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# NEW “GREEN” WATER PURIFICATION TECHNOLOGIES: COMBINED FILTRATION SYSTEMS USING HIGHER AQUATIC PLANTS WITH DEEP ELECTROCHEMICAL PURIFICATION AND OXIDATION WITH CHLORINE DIOXIDE

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This study presents an innovative «green» water purification technology that combines electrochemical oxidation and biological treatment methods for the effective removal of contaminants and water disinfection. A key feature of the system is the autonomous synthesis of chlorine dioxide using a diaphragm electrolyzer. Chlorine dioxide acts as a powerful oxidizing agent capable of neutralizing a wide range of pathogenic microorganisms without generating harmful by-products, which is a major limitation of traditional chlorination processes. The proposed system also incorporates higher aquatic plants for the phytoremediation of nitrogenous compounds, phosphorus, and other complex pollutants, providing a natural and sustainable approach to water treatment.

The integrated modular system includes multiple purification stages: preliminary mechanical filtration, filtration through the rhizomes of higher aquatic plants, electrochemical treatment, and a final stage of bioengineered phytodesalination. The hydroponic bioplateau filter not only purifies water but also ensures its ongoing regeneration and partial desalination by absorbing excess minerals. The entire process is autonomous, does not require chemical reagents, and is powered by renewable natural resources and solar energy.

Field experiments confirm the system’s efficiency, demonstrating up to 67% reduction in salt content and complete microbial disinfection of brackish water with a salinity of 2.5–3.5 g/dm³. These results highlight the high potential of the proposed technology for decentralized, environmentally safe, and sustainable water purification in various settings, including remote or ecologically sensitive areas. The technology represents a promising direction in the development of low-impact, energy-efficient, and reagent-free water treatment systems. *Key words:* chlorine dioxide, disinfection, «green» technology, water purification by photosynthesis, electrochemical treatment, phyto-desalination, bioplato-filter.

**Нові «зелені» технології очищення води: комбіновані системи фільтрації з використанням вищих водних рослин з глибоким електрохімічним очищенням та окисленням діоксидом хлору. Бондар О.І., Курилюк О.М., Филипчук В.Л.**

У статті представлено інноваційну «зелену» технологію очищення води, що поєднує електрохімічне окиснення та біологічну обробку для ефективного видалення забруднень та знезараження води. Основою системи є автономний синтез діоксиду хлору за допомогою діафрагмового електролізера. Діоксид хлору виступає як потужний окисник, здатний нейтралізувати широкий спектр патогенних мікроорганізмів без утворення токсичних побічних продуктів, що є суттєвою перевагою порівняно з традиційним хлоруванням. Додатково у системі використовуються вищі водяні рослини для фіторемедіації сполук азоту, фосфору та інших складних забруднювачів, забезпечуючи природний та сталий підхід до очищення води.

Інтегрована модульна система включає кілька етапів очищення: попередню механічну фільтрацію, фільтрацію через кореневища вищих водяних рослин, електрохімічну обробку та завершальний етап фітодесалінізації. Гідропонний біоплато-фільтр не лише очищує воду, а й забезпечує її постійне оновлення та часткове знесолення шляхом поглинання надлишкових мінералів. Весь процес є автономним, не потребує використання хімічних реагентів і функціонує за рахунок відновлюваних природних ресурсів та сонячної енергії.

Польові експерименти підтвердили ефективність технології: досягнуто до 67 % зменшення мінералізації та повне знезараження слабомінералізованої води з солоністю 2,5–3,5 г/дм³. Отримані результати демонструють високий потенціал запропонованої системи для децентралізованого, екологічно безпечного та сталого очищення води в різних умовах, зокрема в екологічно вразливих або віддалених районах. Технологія відкриває перспективи для створення енергоефективних, безреагентних систем водоочищення нового покоління і, безумовно, стане ефективим засобом на шляху поліпшення якості води в діяльності водногосподарського комплексу країни. *Ключові слова:* діоксид хлору, знезараження, «зелена» технологія, очищення води за допомогою фотосинтезу, електрохімічна обробка, фітодесалінізація, біоплато-фільтр.

The provision of high-quality drinking water from spring and surface sources represents a key challenge in modern water engineering, particularly under conditions of heavy pollution and heightened environmental risk. The urgency of this issue increases in areas with limited infrastructure, necessitating the use of compact, autonomous, and energy-efficient water treatment technologies [1].

A major issue in advanced treatment of natural water is the presence of persistent pollutants, including petroleum residues, nitrogen-based biogenic compounds (ammonium, nitrites), mineralized organic substances, surfactants, and microbiological contaminants. In response to these challenges, a novel water purification technology has been developed and tested, based on a modular block principle integrating filtration, electrochemical, and physicochemical processes. The system implements a multistage water treatment sequence including coagulation, oxidation, ion exchange, electrolysis, electrochemical synthesis of chlorine dioxide, and sorption using activated clinoptilolite.

A key component of the system is an autonomous electromagnetic vortex-layer apparatus (AVLA), integrated into the inlet water line. This device activates the water stream by rotating ferromagnetic elements in a magnetic field, inducing cavitation effects, elevated temperature, and increased oxidation-reduction potential (ORP). These effects promote the breakdown of organic structures, oxidation of complex impurities, and enhancement of subsequent treatment stages such as coagulation, sorption, and filtration.

The filtration module is equipped with a rotatable housing that allows for rapid discharge of spent media. Inside the housing, a composite filtration bed is arranged in three layers: quartz sand, ampholyte-containing metal shavings (aluminum-based), and natural activated clinoptilolite. Each layer fulfills a specific function: quartz sand provides mechanical filtration and water activation, the ampholyte promotes coagulation and oxidation, and clinoptilolite efficiently sorbs ionic impurities including ammonium, heavy metals, and residual coagulants.

A distinctive feature of the technology is the built-in reagent dosing system, which delivers chlorine dioxide ($ClO_2$) synthesized electrochemically in an autonomous electrolyzer with an ampholyte cathode [2], along with coagulants, directly into the interlayer space of the filtration media. This allows for localized intensification of disinfection, oxidation, and flocculation processes without the need for separate flocculators or reagent blocks.

The technology was tested on a pilot unit with a capacity of up to 130 $m^3$/day, treating quarry water containing elevated levels of nitrites (up to 2.0 mg/$dm^3$), petroleum products, organochlorine compounds, and suspended solids (turbidity over 25 mg/$dm^3$). Following treatment, nitrite concentrations were reduced to <0.03 mg/$dm^3$, with ammonium and hardness levels brought in line with national drinking water standards (DSTU 7525:2014), and complete disinfection achieved without sodium hypochlorite. Quality control was performed using photometric, titrimetric, and microbiological methods, accounting for pH, ORP, hardness, and water mineralization.

To ensure drinking water quality, a complex technology and an autonomous installation (Fig. 1, 2 and 3) were developed and tested, which allows to intensify the oxidation processes of toxic nitrites and cyanobacteria without the formation of intermediate toxic products. The installation includes a flow-non-flow type electrolyzer with an inert diaphragm, made on the basis of [2, 3, 4], with a filled cathode-ampholyte for the electrolysis of a sodium chlorite solution ($NaClO_2$). The installation is equipped with a filter with activated filtration layers of floating polystyrene (type PSVS) and granular clinoptilolite loading (zeolite from

*Fig. 1, 2, 3. Autonomous mobile pilot unit for combined filtration and electrochemical water treatment to drinking water standards* the Sokyrian quarry), as well as blocks of "finishing" ultrafiltration and leachate disinfection. The reliability and autonomy of the power supply of the block-modular water treatment plant in field conditions was ensured by an autonomous electric generator, blocked in a single complex with additional modular solar panels-power plants. Uninterrupted autonomous power supply of the electrolyzer with low-voltage direct current was provided by a portable charging station of the HBM type. When testing the technology and autonomous installation in field conditions, water for purification was taken in the summer from a canal in the area of the city of Sloviansk. It was noted that in the source water before being supplied for purification, the content of nitrites and cyanobacteria exceeded the maximum permissible values by 12-15 and 13-28 times, respectively. Water quality was studied using autonomous devices (water tester - Pool Lab 1.0 photometer), as well as in laboratory conditions. The studies established that when water was supplied for purification to the anode cell of the diaphragm electrolyzer, the intensification of the oxidation of toxic nitrites into low-toxic nitrates, as well as the oxidation of cyanobacteria, was carried out due to the complex use of electrolysis gases obtained by vacuum-ejection suction from the electrode space of the anode cell of the diaphragm electrolyzer. Electrolysis gases (chlorine dioxide and oxygen electrochemically synthesized in the anode cell) were intensively mixed with the source water in a vacuum-ejection nozzle (column), hydraulically locked with a feed pump and pneumatically locked with the above-electrode space of the anode cell.

Electrolysis gases from the anode cell contained chlorine dioxide (ClO2), as well as oxygen, the content of which was easily controlled and adjusted by changing the voltage-current characteristics of electrolysis, as well as as a result of the fact that a sodium chlorite solution (NaClO2) and source water of a given flow rate were automatically dosed into the anode cell of the electrolyzer.

As an anode electrically connected to the positive pole of a low-voltage electric current source, high-purity graphite plates were used for electrolysis. Intensification of oxidation of contaminants occurred in the flow anode cell of the diaphragm electrolyzer by gases synthesized on the surface of the graphite anode: chlorine dioxide and partially oxygen. In the electrolyzer, a stainless-steel mesh of the Kh18N9T type was used as a combined cathode, electrically connected to the negative pole of the low-voltage electric current source, as well as a metal scaly aluminum-containing silumin chip-ampholyte, which was in contact with the mesh electrode (cathode) and was placed between the mesh cathode and the inert diaphragm. As an inert diaphragm, a chlorin-type fabric was used, which was fixed on an electrically neutral frame.

The anode cell of the diaphragm electrolyzer was designed as a flow cell, and the cathode cell, which contained a combined cathode with a loose aluminum-containing ampholyte electrode, was designed as a non-flow cell. Flotation sludge with aggregated contaminants, which was formed directly in the electrolysis cells and in the supraelectrode space of the cathode and anode cells, was automatically removed into the sludge collector of the installation.

Studies in real field conditions have established that the complex oxidation of nitrites and cyanobacteria during the electrolysis of NaClO2 solution in flow-through and non-flow electrolyzers with an inert diaphragm and a filled cathode-ampholyte intensifies water treatment by eliminating unpleasant odors of petroleum product residues, mercaptans, skatole, TNT and other impurities that are present in water during water supply from open sources and catchments during the production of drinking water.

After the filtration media's service life (10–30 days) is exhausted, it can be easily removed via the rotation mechanism, and backwashing is performed through the bottom outlet. The spent media can be either disposed of or regenerated for reuse, implementing a closed-loop system that reduces operational costs and solid waste generation.

**Conclusions 1.**

1. Flotation sludge with water contaminants formed in the cathode and anode cells as a result of the action of electrolysis gases is removed to the sludge collector.

2. The combined design of the cathode makes it possible to intensify the process of chlorine dioxide synthesis in the anolyte of the anode chamber due to the fact that OH- ions synthesized in the cathode zone will defund to a lesser extent into the anode chamber and the anode chamber will provide optimal conditions for the use of H+ ions to lower the pH and synthesize chlorine dioxide in an acidic environment.

3. OH- ions in the bulk loading-ampholyte of the cathode chamber will participate in chemical reactions with bulk materials-ampholytes with amphoteric properties (a mixture of aluminum chips, aluminum scrap, and/or silumin crumbs) and to a lesser extent will participate in the neutralization of H+ ions in the anode chamber, preventing a decrease in the pH of the anolyte.

4. It should be noted that when ensuring the lower the pH values of the anolyte, the more effectively the processes of chlorine dioxide synthesis in the anode chamber of the diaphragm electrolyzer will be ensured by the method of acidification of a sodium chlorite solution (NaClO2).

5. The combined cathode design makes it possible to intensify the process of chlorine dioxide synthesis in the anolyte of the anode chamber and use the technology and water installations on an industrial scale for the oxidation of nitrites to low-toxic nitrates and the oxidation of cyanobacteria in water from surface water sources (prevention of eutrophication).

The proposed modular block filtration complex [3] enables full-scale water treatment within a single apparatus, eliminating the need for complex multicomponent systems. The absence of additional reagent blocks, flocculators, and filters, along with a high level of automation, reduces maintenance costs. The system is suitable for deployment in mobile and stationary water treatment units for military, medical, agricultural, recreational, and industrial applications.

At present, there is a trend towards the use of natural methods for water purification and conditioning using renewable natural resources, particularly by means of higher aquatic plants (HAP). Among natural water treatment systems, bioengineering facilities such as bioplato-filters are becoming increasingly widespread. They are applied for reagent-free stages of water treatment, as well as for advanced purification of domestic and industrial wastewater, natural water in water bodies and reservoirs, and polluted surface runoff, with the production of drinking-quality water. The essence of the functioning of most bioplato-filters lies in the fact that phytotreatment of water in them occurs through filtration of water through the root system of HAP, due to photosynthesis in HAP, which ensures their absorption, accumulation, oxidation, and detoxification capacities, as well as the ability to synthesize oxygen during the biological destruction of carbon dioxide (greenhouse gases).

Closed hydroponic-type bioplato-filters (CHBPF) are quite widespread, in which the root systems of HAP are fixed in loose (gravel, more often zeolite) filtration media and are constantly washed with water moving either vertically from top to bottom or from bottom to top. In this process, preliminary oxidation of impurities is carried out by environmentally friendly chlorine dioxide synthesized electrochemically, and the produced catholyte with reducing properties is used to intensify the biological purification of water by HAP.

In bioplato-filters, along with effective removal of suspended solids, organic impurities, and biogenic nitrogen and phosphorus compounds, dissolved salts are also removed from the water by HAP. Thus, when using water hyacinth (Eichhornia crassipes), in addition to the removal of organic pollutants in the biofilter (phyto-bioreactor), the removal of chlorides up to 32% and sulfates up to 43% was observed. Common reed, with a dry matter yield of 44 t/ha, can accumulate up to 419 kg/ha of potassium, 408 kg/ha of chlorides, and 450 kg/ha of sodium. At bioengineering facilities such as filtration-regeneration hydroponic-type bioplato, the purification efficiency of sulfates using higher aquatic plants reached 25–30%, and of sodium ions – up to 10–15%. The authors have obtained a patent [4] for this innovative water treatment technology at the industrial scale and have published a scientific article [5].

In order to purify brackish water from surface sources (with a total salt content of about 3.5‰), there is a need for a comprehensive water treatment technology based on the use of renewable natural resources, self-cleaning clarifier-filters, and solar energy.

Figure 4 presents the schematic diagram "green" technology of water treatment from brackish water sources with intensified oxidation of impurities using electrochemically synthesized chlorine dioxide.

As experimental data show, sulfate removal remains at a high level up to 144 hours of operation of bioplato-filter facilities and is 0.404–0.837 mg/h, then the absorption intensity decreases to 0.121–0.046 mg/h. The same is observed for chloride removal. For restoring the operation of "typical" bioplato-filters, periodic shutdown of the facilities for maintenance and restoration works is necessary, associated with washing and regeneration of the filter media and drainage, which creates stressful conditions for HAP and negatively affects further phytoremediation processes after stoppages for washing the bioplato-filters.

These drawbacks of bioplato-filters are absent when using filtration-regeneration hydroponic-type bioplato-filters (FRBHT), developed by the authors, in which automatic and continuous washing of the filter media, root systems of HAP, and drainage is provided, as well as oxidation of impurities by environmentally friendly chlorine dioxide synthesized in a diaphragm electrolyzer with an inert membrane and a complex ampholyte cathode. Washing and regeneration of the bioplato-filter is carried out by hydro-automated removal of contaminated circulation-washing waters from the filter media of the bioplato-filter through a special intermediate drainage, followed by their purification in a self-cleaning polystyrene foam filter with floating filtration media. This allows providing a self-restoring mode of operation of phytostructures bioplato-filters without creating stressful conditions for the growth of HAP on the bioplato-filters.

Thanks to the developed technology and FRBHT design using oxidation processes of water impurities by environmentally clean chlorine dioxide synthesized in the diaphragm electrolyzer with an inert membrane and

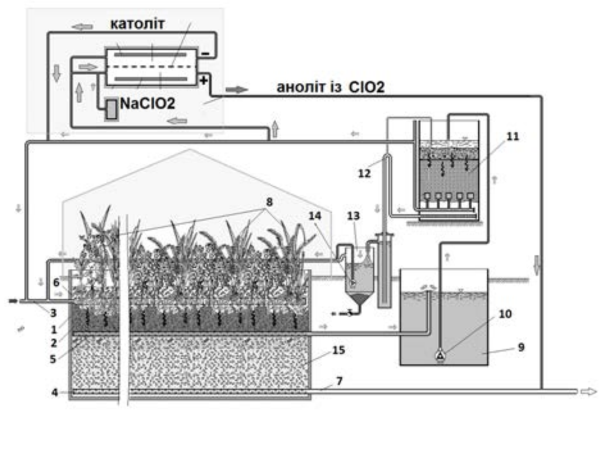


*Fig. 4. Principal scheme of water treatment from brackish water sources using higher aquatic plants for phyto-desalination of water, self-cleaning clarifier-filters with complex floating media and natural filtration granules of clinoptilolite, as well as a diaphragm electrolyzer for synthesis of chlorine dioxide and catholyte ("green" technology)*

a complex ampholyte cathode, the mode of operation of the bioplato-filter allows achieving, regardless of the concentration of organic, bacteriological, and mineral pollutants in the source water, the cyclicity of its supply for treatment, presence of service personnel, and in any climatic conditions, a higher quality and stability of water purification using higher aquatic plants and the diaphragm electrolyzer with an inert membrane and complex ampholyte cathode for chlorine dioxide synthesis.

Therefore, the use of FRBHT and diaphragm electrolyzer with an inert membrane and complex ampholyte cathode for chlorine dioxide synthesis for complex removal of contaminants and salts from mineralized water can be promising in water treatment and reagent-free and membrane-free desalination of mineralized water, particularly brackish waters with salt content of 2.5–3.5 g/dm³.

According to the technological scheme of the filtration-regeneration hydroponic-type bioplato-filter (FRBHT), phyto-desalination, oxidation of impurities, and water purification are performed in multiple stages. The main stage of desalination, oxidation of impurities, and water purification takes place directly in the bioplato-filter itself and by chlorine dioxide synthesized in the diaphragm electrolyzer with an inert membrane and a complex ampholyte cathode by means of photosynthesis processes in HAP with absorption of salts and biogenic compounds from water and their accumulation in the biomass of HAP. Thus, according to research data by Professor V. Kravets, it was established that in active phytoremediation systems using HAP, removal of sulfates and chlorides in bioplato-filters amounts to 58–35% and 67–49%, respectively, depending on the design of the bioplato-filter, season, and type of HAP. Overall removal of dissolved salts in bioplato-filters from mineralized waters can average 40–55% of the total salt content of the source water with a salt concentration of 2.5–3.5 g/dm³ (brackish waters). An additional stage of desalination of mineralized (brackish) water in the FRBHT technology is carried out by purifying the water and accompanying salt removal from circulation-regeneration waters of the bioplato-filters using chlorine dioxide synthesized in the diaphragm electrolyzer with an inert membrane and complex ampholyte cathode, as well as bioreagents and probiotics in a bioflotation reactor-clarifier and further in a polystyrene foam self-cleaning filter (floating filtration media), hydraulically connected with the bioplato-filter into a single water treatment complex. For purification and desalination (desalting) of circulation-regeneration waters, “green” coagulants, “clean” metal hydroxides (without salt “tails”), filtration materials and suspensions of natural minerals such as clinoptilolite, diatomite, brucite, tuff, bentonite, and peat, and their combinations, as well as chlorine dioxide synthesized in the diaphragm electrolyzer with an inert membrane and complex ampholyte cathode can be used.

When using aluminum hydroxychloride coagulants with sodium aluminate in combination with chlorine dioxide synthesized in the diaphragm electrolyzer with an inert membrane and complex ampholyte cathode for purification of mineralized (brackish) waters with sulfate concentrations of 500–700 mg/dm³, the degree of sulfate removal reaches 83–88%.

High sorption properties regarding dissolved salts are exhibited by magnetite, electrochemically synthesized iron and aluminum hydroxides obtained as a result of electrolysis using metallic anodes, known as the “electrocoagulation” process.

Experimental data obtained by the authors show that during electrocoagulation, the degree of chloride removal from mineralized brackish water reaches 13–15%, and sulfates – 20–31% and more due to the high sorption capacity of metal hydroxides at the moment of their formation after ionization of metallic anodes under the influence of direct electric current or internal electrolysis of metal shavings.

To intensify photosynthesis processes in HAP with ensuring constant growth of green biomass of HAP in bioplato-filters, probiotics-enzymes and activated natural suspensions based on zeolite (clinoptilolite) and other natural minerals or their complex mixtures are dosed into the aerated source water using catholyte and chlorine dioxide synthesized in the diaphragm electrolyzer with inert membrane and complex ampholyte cathode.

Activation of natural zeolite suspension can be carried out by effective microorganisms-enzymes, probiotics, as well as catholyte obtained in the cathode zone of the diaphragm electrolyzer, or by complex activation using chlorine dioxide synthesized in the anode zone of the diaphragm electrolyzer with inert membrane and complex ampholyte cathode.

Activation of the suspension provides more intensive accumulation by the root system of HAP, as well as by zeolite and other natural filtration materials and suspensions of biogenic nitrogen and phosphorus compounds and stimulates intensive growth of the root system of HAP, which promotes acceleration of photosynthesis and immobilization of salts from water by higher aquatic plants on the bioplato-filters.

The technological scheme of purification and concurrent desalination of mineralized (brackish) water in FRBGT facilities, which includes the unit for electrochemical synthesis of chlorine dioxide in a diaphragm electrolyzer with an inert membrane and complex ampholytic cathode, operates as follows. The source mineralized (brackish) water is fed via the collector (8) into the bio-plateau filter (1) and, through the upper drainage (2), is evenly distributed in the upper layer of the filter media (3), where the most active absorption zone of the root system of the HAP (12) is located and where active aeration of the water occurs.

Due to the constant contact of the HAP with the source water, active mass exchange between the water and the root system of HAP, and photosynthesis in HAP, complex biochemical processes occur in the bio-plateau filter converting organic and mineral impurities present in the water, with the biomass of the HAP absorbing dissolved salts from the water. Then, the water is filtered from top to bottom through the layers of the filter media (3, 4), collected evenly over the filtration area by the lower drainage (6), and removed for further use.

During the flow of water through the layers of the filter media in the root zone of the bio-plateau filter plants, there is a constant accumulation of a film of active sludge, microscopic algae, dead root hairs of the HAP, suspended mineral and organic impurities causing clogging (colmatation) of the filter media layers and drainages. The hydraulic resistance of the filtering layers increases, suffusion processes begin to occur, which leads to a reduction in the productivity of the facility and deterioration in the quality of the purified water.

To prevent this process, a portion of the polluted water is withdrawn from the upper filter layer of the bio-plateau filter using the middle drainage (5), ensuring constant regeneration of the upper layers of the filter media and root system of the HAP in the bio-plateau filter. Initially, the polluted circulation-regeneration waters are sent for additional purification in the bio-flotation reactor-clarifier (9), where bioreagents for coagulation and sorption of suspensions and removal of dissolved salts are also supplied, as well as compressed air for flotation of suspensions and saturation of water with oxygen and electrochemically synthesized chlorine dioxide. The formed flotation sludge and sediment are periodically removed from the reactor-clarifier (9).

Further purification of clarified water from suspensions occurs by oxidation of water impurities using the unit for electrochemical synthesis of chlorine dioxide in the diaphragm electrolyzer with inert membrane and complex ampholytic cathode, as well as on the polystyrene foam filter (10) with combined zeolite and floating filtration media. The filter media of the filter is periodically washed as it clogs in a hydro-automatic ("unmanned service") mode using a special valve-free siphon device (11) designed for self-regeneration of the filter media. The wash waters are collected in the tank (15) and then sent for treatment to the bio-flotation reactor-clarifier (9) together with the circulation-regeneration waters. If necessary, probiotic solutions, enzymes, and suspensions of effective microorganisms (EM) can be dosed into the purified circulation-regeneration waters after the polystyrene foam filter.

After purification in the bio-flotation reactor-clarifier (9) and in the self-washing polystyrene foam filter (10), the circulation-regeneration waters are mixed with the flow of source brackish water and supplied to the "head" of the bio-plateau filter (1).

Thus, circulation-regeneration waters continuously circulate during the day through the upper layer of the filter media of the bio-plateau filter (3), repeatedly washing the root system of the HAP, ensuring their constant rinsing and allowing automatic stabilization of

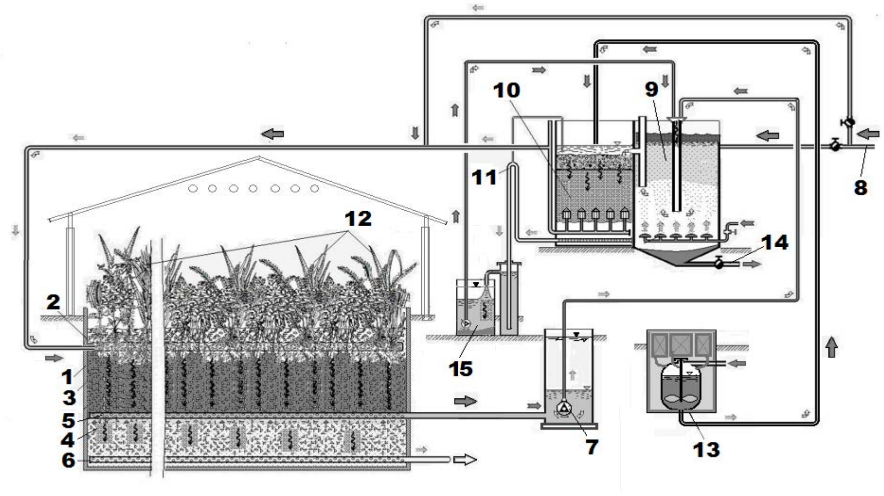


*Fig. 5. Principal scheme "green" technology of a filtration-regeneration hydroponic bio-plateau filter (FRBGT) for complex purification and desalination of mineralized waters with intensification of water treatment using chlorine dioxide synthesized electrochemically in a diaphragm electrolyzer with an ampholytic cathode.*

*1 – bio-plateau filter body, 2 – upper drainage for water supply into the bio-plateau filter, 3 – upper layer of the filter media, 4 – lower layer of the filter media, 5 – middle drainage for collection and removal of circulation-regeneration waters, 6 – lower drainage for collection and removal of purified water, 7 – circulation-regeneration water pump, 8 – collector for supplying source mineralized (brackish) water for treatment, 9 – flotation reactor-clarifier, 10 – self-washing polystyrene foam filter with floating filtration media, 11 – device for hydro-automatic washing of the filter, 12 – higher aquatic plants (HAP), 13 – reagent facility including a unit for electrochemical synthesis of chlorine dioxide in a diaphragm electrolyzer with an inert membrane and complex ampholytic cathode, 14 – sludge disposal, 15 – tank for accumulation of filter wash waters after hydro-automatic washing.*

the purification and desalination process of brackish water in the bio-plateau filter by the FRBGT technology, using electrochemically synthesized chlorine dioxide in the diaphragm electrolyzer with inert membrane and complex ampholytic cathode for oxidation of water impurities and water disinfection processes. The electrolyzer can be powered by solar power plants (autonomous unit based on solar modular power stations).

Depending on the degree of pollution and mineralization of the source water, the complex block of FRBGT facilities with higher aquatic plants can operate under some combined variants according to the specified operating modes of the purification and phyto-desalination system. With relatively high concentrations of pollutants and mineral salts, the entire flow of source water can be directly supplied to the bio-flotation reactor-clarifier (9) and the self-washing polystyrene foam filter (10) for preliminary purification and desalination before the bio-plateau filter along with circulation-regeneration waters. With relatively medium pollution concentrations, the source water flow can be divided into two streams, one directed directly to the bio-plateau filter and the other mixed with circulation-regeneration waters and purified in the reactor-clarifier and the self-washing polystyrene foam filter. The flow ratios are determined by parameters such as pollutant concentration, water supply regime for purification, requirements for quality of purified and desalinated water, design of the FRBGT bio-plateau filter, and the chlorine dioxide electrochemical synthesis unit in the diaphragm electrolyzer with inert membrane and complex ampholytic cathode.

The operation modes of the FRBGT bio-plateau filter facilities are also determined by the types of bioreagents-enzymes, activated natural suspensions, effective enzymes EM, and probiotic enzymes which will be dosed or synthesized using the reagent facility (13). This allows regulating water properties or changing them in the necessary direction for the consumer of purified water, as well as purifying and disinfecting water in any climatic conditions and on an industrial scale. In particular, with bioreagents and probiotics, especially toxic impurities (heavy metals, complex industrial organic impurities, surfactants, TNT, antibiotic residues, GMO products, medicines, pesticides, and chemical fertilizers) can be removed, and water conditioning can be performed, etc.

The FRBGT bio-plateau filter combined with the chlorine dioxide electrochemical synthesis unit in a diaphragm electrolyzer with inert membrane and complex ampholytic cathode can be part of a general comprehensive physicochemical technological water purification scheme on a large industrial scale. In this case, the bio-plateau filter can be placed at the beginning or the end of the overall technological purification scheme of polluted water. If the source water contains high concentrations of easily oxidizable organic and mineral impurities and requires deep mineralization reduction, the bio-plateau filter is preferably placed at the beginning of the technological scheme. This allows removing the main mass of organic and especially toxic mineral and organic impurities on the bio-plateau filter and reducing salt concentration, while the next stage achieves deep purification and desalination of clarified and preliminarily purified water. Placement of the bio-plateau filter combined with the chlorine dioxide electrochemical synthesis unit in the diaphragm electrolyzer with inert membrane and complex ampholytic cathode at the end of the water treatment technological scheme allows deep purification of water from organic and inorganic impurities and restoration of its natural properties due to contact with higher aquatic plants, natural suspensions, and ensures multistage disinfection of water by HAP and chlorine dioxide.

Calculations considering the existing degree of desalination of brackish water on bio-plateau filters show that individual use of the FRBGT in combination with the chlorine dioxide electrochemical synthesis unit in a diaphragm electrolyzer with inert membrane and complex ampholytic cathode can achieve overall demineralization (desalination) of brackish water with an initial salt concentration of 2500–3500 $mg/dm^3$ up to 67% with ensuring the required degree of recirculation and filtration treatment of regeneration waters.

**Conclusions 2.**

The analysis of the possibility of phyto-desalination of mineralized waters in filtration-regeneration bioplato-filters of the FRBGT type in combination with the unit of electrochemical synthesis of chlorine dioxide in a diaphragm electrolyzer with an inert membrane and a complex ampholytic cathode shows:

1. The bioplato-filter based on FRBGT technology using chlorine dioxide can be used for hydroautomated (“unmanned”) purification and concomitant membrane-free phyto-desalination of mineralized (brackish) waters under any climatic conditions. Phyto-desalination of mineralized (brackish) waters in the FRBGT is carried out by salt extraction by HAP in the bioplato-filters and treatment of circulation-regeneration waters using activated “green” coagulants, magnetite, metal hydroxides without salt “tails,” suspensions of natural minerals with additional electrochemical activation of bioreagents and EM probiotic enzymes with chlorine dioxide. Higher aquatic plants also help restore the natural properties of water by enabling biological utilization (decarbonization) of carbon dioxide from water and air and promoting oxygen synthesis.

2. The unit for treatment and purification of circulation-regeneration waters of bioplato-filters should include, as a complex, the unit of electrochemical synthesis of chlorine dioxide in a diaphragm electrolyzer with an inert membrane and a complex ampholytic cathode, as well as a bioflotation reactor-clarifier for introduction of additional bioreagents and a self-cleaning complex polystyrene foam filter-clarifier with dosing of enzymes, EM bioreagents, and probiotics into clarified water, which allows intensification of salt extraction (water desalination) by HAP of the bioplato-filter, oxidation of multicomponent impurities,

and ensures a constant increase of green biomass of HAP in the bioplato-filters, utilization of greenhouse gases (carbon dioxide, hydrogen sulfide, and methane), as well as synthesis of useful phytoaerosols.

3. Calculations show that during individual use of FRBGT, the total demineralization (desalination) of brackish water with an initial total salt concentration of 2500-3500 mg/dm³ can reach 40-60%, provided the necessary degree of recirculation of regeneration waters of the bioplato-filter and depending on the design of the FRBGT bioplato-filter in combination with the self-cleaning filter and the unit of electrochemical synthesis of chlorine dioxide in the diaphragm electrolyzer with inert membrane and complex ampholytic cathode.

4. The next stage of work and research is the modeling of water treatment processes, complex purification, and concomitant phyto-desalination of brackish water using FRBGT technology in combination with the unit of electrochemical synthesis of chlorine dioxide in a diaphragm electrolyzer with inert membrane and complex ampholytic cathode, and determination of the main parameters of functioning of the technological scheme structures depending on the degree of water recirculation, design of the FRBGT, as well as the design of the unit for electrochemical synthesis of chlorine dioxide in the diaphragm electrolyzer (Filipchuk electrolyzer) with inert membrane and complex ampholytic cathode and concentrations of contaminant components and impurities in the feed water.

5. It is necessary to continue research on defining the conditions of use of stations and block-modular installations for water treatment, complex purification, and concomitant phyto-desalination of brackish water using FRBGT technology with renewable natural resources and solar energy in combination with the unit of electrochemical synthesis of chlorine dioxide in a diaphragm electrolyzer with inert membrane and complex ampholytic cathode with integrated elements of artificial intelligence (AI) systems.

Economic analysis suggests that implementing the described system can yield annual savings of €51,000 to €150,000 at a daily output of 700–1300 m³, achieved through reduced consumption of reagents, energy, and labor resources [2–3].

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