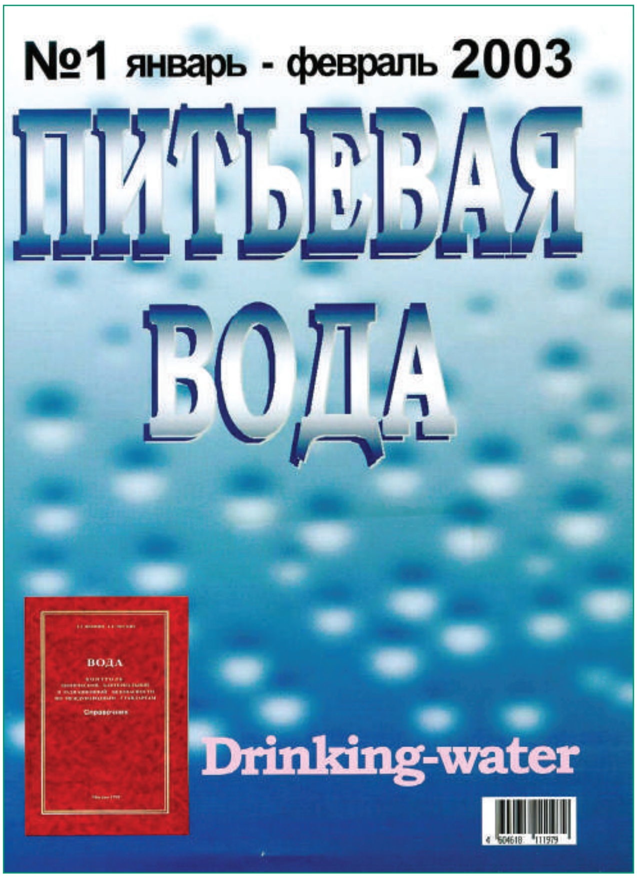
5.5. AQUACHLOR SYSTEMS: FIRST STEPS



V. M. Bakhir. ***Drinking-water, No. 1, 2003***

The main criteria for the quality of tap water formulated in the middle of the twentieth century are as follows: drinking water must be safe in terms of epidemic, harmless in chemical composition, and must also have favorable organoleptic properties. These criteria are now accepted all over the world. Based on them, various countries are creating regulations in the field of tap water quality, including in Russia — SanPiN 2.1.4.1074-01. The same criteria underlie the Guidelines for Drinking Water Quality Control published by the World Health Organization in 1984 and 1994 [1, 2].

When assessing the degree of health risk depending on the nature of undesirable impurities in water, microbiological contaminants play the most important role. Thus, the research of Dr. Robert Tardiff [3,4] (USA) has shown that the risk of diseases from microbiological water pollution is many thousand times higher (up to 100,000 times) than when water is polluted with chemical compounds of various origins.

This assessment is most clearly manifested in the existing practice of tap water disinfection in most developed countries. For example, in the United States, 98.6% of tap water is chlorinated. Ozonation makes only 0.37%, other methods — 0.75% [5]. The reason is that chlorination is the most economical and effective method of disinfecting tap water compared to any other known method. Chlorination ensures microbiological safety of water at any point in the distribution network at any time due to the aftereffect. All other methods of water disinfection, not excluding ozonation and ultraviolet light, do not provide a disinfecting aftereffect and, therefore, require chlorination at one of the stages of water treatment. This rule is no exception for Russia, where all available ozonation systems for tap water of municipal distribution networks are used together with chlorination equipment.

One of the disadvantages of water chlorination is the formation of by-products — halogenated compounds (HCC), most of which are trihalomethanes (THM): chloroform, dichlorobromomethane, dibromochloromethane and bromoform. The formation of trihalomethanes is due to the interaction of active chlorine compounds with organic substances of natural origin. The process of formation of trihalomethanes stretches in time to several tens of hours, and their number, other things being equal, is the greater, the higher the pH of the water. Therefore, the use of sodium or calcium hypochlorite for water disinfection instead of molecular chlorine does not reduce, but significantly increases the probability of the formation of trihalomethanes. The most rational method for reducing chlorination by-products is to reduce the concentration of organic substances — precursors of trihalomethanes at the stages of water purification prior to chlorination.

At present, the maximum permissible concentrations for substances that are by-products of chlorination are established in various developed countries in the range from 0.06 to 0.2 mg/l and correspond to modern scientific ideas about the degree of their health hazard. Scientific discussion about the ability of these substances to cause cancer and exhibit mutagenic activity which had lasted for many years in the United States, ended in recognition of their safety in the above concentration range [6–12]. However, undoubtedly, the decrease in the concentration of chlorination by-products, as well as ozonation by-products, which are much more hazardous (see Table 5.5.1) than chlorination by-products, is one of the main reasons for the search for new technologies and means of drinking water disinfection.

Table 5.5.1 provides information on the advantages and disadvantages of the known basic and alternative methods and technologies for water disinfection.

Analysis of these data allows us to see that among the known methods there is no perfect one, just as there is no recipe for "perfect" drinking water, despite all the importance of the effect of its composition on human health. Obviously, the composition and properties of drinking water are determined by geographic, geological, climatic, hydrological conditions and regional differences in the degree and nature of the economic development of the territory. Therefore, drinking water quality regulation in developed countries is based on reliable, scientifically grounded standards for its microbiological (priority indicator) and chemical composition from the standpoint of safety and harmlessness for humans, and determines the procedure for monitoring the quality of water supplied to the population, maximally taking into account the regional conditions of formation and composition of the source water, as well as the applied methods of water treatment and delivery to consumers.

For modern water disinfection technologies, the most important task is to find a method combining the best qualities of known disinfectants (Table 5.5.1) and eliminating their negative features.

These methods include the technology of water disinfection with a solution of oxidants produced in AQUACHLOR devices [13, 14].

In AQUACHLOR type devices, for the first time, the issues of a rational combination of the positive properties of known oxidants — chlorine, chlorine dioxide and ozone — were solved, and the negative aspects inherent in each of the above reagents separately were eliminated, that is, the formation of chlorination and ozonation by-products was excluded. AQUACHLOR devices are an alternative and safe in application source of chlorine and can be used instead of cylinders and containers with liquid chlorine at water treatment systems for domestic and drinking water supply of any capacity, at household and industrial waste water treatment systems, and in water treatment systems in swimming pools.

The principle of operation of AQUACHLOR devices consists in the electrochemical synthesis of a wet gaseous mixture of oxidants — chlorine, chlorine dioxide and ozone from an aqueous solution of sodium chloride with a concentration of 200–250 g/l under pressure in diaphragm modular electrochemical cells FEM-7, each being a separate cell of the electrochemical reactor.

The block diagram of the AQUACHLOR device is shown in Fig. 5.5.1.

The starting sodium chloride solution is dosed under pressure into the anode chambers of the electrochemical reactor. Due to the design features of the FEM-7 elements with a pressure drop across the diaphragm from 0.5 to 1.0 kgf/cm^2, the electrodiffusion selection of sodium and water ions is carried out through the ceramic diaphragm, resulting in a complete separation of the sodium chloride solution into gaseous products that are removed from the anode chamber, and a sodium hydroxide solution with a concentration of 120–150 g/l, formed in the cathode chamber. The gaseous oxidants obtained in the anode chamber, together with water microdroplets containing hydroperoxide oxidants — singlet oxygen, hydrogen peroxide and superoxide, enter the ejector mixer of the device, where they dissolve in the treated water in the range from 0.5 to 2.0 g/l (on average, about 1 gram of oxidants per 1 liter of water). In the cathode chambers of the FEM-7 electrochemical cells, in addition to sodium hydroxide solution, hydrogen is formed at the rate of 1.4 g per 100 g of gaseous oxidants. To obtain 1 kilogram of oxidants in AQUACHLOR devices, it takes no more than 1.7—2.0 kg of dry sodium chloride and about 2 kWh of electricity.

In the electrochemical reactor of AQUACHLOR devices, the main reaction is the release of molecular chlorine and the formation of sodium hydroxide:

$$NaCl + H_2O — e \rightarrow NaOH + 0,5\ H_2 + 0,5\ Cl_2$$

Simultaneously with a lower current efficiency, reactions of chlorine dioxide synthesis occur directly from a saline solution, as well as from hydrochloric acid, which is formed when molecular chlorine is dissolved in an anode medium (Cl +HO↔HClO+HCl):

$$2NaCl + 6H_2O — 10e \rightarrow 2ClO_2 + 2NaOH + 5\ H_2;$$

$$HCl + 2H_2O - 5e \rightarrow ClO_2 + 5\ H^+.$$

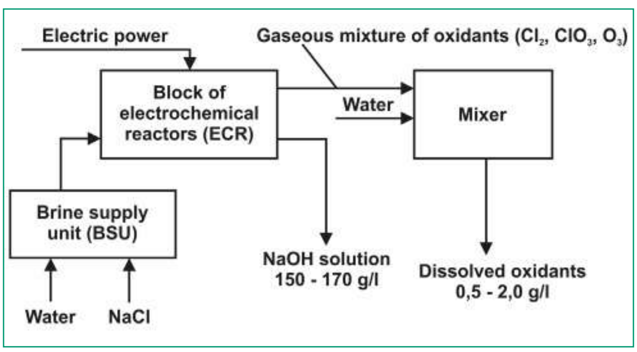


Fig. 5.5.1. *Block diagram of AQUACHLOR device.*

Table 5.5.1

Characteristics of some water disinfectants

Disinfectant name and characteristics	Advantages	Disadvantages
BASIC DISINFECTANTS		
Chlorine Used in gaseous form, requires compliance with the strictest safety measures	▪ effective oxidizer and disinfectant; ▪ effective in removing unpleasant tastes and odors; ▪ has aftereffect; ▪ prevents the growth of algae and biofouling; ▪ destroys organic compounds (phenols); ▪ oxidizes iron and manganese; ▪ destroys hydrogen sulfide, cyanides, ammonia and other nitrogen compounds	▪ increased requirements for transportation and storage; ▪ potential health risk in case of leakage; ▪ formation of disinfection by-products — trihalomethanes (THM); ▪ forms bromates and organobromine by-products of disinfection in the presence of bromides
Sodium hypochlorite Used in liquid form (commercial concentration of solutions — 10–12%), it is possible to obtain it on the site of application by electrochemical method	▪ effective against most pathogenic microorganisms; ▪ relatively safe during storage and use; ▪ when obtained on site does not require transportation and storage of hazardous chemicals	▪ ineffective against cysts (Giardia, Cryptosporidium); ▪ loses activity in case of prolonged storage; ▪ potential danger of chlorine gas release during storage; ▪ forms disinfection by-products, including trihalomethanes, such as bromoform, and bromates in the presence of bromides; ▪ when obtained on the site, requires either immediate use or, to ensure the possibility of storage, special measures for the purification of source water and salt from ions of heavy metals; ▪ when storing NaClO solutions with an active chlorine concentration of more than 450 mg/l and a pH of more than 9, the accumulation of chlorates takes place
Chlorine dioxide Obtained only at the site of use. Currently considered the most effective disinfectant among chlorine-containing reagents for water treatment at elevated pH	▪ works at reduced doses; ▪ does not form chloramines; ▪ does not cause the formation of trihalomethanes; ▪ destroys phenols — a source of unpleasant taste and odor; ▪ an effective oxidant and disinfectant for all types of microorganisms, including cysts (Giardia, Cryptosporidium) and viruses; ▪ does not form bromates and organobromine by-products of disinfection in the presence of bromides; ▪ promotes the removal of iron and manganese from water by their rapid oxidation and precipitation of oxides	▪ must be received at the place of application; ▪ requires the transportation and storage of flammable starting materials; ▪ forms chlorates and chlorites; ▪ in combination with some materials and substances leads to the development of a specific smell and taste

Disinfectant name and characteristics	Advantages	Disadvantages
Chloramine Formed by the interaction of ammonia with compounds of active chlorine, used as a disinfectant with prolonged action	▪ has a stable and long-term aftereffect; ▪ helps to remove unpleasant taste and odor; ▪ reduces the level of formation of trihalomethanes and other organochlorine disinfection by-products; ▪ prevents the formation of biofouling in distribution systems	▪ weak disinfectant and oxidizing agent in comparison with chlorine; ▪ ineffective against viruses and cysts (Giardia, Cryptosporidium); ▪ requires high dosage and prolonged contact time for disinfection; ▪ poses a danger to patients using dialyzers, since it is able to penetrate the dialyzer membrane and affect erythrocytes; ▪ forms nitrogen-containing by-products
ALTERNATIVE DISINFECTANTS		
Ozone Used for several decades in some European countries for disinfection, color removal, taste improvement and odor elimination	▪ strong disinfectant and oxidizing agent; ▪ very effective against viruses; ▪ most effective against Giardia, Cryptosporidium, as well as any other pathogenic microflora; ▪ helps to remove turbidity from water; ▪ removes foreign tastes and odors; ▪ does not form chlorine-containing trihalomethanes	▪ forms by-products, including: aldehydes, ketones, organic acids, bromine-containing trihalomethanes (including bromoform), bromates (in the presence of bromides), peroxides, bromoacetic acid; ▪ requires using biologically active filters to remove the formed by-products; ▪ does not provide residual disinfecting effect; ▪ requires high initial equipment costs; ▪ significant costs for training operators and maintenance of devices; ▪ ozone, reacting with complex organic compounds, breaks them down into fragments, which are a nutrient medium for microorganisms in water distribution systems
Ultraviolet The process consists in irradiating water with ultraviolet light, which can kill various types of microorganisms.	▪ does not require storage and transportation of chemicals; ▪ does not form by-products; ▪ effective against cysts (Giardia, Cryptosporidium)	▪ no aftereffect; ▪ requires large expenditures for equipment and maintenance; ▪ requires high operating (energy) costs; ▪ disinfecting activity depends on the turbidity of the water, its hardness (formation of deposits on the lamp surface), the deposition of organic contaminants on the lamp surface, as well as fluctuations in the electrical network that affect the change in wavelength; ▪ no possibility of operational control of the efficiency of water disinfection

In addition, ozone is formed in the anode chamber due to the direct decomposition of water and due to the oxidation of the released oxygen:

$$3H_2O - 6e \rightarrow O_3 + 6H^+;$$

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

With a very low current efficiency, the reactions of the formation of active oxygen compounds take place:

$$H_2O - 2e \rightarrow 2H^+ + O^\bullet;\ H_2O - e \rightarrow HO^\bullet + H+;$$

$$2H_2O - 3e \rightarrow HO_2 + 3H^+.$$

Unlike traditional technologies for the production of chlorine — mercury, diaphragm electrolysis and electrolysis with an ion-exchange membrane, the technology for obtaining a gaseous mixture of oxidants in the AQUACHLOR system does not require acidification of the starting sodium chloride solution, does not require additional consumption of water and chemical reagents, and allows the separation of the chloride solution into necessary products in one cycle of processing in an electrochemical reactor, that is, it is fundamentally new.

The main target end product of AQUACHLOR devices is an aqueous 0.1% solution of a mixture of oxidants (chlorine, chlorine dioxide, ozone), intended for disinfection of household and drinking water, industrial and domestic waste water and water of swimming pools.

An aqueous solution of oxidants is a colorless transparent liquid with $pH = 2.5 \pm 0.5$, with the smell of chlorine. The gaseous mixture of oxidants synthesized in the AQUACHLOR device consists of molecular chlorine (90–95%), chlorine dioxide (3–7%) and a small amount of ozone (0.5–3.0%). Also, the gaseous mixture of oxidants contains 0.5–1.5% of an extremely active oxidant — singlet oxygen and microdroplets of moisture with hydroperoxide and chlorine-oxygen oxidants — products of electrochemical reactions in the anode chamber operating at elevated pressure under conditions of ion-selective electrodiffusion selection of sodium ions from the initial solution sodium chloride through the ceramic diaphragm of electrochemical modular cells.

Accordingly, the main active antimicrobial substances in the solution of oxidants are hypochlorous acid, which is formed in the process of interaction of chlorine with water during its dissolution, as well as dissolved chlorine and chlorine dioxide. These substances make up more than 98% of all oxidants contained in the solution with a total concentration of 1 g/l. The advantages and disadvantages of the oxidant solution produced by AQUACHLOR devices are presented in Table 5.5.2.

The performance of the AQUACHLOR device is regulated by changing the current strength. There is a possibility of instant stopping of the process and its instant start.

AQUACHLOR devices have a certificate of conformity of the Russian Federation, and the solution of oxidants they produce has a sanitary and epidemiological conclusion of the State Sanitary and Epidemiological Supervision of the Russian Federation. The use of a solution of oxidants produced by AQUACHLOR devices for the disinfection of drinking water supply, domestic and industrial waste water and swimming pool water is regulated by the Instruction approved by the State Sanitary and Epidemiological Supervision of the Russian Federation. AQUACHLOR devices are serially produced in two main modifications: AQUACHLOR-100 and AQUACHLOR-500 with a capacity of 100 and 500 grams of oxidants per hour, respectively (TU 3614-702-05834388-02, OKP 361469). The block of electrochemical cells of the AQUACHLOR-500 device is made in the form of a module, which makes it possible to achieve any required productivity in terms of oxidants by combining these modules into a unified hydraulic system.

The productivity of the AQUACHLOR-100 and AQUACHLOR-500 devices in terms of oxidant solution is 100 and 500 liters per hour, respectively.

Safe operation of AQUACHLOR devices and absence of the risk of poisoning of the operating personnel and the environment by uncontrolled release of chlorine are guaranteed by a small volume of gaseous oxidants (less than 200 ml), which, under low pressure (about 1 kgf/cm^2) during the device operation, flow through the pipeline inside the device through a gas pressure regulator and enter the ejector mixer, where they dissolve in a small volume of treated water, thus turning into an analogue of chlorine water.

Thus, to summarize the available comparative data, the chlorination technology using AQUACHLOR devices has obvious advantages in terms of occupational safety and health, environmental safety and cost-effectiveness of this method of water disinfection and minimization of the amount of associated risks.

The solution of oxidants obtained in AQUACHLOR devices is mixed with disinfected water in a proportion that provides the initial specified level of oxidants content in accordance with the technology of water treatment with free (gaseous or liquid) chlorine. In this case, hydroperoxide compounds, ozone and chlorine dioxide interact with substances contained in the water, and decompose within

Table 5.5.2

Characteristics of a new alternative water disinfectant — a solution of oxidants from an AQUACHLOR device

Disinfectant name and characteristics	Advantages	Disadvantages
A solution of oxidants from an AQUACHLOR device Electrochemical synthesis from a sodium chloride solution of a moist gaseous mixture of oxidants — chlorine, chlorine dioxide, ozone, hydroperoxide compounds	▪ works at reduced doses; ▪ does not form chloramines; ▪ does not cause the formation of trihalomethanes; ▪ destroys phenols — a source of unpleasant taste and odor; ▪ effective oxidizer and disinfectant for all types of microorganisms, including cysts (Giardia, Cryptosporidium) and viruses; ▪ does not form bromates and organobromine disinfection by-products in the presence of bromides; ▪ promotes removal of iron and manganese from water through their rapid oxidation and precipitation of oxides; ▪ helps to remove turbidity from water; ▪ removes foreign tastes and odors; ▪ does not require transportation and storage of hazardous chemicals.	▪ requires electricity, pressure line for water supply; ▪ requires a small consumption of hydrochloric acid to clean the electrodes when using low quality salt (with a high content of calcium, magnesium and iron ions), or a system of chemical, for example, by sodium bicarbonate, softening of the starting sodium chloride solution.

the first 5–10 minutes. Hypochlorous acid (HClO) is the main disinfectant in water that ensures the aftereffect of the oxidant solution, the presence of which guarantees the disinfection of water in full accordance with the known technological processes of using liquid or gaseous chlorine. The presence of ozone oxidants and hydroperoxide compounds in the solution ensures the absence of chlorination and ozonation by-products, which has been confirmed by a number of experimental studies during the practical operation of AQUACHLOR devices at tap water treatment systems, as well as at wastewater treatment systems.

It is advisable to use a solution of sodium hydroxide (caustic soda) for the preparation of solutions of coagulants, and also as an effective detergent (dilution is required).

The concentration of oxidants in the solution produced by AQUACHLOR devices should be determined by standard methods used in water chlorination technology.

The amount of oxidants produced by AQUACHLOR devices can also be determined by calculation based on the direct relationship between the effective current flowing through the electrochemical cells of the AQUACHLOR device and the amount of oxidants formed.

It is recommended to install and operate AQUACHLOR devices in a standard chlorination room or in any other ventilated room. Their overall dimensions in chlorine capacity equivalent are comparable to those occupied by tanks for storing liquid chlorine. The hydrogen generated during the preparation of a solution of oxidants is removed through a special pipeline outside the premises for dispersion in the atmosphere.

Disinfection of household drinking water with a solution of oxidants produced by AQUACHLOR devices is carried out in accordance with the requirements of SanPiN 2.1.4.1074-01.

If it is necessary to combat biological fouling in the water supply network, the injection sites and doses of chlorine are coordinated with the sanitary and epidemiological services. At the stage of controlled operation of specific water supply systems to the consumer, the dose of chlorine supplied to the distribution system is produced to grant the final technological effect: disinfection of water to the norm in accordance with the requirements of SanPiN 2.1.4.1074-01.)

REFERENCES

1. *Guidelines for Drinking Water Quality Control. V. 1–3. Hygiene criteria and other relevant information. — WHO. — Geneva, 1984–1987. Руководство по контролю качества питьевой воды. Т. 1–3. Гигиенические критерии и другая релевантная информация. — ВОЗ. — Женева, 1984–1987.*
2. *Guidelines for Drinking Water Quality Control. V. 1. Recommendations. — WHO. — Geneva, 1994. — 255 p. Руководство по контролю качества питьевой воды. Т. 1. Рекомендации. — ВОЗ. — Женева, 1994. — 255 с.*
3. *Tardiff, R. G. 1993. Balancing Risks from Chemical Carcinogens at Waterborne Infectious Microbes: A Conceptual Framework. Report prepared for EPA Advisory Committee to Negotiate the Disinfection By-products Rule.*
4. *American Water Works Association Journal. September 1992. Survey of Water Utility Disinfection Practices. Water Quality Disinfection Committee Report, p. 121–128.*
5. *Epstein, S.S. Understanding the Cause of Aging and Cancer.//Cancer Research, 34, 2425–2435 (Oct. 1974)*
6. *Ames, B. N., Gold, L. S., and Willett, W.C. The Causes and Prevention of Cancer//J. American Medical Association, Special Issue on Cancer, 1995.*
7. *Ames, B. N., Profet, M., and Gold, L.S. Nature's Chemical and Synthetic Chemicals: Comparative Toxicology.//Proc. Natl. Acad. Sci USA, 87, 7782–7786 (Oct. 1990)*
8. *U.S. Environmental Protection Agency. 1991. Status Report on Development of Regulations for Disinfectants and Disinfection By-Products.*
10. *U.S. Environmental Protection Agency. June 1996. National Drinking Water Program Redirection Strategy. EPA-810-R-96–003.*
11. *Faust, S. D., Aly, O.M. Chemistry of water treatment», 2nd Edition, Lewis Publishers, L., NY, W.D. C., 1998, p.582*
12. *Geo, Clifford White. Handbook of chlorination and alternative disinfectants», Fourth Edition, A Wiley-Interscience Publication*
13. *Bakhir V.M. Modern Electrochemical Systems for Water Disinfection, Purification and Activation. — M.: VNIIIMT, 1999. — 84 p; — ill. Бахир В.М. Современные технические электрохимические системы для обеззараживания, очистки и активирования воды. — М.: ВНИИИМТ, 1999. — 84 с; — ил.*
14. *Bakhir V.M., Zadorozhny Yu. G., Leonov B.I., Panicheva S.A., Prilutsky V.I. Electrochemical Activation: Water Purification and Production of Functional Solutions. — M.: VNIIIMT, 2001. — 176 p.; — ill. Бахир В.М., Задорожний Ю.Г., Леонов Б.И., Паничева С.А., Прилуцкий В.И. Электрохимическая активация: очистка воды и получение полезных растворов. — М.: ВНИИИМТ, 2001. — 176 с.; — ил.*

УДК 544.6+625.35
ББК 24.57
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.

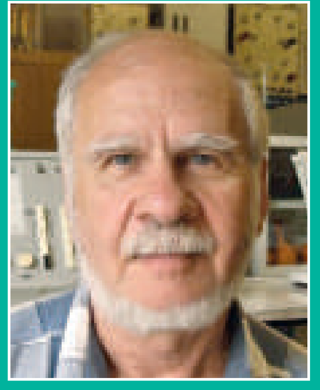
Based on the experience of engineering and practical use of electrochemical systems for production environmentally friendly, safe for humans and animals electrochemically activated detergents, disinfectants and for production of the environmentally friendly sterilizing solutions, the authors predict 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.

ISBN 978-5-6047707-0-2

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.

SVETLANA PANICHEVA — Ph. D., expert in medical electrochemical solutions, experienced in electrochemical medical devices, investigational new drug applications and food safety products development, creation of cGMP manufacturing for stabilized electrochemically activated hypochlorous acid formulations, preparing FDA submissions for topical drug products, validation, and manufacturing. The author of more than 50 international patents and more than 100 publications.



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.

ISBN 978-5-6047707-0-2

9 785604 770702

ELECTROCHEMICAL ACTIVATION

BAKHIR V. M.
PANICHEVA S. A.
PRILUTSKY V. I.
PANICHEV V. G.

ELECTROCHEMICAL ACTIVATION

INVENTIONS SYSTEMS TECHNOLOGY

Vitold Bakhir Institute