) appears at different times in the same active element (electrochemical reactor), but in another electrode chamber with directly opposite direction of energy and mass transfer.

The use of filters with automatic purification, for example, by backwashing, will save the user from the need to buy replacement cartridges and eliminate the need for manual cartridge replacement. Cleaning of the device will be limited only to periodic automatic removal of sediment from filters and periodic flushing (also automatic) of all chambers of electrochemical cells with citric or weak hydrochloric acid. In order for the acid to accumulate in the filters during flushing of the electrode chambers, bypasses are provided with manual (as in the diagram shown in Fig.6.2.8) or automatic (using solenoid valves) switching the hydraulic circuit from the operating mode of water purification to the mode rinsing the electrode chambers and back to the operating water purification mode.

The research results have confirmed the correctness of the choice of the new concept of EMERALD water treatment systems in comparison with the previously created technical solutions [1, 6]. The new concept is enriched by the requirement for the mandatory thorough removal of colloidal dispersed products of anode oxidation and cathode reduction from water by filtration before the start of the next active (electrochemical) stage of water treatment, as well as after the end of the last active stage of water preparation. The processes for removing the colloidal dispersed phase from water can be different in nature. Filtering is the simplest and most accessible technique. However, flotation, sedimentation, sorption in pressure reactors can also be used.

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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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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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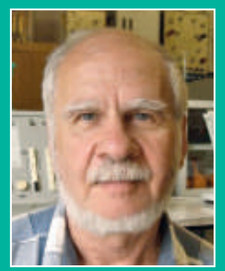

VLADIMIR PRILUTSKY — Ph. D., Scientific Consultant at Electrochemical Systems and Technologies Institute, expert in medical sciences, the author of 20 inventions, 5 monographs and more than 200 scientific articles in the field of electrochemical activation. The author of a number of new concepts on the interaction of electrochemically activated water and solutions with objects of animate and inanimate nature. His ideas have served as a basis for creating fundamentally new technological processes and technical electrochemical systems widely recognized and used in practical medicine.

VADIM PANICHEV — expert in Electrochemical Technology Applications for Regulated Industries (Pharma, Medical Devices, Biotech, etc.), working over the past 25 years in Electrochemical Equipment Design and Development, Product Development and process validation for DOD, Agricultural, Medical Devices and Pharma Industries. The author of international patents for methods of manufacturing and application of electrochemically activated solutions and stabilized hypochlorous acid formulations.

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