ANALYSIS OF CHALLENGES AND PROBLEMS IN THE APPLICATION OF ELECTRODEIONISATION FOR DEMINERALIZED WATER PRODUCTION

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DOI: https://doi.org/10.20535/2218-930012025339353

The article presents an analysis of the challenges and problems that limit the widespread use of the electrodeionization method for water desalination. Nevertheless, this technology has already proven itself in the pharmaceutical industry, in the production of microelectronics and at thermal power facilities. But it also has prospects for wider application, for example, in the chemical and food industries, thermal power engineering, biotechnology, hydrogen production, etc. In combination with preliminary water treatment using the method of double stage reverse osmosis, has the potential to completely replace the use of cation and anion exchange filters for water desalination. The aim of this work is to review and analyze the fundamental principles and practical aspects of the application of electrodeionization, the design and operation of electrodeionization units, and possible approaches to improving their efficiency in order to obtain a high degree of water desalination. To this end, technological approaches to improving the design of electrodeionizers and the possibility of modifying ion-exchange resins in order to reduce energy consumption, increase selectivity and productivity, etc. are considered in detail. The main parameters of the electrodeionization process modes are determined, and the impact of modifying ion-exchange materials with water dissociation catalysts and varying the ratio of cation- and anion-exchange resins on the efficiency of the modules is assessed. The influence of the above factors on productivity, selectivity, energy consumption, continuous operation time of electrodeionization units, degree of ion exchange resin regeneration, degree of water purification, reduction of fouling of ion exchange membranes and degree of electrode corrosion has been analyzed.

***Keywords**: concentration channel, desalination, electrical resistance of water, electrodeionization, ion-exchange membrane, modification, spacer.*

Received: 9 June 2025 Revised: 5 September 2025 Accepted: 6 September 2025

1. Introduction

Obtaining high-level desalinated water is currently critical for pharmaceutical companies, microelectronics manufacturers, and critical infrastructure heat-generating facilities such as thermal power plants (TPPs) and nuclear power plants (NPPs). Barometric water desalination methods, such as reverse osmosis (RO) and nanofiltration (NF), are increasingly being used to replace outdated ion exchange technologies. However, using RO alone often makes it impossible to achieve the desired purified water quality parameters.

For example, to obtain water of the desired quality for the pharmaceutical industry, the electrical conductivity of purified water must not exceed 4.3 μS/cm

(DSTU, 2013), and for TPPs, the electrical conductivity (acidic) of water must not exceed 0.2 μS/cm (VGB, 2011).

In general, the choice of the most rational method of water desalination depends on parameters such as the water supply source, the chemical composition of the source water, the quantitative and qualitative indicators of organic and mechanical impurities and suspended solids in the water, the dimensions of the installation site, the availability of qualified service personnel and laboratories at the production site, and other factors. The main methods of water desalination are ion exchange (IE), reverse osmosis (RO), nanofiltration (NF), and electrodeionization (EDI).

IE is one of the most effective methods for removing cations and anions from aqueous solutions, widely used in technologies for obtaining high-purity water, in particular for pharmaceutical purposes and thermal power engineering (Zapolskiy, 2005), the essence of which is the exchange of ions between mobile ions of ion exchangers and corresponding ions in solution. However, in the case of water treatment at pharmaceutical enterprises, for example, for the production of parenteral dosage forms, the use of the ion exchange method is not capable of ensuring an adequate level of disinfection, therefore water purified in this way does not meet the requirements of microbiological purity and requires further purification stages. Another disadvantage of this method is the need to regenerate resins with acids and alkalis, which requires special permits, as these reagents can be used as precursors.

RO is a baromembrane process in which, under the action of external pressure exceeding osmotic pressure, the solvent passes through a semipermeable membrane from the side of the solution with high mineralization into the compartment with purified water. The driving force is the pressure difference, which causes water molecules to diffuse in the opposite direction to direct osmosis (Zmievskii, 2017).

Reverse osmosis membranes provide a high level of selectivity: they retain salts dissolved in water, inorganic and organic compounds with a molecular weight of more than 100 g/mol, colloidal particles, microorganisms and pyrogens. On average, after RO, the content of dissolved substances in the treated water is reduced to 1–9% of the initial value, organic substances — to 5%, and the content of total organic carbon is minimal. Purified water is characterized by the absence of colloids, microorganisms and pyrogens, which makes RO one of the most effective methods for preparing high-purity water. The disadvantages of the method include the need for high-quality preliminary treatment, namely the removal of mechanical impurities, residual chlorine, iron, manganese, hardness salts and suspended solids from the water in accordance with SDI (Silt Density Index), which should be no more than 5 units and which is an indicator of the rate of membrane contamination. A disadvantage of RO is the often low yield of purified water, which can vary from 90% to 20% of the initial water volume and, as a result, leads to the formation of a large amount of waste in the form of concentrate. Another disadvantage of this method is the significant energy consumption due to the use of high-pressure pumps in reverse osmosis plants (Sumit, 2020).

NF generally refers to methods of preliminary water purification and is designed to remove organic compounds with a molecular weight of 250–1000 g/mol, as well as individual ions, mainly divalent ones

(Mitchenko, 2023). That is why NF is called membrane softening. Compared to RO, this method is characterized by lower energy consumption but also lower efficiency. The main limitations for wider use are the need for frequent filter replacement, the risk of contamination and damage to membranes, and the possibility of microbiological contamination.

EDI is a type of ion exchange that combines the use of mixed layers of ion-exchange resins, ion-selective membranes, and a constant electric field for simultaneous water desalination and continuous regeneration (Dzyazko, 2004). The EDI water purification process involves the supply of pre-treated water, which is divided into three streams: through electrode channels, a purification channel and a concentration channel. The purification and concentration channels are filled with a mixture of cationites and anionites placed between cation- and anion-selective membranes.

EDI is a method that belongs to the category of deep desalination methods, as it ensures the removal of more than 99% of dissolved salts, a reduction in specific electrical conductivity by more than 15 times compared to the inlet water, and a reduction in total organic carbon content by 50–90%, depending on the composition of the source water and the efficiency of preliminary purification. During operation, dissolved CO_2 is converted into hydrocarbonate ions and removed with the concentrate stream, while dissolved SiO_2 is removed by 80–95% (Kumar, 2024).

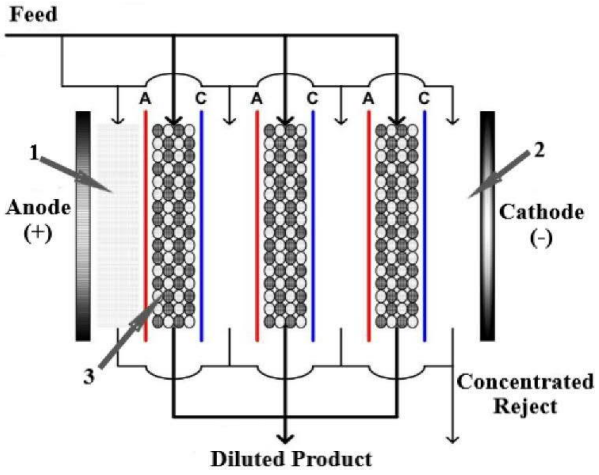
To achieve deep desalination of water using the EDI method, it is necessary to ensure the appropriate quality of water supplied to the EDI unit. Methods such as softening, deferrization, sorption and RO are usually used for preliminary water treatment before desalination at the EDI unit. This can be most successfully achieved with RO, which can significantly reduce the load on membranes and resins and extend the life of EDI units. In this case, the purified water is characterized by high purity and fully meets the requirements for water used in pharmaceutical and energy enterprises and in the production of microelectronics. Thus, provided that high-quality pre-treatment is carried out, the electrodeionization method allows water with a high degree of desalination to be obtained without using chemical reagents for the regeneration of ion-exchange resins included in EDI modules (Son, 2020).

The purpose of this scientific article is to review and analyze the fundamental principles and practical aspects of electrodeionization, the design and operation of EDI units, and possible approaches to improving their efficiency.

2. Fundamentals of the electrodeionization process

EDI is an advanced water desalination technology that combines electrodialysis and ion exchange methods, allowing for more efficient removal of ions from the aqueous environment. According to (Kumar, 2024), the electrodeionization method involves the use of ion-exchange resins and ion- selective membranes to separate cations and anions under the influence of an electric field, which allows cations and anions to pass through accordingly (Figure 1). The terminology used to describe electrodeionization processes covers the following key concepts: ion exchange resins (used as a medium for transporting ions and increasing the

conductivity of the solution); water electrolysis (the process of dissociation of water molecules with the formation of hydroxide ions (OH^-) and protons (H^+), which are involved in the regeneration of ion exchange resins); concentration polarization (a phenomenon observed at high current values, during which a zone with an increased concentration of ions can form on the surface of the membranes, which can affect the efficiency of ion transfer processes).



A – anion-exchange membrane; C – cation-exchange membrane; 1, 2 – electrode rinses; 3 – ion-exchange resin

Figure 1. *Typical configuration of the electrodeionization module (*Anil, 2002*)*

EDI, as a method of water purification, involves several key processes, the first of which is ion transport. For example, sodium (Na^+), which is soluble in water, will be exchanged for hydrogen ions (H^+) of ion-exchange resin, and chloride (Cl^-) – for hydroxide ions (OH^-). The second process is ion exchange, during which solutions pass through ion-selective membranes, causing the selective movement of cations and anions through the corresponding membranes in the direction of current flow. Another factor that affects the operation of an electrodeionizer is the pH level – hydrogen and hydroxide ions produced during the dissociation of water and interaction with ion- exchange materials play a significant role in maintaining the balance of ion exchange and can affect the chemical composition of purified water (Hegazy, 2020).

Electrochemical methods of ion separation and water purification have a number of unique features: high selectivity, reduction of secondary waste, resulting in environmental friendliness, and compact equipment. The combination of the properties of ion-exchange resins and ion-selective membranes with the advantages of electrochemical processes in EDI leads to a synergistic effect, as a result of which growth in the EDI unit market can be predicted (Yang, 2025). In the next section, we will analyze the parameters that affect the efficiency of EDI installations (Zaheen, 2023).

3. Analysis of factors affecting the efficiency of EDI units

There are several major trends in the global market for the production of electrodeionization water purification and desalination units, namely the development of EDI systems and their improvement due to the rapid growth in demand and strict quality requirements for purified water in various industries, particularly in pharmaceuticals, energy, electronics and food (Khoiruddin, 2023). For example, the use of electrodeionization units allows water with a specific electrical resistance of 18 MΩ·cm² to be obtained, with the percentage of water discharged into the sewerage system being about 10% of the total volume of water. Meanwhile, the use of reverse osmosis allows

the electrical resistance to be reduced to 0.18 MΩ·cm² (depending on the quality of the inlet water and the degree of pre- treatment of the reverse osmosis unit). In the case of mixed-bad filters (MBF), the quality of the purified water can also be 18 MΩ·cm², but acids and alkalis must be used for their regeneration, which makes them less economically attractive compared to electrodeionization units (Brian, 2005).

Despite the advantages of EDI over other methods, the global market for the production of electrodialysis units faces some challenges. Factors affecting the efficiency of electrodeionization include: applied current (affects the rate of ion removal); liquid flow rate (optimal balance between cleaning efficiency and productivity); temperature (using too high a temperature is not energy-efficient and can cause membrane damage); dissolved salt content in the source water; carbon dioxide content; quality of pre-treatment before EDI, etc (Gülseren, 2023).

An important challenge among a wide range of issues remains the high energy consumption, which, however, can be overcome by selecting rational operating conditions, for example, through modelling, improving the design of EDI installations, and modifying/functionalizing ion-exchange materials. For example, as shown in (Fengting, 2022), modelling using nonlinear programming of the electrodeionization water purification process can improve the operating conditions of an industrial EDI module, namely, increase the degree of removal of pollutant ions and reduce energy consumption. The results of these studies show that modelling operating conditions alone can reduce the energy consumption of the current industrial EDI system by 22.4%, and optimizing the design of the EDI unit can lead to a 50.4% reduction in annual costs (Paolo, 2024).

EDI units operate at relatively low operating pressures and temperatures, but the significant potential for applying the EDI method is largely determined by the ability to influence the operating conditions of the EDI module, including: spacer thickness, applied voltage, water flow rate, etc. (Khoiruddin, 2023). Researchers have shown that varying the spacer thickness – reducing it to 4 mm – allows 99% of salts to be removed from water at an applied voltage of 20 V, 75% water purification and a circulation rate of 2 cm^3/s. In addition, a smaller spacer thickness can increase the desalination rate, inhibit reverse salt diffusion and thus reduce the duration of the desalination process. The study also shows that about 60% of the electric current circulates through the solid phase – ion exchange resin, which in turn indicates the significant role of the ion exchange resins used, in particular their properties.

Scientific literature (Honarparvar, 2021) contains studies on the use of EDI for desalination of brackish water, but commercially available EDI units are currently used to obtain highly demineralized water after preliminary treatment and are not suitable for solutions with ultra-high total dissolved solids (TDS), such as seawater. However, scientists are conducting relevant research to identify technical obstacles in the process of electrodeionization of concentrated solutions and to overcome the challenges associated with this. Thus, in (Khoiruddin, 2014), the effectiveness of an EDI unit in the process of removing relatively high concentrations of inorganic substances and compounds that give solutions colour in sugar refining is considered. The existing module used cation exchange (MC-3470) and anion

exchange (MA-3475) membranes as ion-selective barriers; ion exchange resins in a mixed layer (Purolite, C- 100E, A-400); platinum and stainless steel as the anode and cathode, respectively. The internal thickness of the spacer for each compartment was 3 mm. A low-grade raw sugar solution with a colour index of about 300 ICUMSA (according to the "ICUMSA GS 2/3-9" method, DSTU 4866:2007) and the presence of NaCl in deionized water with different sugar concentrations (10–40% by mass). The degree of ion removal from solutions decreased by 6% with an increase in sugar concentration from 10% to 30% and decreased by almost 16.3% at a sugar concentration of 40%, which can be explained by a decrease in solution conductivity with an increase in viscosity. It has been determined that the influence of the technical parameters of electrodeionization on its effectiveness in purifying highly concentrated solutions has certain features and challenges, namely: the higher current density used did not increase ion removal, which can be explained by the lower efficiency of the current, and increasing the applied voltage from 36 V to 55 V also did not significantly affect ion removal. However, the absence of water colour in the concentrate stream allowed us to hypothesize that the reduction in the colour of the solutions may be associated with the breakdown of complex bonds between organic and inorganic dye molecules due to the dissociation of water in the dilution compartment. These experimental results highlight the obvious relevance and promise of EDI in the removal of pollutants of various origins from aqueous solutions, even at elevated concentrations, and the experience of using EDI units described in this work demonstrates the high efficiency of demineralization of diluted solutions, but at high ion concentrations in the solution, the so-called reverse diffusion of salts occurs (Nima, 2023).

Thus, as shown above, the industry for the production and application of electrodeionization units is growing rapidly due to the growing industrial demand for the modernization of water treatment technologies. However, there are many challenges and problems of a structural, chemical and technological nature in the operation of EDI units that need to be overcome and that require constant innovative solutions to achieve a high degree of water demineralization and additional opportunities to reduce energy and operating costs.

4. Improving the efficiency of electrodeionizers

One of the modern approaches used to optimize the operation of electrodeionizers is to plan experiments by modelling them in various programs, such as COMSOL Multiphysics (Design Expert 13 software) (Subramanian, 2022). This program runs on multiple platforms and offers an integrated development environment and a single workflow for electrical, mechanical, hydrodynamic, acoustic and chemical applications. Using the Tertiary Current Distribution model to simulate ion transport, diffusion, electromigration, and convection processes in a solution and membranes, this work constructed an equation to predict the pH value as a function of four factors: voltage (7–14 V); salt concentration in the feed water (0.01–0.05 mole/L NaCl); temperature (288–303 K); flow rate (0.5–1 L/min). The model was tested on a laboratory EDI unit with four compartments, with anion and cation

exchange membranes, a mixture of Lewatit S-100 (cation) and M-500 (anion) resins, a platinum-coated titanium anode and a stainless steel cathode. As a result, a model was developed that allowed the quality of deionized water to be predicted. It was shown that the conditions optimized using the program ensured a pH of 7.0 with an accuracy of 99.2%, and voltage proved to be the most critical factor affecting the efficiency of ion transfer. Thus, the use of the simulation program made it possible to significantly reduce the number of practical experiments without losing the accuracy of the model and without additional time spent on laboratory research (Cho, 2024).

There are also technological approaches to improving the design of electrodeionizers, which make it possible to increase the efficiency of the installations, in particular to reduce energy consumption, increase selectivity and productivity, extend the service life of the modules, increase the percentage of pure water obtained in comparison with the input flow, and improve the removal of certain components from the water (such as heavy metals), and more. These include:

1) Combining resin layers with separation of cation and anion exchange zones in EDI cells, which can improve the resin regeneration process in the cell;

2) Varying the design of the dilution compartment spacer, which can reduce energy consumption, ensure uniform water flow in the spacer and increase selectivity;

3) Using EDI units connected in series, which can increase productivity, reduce concentrate flow and energy consumption;

4) Use of ion exchange wafers inside the EDI module, which can reduce energy consumption and increase selectivity;

5) Modification of the surface of ion exchange resin with water dissociation catalysts, which improves ion balance and increases process efficiency;

6) Adding a "protective chamber" to the EDI stack, which will help prevent $Mg(OH)_2$ fouling when feeding inlet water with increased hardness.

A review of the literature shows that combining layers of different types of resins can improve some EDI performance indicators. For example, in (Xu, 2021), a new resin layer design is proposed – a combined layer in which cation and anion exchange resins are located in separate cells rather than mixed, as in typical electrodeionizers. The work shows that in electrodeionization units based on a combined resin layer, regeneration reached 73.1% at a current density of 9 mA/cm^2 in 5 hours of operation, which significantly exceeded the performance of typical electrodeionizers. In the combined resin layer, ion transfer and a decrease in concentration polarization were observed, which increased the efficiency of water purification, and due to the lower electrical resistance in it, electricity consumption was reduced compared to mixed resin layers. Electrodeionization units based on a combined resin layer also prevented the formation of $CaCO_3$ and $Mg(OH)_2$ deposits, thus extending the service life of the system. Therefore, the proposed approach allowed for the effective regeneration of ion-exchange resins inside EDI units without the use of acids/alkalis, which can be adapted for industrial water purification, even with higher hardness and conductivity, and ensure long-term continuous operation of electrodeionization without membrane contamination (Yuan, 2022).

In study (Yiqing, 2010), a comparison was made of five spacer designs, each with a different structure: without a distribution system, wafer, slotted, channel and mesh, and it was found that the structure of the distributor affects the performance of the electrodeionization process. The use of wide spacers (8– 10 mm) in a multilayer electrodeionization module increased the rate of ion removal and improved the efficiency of their transport. The channel spacer proved to be the optimal design, providing the best insulation of individual resin layers, uniform flow, and high electrochemical separation efficiency. Thus, the EDI unit design modified in this way ensured high water quality (resistance greater than 17 MΩ·cm), system productivity of 5.5×10^{-5} $m^3/(cm^2\cdot h)$ and energy consumption of less than 0.7 kWh/m^3. These results prove that innovations in spacer design play a key role in improving the efficiency of electrodeionization and can be useful for the large-scale application of this process to obtain highly demineralized water (Tse-Lun, 2025).

The main challenges for the development of electrodeionization technology also include increasing the productivity and reliability of modules and reducing the overall cost of installations. Thus, work (Anil, 2002) presents the results of improving the design of EDI units, which made it possible to use electrodeionization as the most effective method compared to mixed-bed ion exchange filters. In particular, the use of an electrodialysis system design in which several modules are connected in series, as in RO systems, has contributed to an increase in system productivity, a reduction in equipment size, a reduction in energy consumption, reduced concentrate flow, improved ion- transport efficiency, and increased the degree of removal of weakly dissociated impurities such as boron ions and silicate ions (Yong, 2025).

Productivity can also be increased by using a sequential connection of electrodeionization units in several stages, similar to reverse osmosis systems, which can significantly reduce concentrate flow costs and maintenance costs (Figure 2). The introduction of sealing rings into the design of the electrodeionization module and the use of polymer composite housings increase the durability of the modules, ensuring operation at high pressure (up to 7 bar). The proposed electrodeionization scheme has been tested for water treatment in the production of semiconductor materials. The tests showed high quality of purified water – the specific electrical resistance of purified water was over 18 MΩ·cm. The removal of boron ions reached 99.9%, silicate ions – 99.95%, and sodium ions – 99.99%. It was also proven that the electrodeionizer could maintain stable performance characteristics for six months of operation without the need for ion exchange resin regeneration. Thus, the use of a sequential scheme makes electrodeionization technology more attractive for industrial applications, particularly in the production of highly demineralized water for microelectronics and pharmaceuticals (Kumar, 2024).

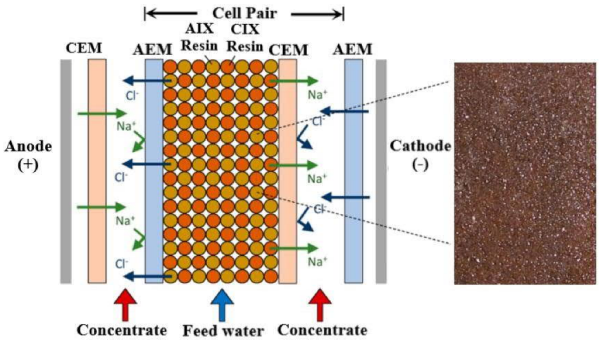
An innovative approach is presented in (Shu-Yuan, 2018), where an EDI unit using ion-exchange wafers was studied, which made it possible to reduce energy consumption and increase the efficiency of ion transport by using porous resin wafers instead of traditional granular ion-exchange resins. The manufactured ion-exchange wafers consisted of anion- and cation-

exchange resins, a polymeric binding agent, and a porogen (Kumar, 2025).

Figure 2. *System of modules connected in a line using connecting tubes (Al-Rawajfeh, 2014)*

The authors (Kumar, 2020) investigated the effect of voltage, flow rate, and processing time on the efficiency of the EDI process and analyzed energy consumption using response surface methodology (RSM). It was shown that ion-exchange wafer electrodeionization provides 35% greater energy efficiency than reverse osmosis (0.35–0.66 kWh/m³ vs. 1.2–1.5 kWh/m³, respectively), and energy consumption depends on voltage and flow rate – the optimal parameters are 1.73 V/cell and 775 cm³/min, respectively. Ion-exchange wafer electrodeionization ensured salt removal with an efficiency of over 99% within 120 minutes at a productivity of 20.1 L/hour·m² to 44.7 L/hour·m², which exceeded the performance of traditional methods. The cost of desalination was 0.35–0.45 USD/m³, which is lower than for reverse osmosis (0.42–1.20 USD/m³). Therefore, ion-exchange wafer electrodeionization is a promising alternative to reverse osmosis for water desalination, allowing for reduced energy consumption and operating costs. Optimization of voltage and flow rate is critical for balancing performance and economic feasibility (Kumar, 2021).

In (Shu-Yuan, 2017), the use of ion-exchange wafers for electrodeionization units (Figure 3) is also proposed, which allows reducing energy consumption by 35% compared to reverse osmosis units and improving water desalination efficiency.



AEM – anion-exchange membrane, CEM – cation-exchange membrane, AIX Resin and CIX Resin – resin wafer material

Figure 3. *Scheme of the resin wafer electrodeionization process (RW-EDI) (Jitendra, 2010)*

In this case, the electrodeionization unit stack with ion-exchange wafers contained cells consisting of a compartment for diluted solutions with a thickness of 3.8 mm and a compartment for concentrated solutions with a thickness of 1.5 mm (Goncagül, 2023). Cation exchange membranes ("Neosepta CMX", strong acid cation), anion exchange membranes ("Neosepta AMX", strong base cation) and bipolar membranes ("Neosepta BP", thickness 0.22 mm) were used. The resin wafers were made using a mixture of anion exchange resin beds (Purolite PFA444) cation exchange resin beds ("Purolite PFC100E") and a porous polymer binder, which was heated to 120 °C for 1 hour and cast into a mould to form a porous wafer. The authors investigated the energy efficiency of ion

exchange wafers (energy consumption: 0.354−0.657 kWh/m³), the productivity of the installation (20.1−41.3 L/year·m²) and the influence of key parameters: voltage, water consumption, NaCl concentration. Thanks to the porous structure of the ion-exchange wafers, the EDI productivity level increased by 2 times compared to typical electrodeionization. It was found that the ratio of cation exchange resin to anion exchange resin (2:3) allows maintaining an acidic environment (pH at 2–3) in the concentration chamber. This reduces the voltage drop across the ion-exchange resin layer at the same current, which reduces energy consumption by 15–30% (Gülsev, 2023).

The purification and reuse of wastewater from cooling towers is an important environmental and economic task for industrial enterprises. Electrodeionization technology with ion-exchange wafers has been used to desalinate wastewater from cooling towers in order to reduce fresh water consumption and energy costs (Po-Chih, 2022). The study evaluated the effectiveness of electrodeionization based on ion exchange wafers (anion exchange, cation exchange and bipolar) in reducing water hardness, chloride content and other dissolved salts. Tests conducted with a calcium carbonate solution (simulating real cooling tower wastewater) showed a 90% reduction in water hardness after 70 minutes of operation, and at a voltage of 12 V, 95% of Ca^{2+} was removed in 25 minutes. The minimum energy consumption of the EDI unit was observed at 0.28 kWh/m³, which is significantly lower than that of traditional reverse osmosis (0.83–1.2 kWh/m³). It has been shown that electrodeionization based on ion-exchange wafers allowed energy savings of up to 410 GWh/day on an industrial scale, which can be an effective alternative to traditional wastewater treatment methods for conserving water resources and energy (Aicha, 2022).

The use of electrodeionization units in the energy sector is particularly relevant, as high water quality is necessary to prevent corrosion and the formation of carbonate deposits on the walls of steam generators in nuclear and thermal power plants. Research (Brian, 2005) proves that the use of electrodeionization in water treatment technologies in the energy sector allows us to abandon classical ion exchange methods, reduce the frequency of ion exchange material regeneration and increase the durability of water treatment systems. The article discusses two approaches to obtaining demineralized water, namely: two-stage RO and single-stage reverse osmosis combined with electrodeionization, with the latter showing a significantly higher degree of Na^+, Cl^- and SO_4^{2-} ion removal, providing highly demineralized water. The research was conducted at an electrodeionization unit at the Grand Gulf Nuclear Power Plant (USA), where the source water contained 20 mg/L of silicic acid (H_2SiO_3) with a total conductivity of 400–500 μS/cm. After preliminary purification of the source water by reverse osmosis, followed by electrodeionization and the use of mixed-bed filters, the electrical conductivity of the resulting water was less than 0.06 μS/cm, the removal of silicic acid reached 99.8%, the removal of all ions reached 99.9%, and the resource of ion exchange columns increased 20 times. The water purification system operated without regeneration of ion exchange resins for 7 months, which significantly reduced operating costs. The dependence of the efficiency of the EDI unit on the temperature of the feed water was revealed, namely, it was shown that at

temperatures above 16 °C, the removal of silicic acid reached 95%, and when the temperature dropped to 10 °C and below, the purification efficiency decreased due to slower ion transport. Thus, electrodeionization in combination with reverse osmosis increased the service life of ion exchange resins and reduced the cost of their regeneration, significantly improved the quality of purified water, reducing the content of impurities during continuous operation, and achieving water conductivity values of less than 0.06 μS/cm, which reduced the risk of scale formation and corrosion in steam generators. The combination of reverse osmosis units with electrodeionization proved to be a more effective alternative to two-stage reverse osmosis (Helen, 2021).

There are also studies (Gede, 2013) on the use of a tandem reverse osmosis system with electrodeionization units in the preparation of feed water for high-pressure boilers, with an assessment of the technical and economic aspects of this approach. The key parameters of the system's operation were evaluated: electrical conductivity, pH level, concentration of Na^+, SiO_2, HCO_3^-, etc. The electrical conductivity of water after installing the RO and electrodeionization systems was 0.3–0.4 μS/cm, which is better than with single-stage osmosis (5 μS/cm). It was found that the low pH level of purified water (pH 6.3) is associated with the presence of dissolved CO_2 in the form of HCO_3^-, which affects the acid-base balance. The cost of producing 1 m³ of demineralized water using a combination of reverse osmosis and electrodeionization was 0.53 USD, which is 20% lower than traditional ion exchange methods (0.66 USD). Thus, it has also been shown that the combination of reverse osmosis and electrodeionization is an effective alternative to traditional ion exchange filters for the production of feed water for high-pressure boilers. It ensures stable water quality, even when the quality of the source water changes, and has lower operating costs (Ji-Hyeon, 2025).

Another challenge for the successful operation of electrodeionization units is chlorine corrosion caused by residual chlorine. Chlorine compounds can cause oxidative effects on ion exchange membranes and electrodes, reducing their efficiency and shortening their service life. In (Al-Rawajfeh, 2011), the mechanism of chlorine corrosion was analyzed and methods for its minimization were evaluated, including chemical removal of chlorine and its catalytic decomposition. The authors determined the concentrations of Cl_2, HOCl and OCl^- in the source water and in the water after electrodeionization, and assessed the effect of pH and temperature on electrochemical reactions involving Cl_2 on the surface of anion-exchange and cation-exchange membranes. When the concentration of Cl_2 is above 0.1 mg/L, the membranes begin to lose their functionality: chlorine oxidizes quaternary ammonium groups in anion-exchange membranes, leading to a decrease in ionic conductivity. Also, at pH values below 6, membrane oxidation is significantly accelerated, so controlling the pH in the range of 6.5–7.5 and removing residual chlorine is extremely important and can extend the service life of membranes by 30–40%. The authors also studied the effect of chemical neutralizers (Na_2SO_2, $NaHSO_2$, ascorbic acid) on the decomposition of residual chlorine. It was shown that the addition of Na_2SO_3 provides rapid chemical neutralization of chlorine, but forms sulphate ions, which requires additional water purification, while

the introduction of pre-chlorine removal systems increases the service life of EDI units and reduces operating costs by 25–30% (Araslou, 2023).

From the point of view of reducing the harmful effects of chlorine ions (Cl^-) and hardness salts (Ca^{2+}, Mg^{2+}) on the occurrence of electrode corrosion in electrodeionization units, damage to ion-exchange membranes and the formation of toxic gaseous chlorine (Cl_2), two approaches to reducing the concentration of chloride ions and the degree of hardness in water are presented in article (Al-Rawajfeh, 2014). The first approach is the adsorption of chloride ions using a mixture of natural minerals (tripol, pumice (pozzolan), feldspar) and synthetic clays (layered double hydroxide based on magnesium and aluminium – Mg/Al LDH, Layered Double Hydroxides). The second approach is to use a composite filter containing 60% tripol and 40% $Mg/AlOH_2$, which was installed to prevent Cl^- from coming into contact with the anode and to reduce corrosion. Using this approach, the chloride ion content in water was reduced by 60%, and the concentration of molecular chlorine in the gas phase was reduced from 4.8 mg/L to 1.9 mg/L. According to the results of the studies, the most effective adsorbent was the mineral pozzolan (45%), which has a microporous structure and ensured the removal of Ca^{2+} and Mg^{2+} at 95% and 60%, respectively. The use of NF in combination with RO provided better salt removal efficiency compared to single-stage osmosis. The use of the proposed combined technologies can reduce maintenance costs and increase the service life of membranes and electrodes. Particularly promising is the use of a $Mg/AlOH_2$ filter, which is automatically regenerated without chemical regeneration, making it an effective solution for industrial installations that require stable and continuous operation without the use of chemical reagents (Zhang, 2025).

Ways to solve problems associated with carbonate deposits and fouling on CEDI membranes for high-level demineralization water treatment are discussed in (Ying Liua, 2019). In particular, the aim of the work was to reduce the risk of $Mg(OH)_2$ formation due to hydrolysis and concentration polarization, especially in the presence of a significant degree of hardness in the feed water ($CaCO_3$ concentration – 7.9 mg/L). The authors proposed a new CEDI configuration with a "protective chamber" formed by an additional cation exchange membrane and a special loading of ion exchange resins with an increased proportion of cationic resin. This made it possible to locally reduce the concentration of Ca^{2+} and Mg^{2+} near the anion exchange membrane and limit the formation of $Mg(OH)_2$. As a result, the optimal operating conditions for EDI systems were established: voltage – 8 V, concentrated flow rate at 6 L/hour, energy consumption of the process less than 0.03 kWh/m³, which are competitive indicators compared to existing RO/EDI systems. Thus, the results of applying the improved stack design demonstrate high efficiency in the preparation of high-purity water from feed water with increased hardness, achieving a significant reduction in the formation of $Mg(OH)_2$ deposits without the use of antiscalants. This design approach has great potential for reducing the cost of preparing demineralized water in industry, especially in the microelectronics and pharmaceutical sectors (Saravanan, 2023).

Work (Özgür, 2014) demonstrates the use of electrodeionization for the production of high-level demineralized water in terms of

removing heavy metal ions (Cu^{2+}, Ni^{2+}, Co^{2+}, Cr^{+6}, Zn^{2+}, Pb^{2+}). The problem with purifying water from heavy metal ions is the possibility of precipitation of insoluble hydroxides (e.g., $Cu(OH)_2$, $Ni(OH)_2$), which can accumulate in the system and reduce its efficiency. To avoid this, it is important to control the pH, voltage, and flow rate. For effective removal of copper ions, it is recommended to lower the pH of the inlet water, which prevents the formation of copper (II) hydroxide, and to increase the voltage, which improves the efficiency of copper ion transfer to the cathode. The measures taken made it possible to increase the efficiency of copper ion removal to 99.9%. The removal of nickel ions using EDI with a reduction in pH also improved, and an increase in flow and the use of resins with a small particle size contributed to the process of purifying water from Ni^{2+}. Both inorganic ion-exchange resins (zirconium hydrogels) and combined systems with mixed layers were used to remove chromate ions. It was found that CrO_4^{2-} transfer increased with increasing voltage. With the use of a polyelectrolyte coating of resins, the concentration of Zn^{2+} in purified water decreased 50 times, and the degree of Pb^{2+} removal increased (95%) with the use of ion-exchange membranes with bifunctional groups. To achieve the maximum effect of heavy metal ion removal, a special resin layer configuration was used: first cationite, then anionite, and on top – a mixed layer. This made it possible to avoid the formation of sediments and achieve over 99% removal of cobalt ions. The efficiency of electrodeionization also increased when using purely mixed ion-exchange layers (removal rate – 99.8% in 1.3 hours of EDI operation). It was shown that in the case of the simultaneous presence of several metals (e.g., Zn^{2+}, Cu^{2+}, Cd^{2+}, Pb^{2+}), the purification efficiency remained high with the correct selection of the applied current and the nature of the electrolyte.

In (Alvarado, 2009), a comparative removal of Cr^{6+} from aqueous solutions (100 mg/L, pH 5) was carried out using three methods: ion exchange, electrodialysis and electrodeionization. Particular attention was paid to studying the role of ion exchange resin in the EDI system (anion resin and mixed-action resin). Traditional methods of removing heavy metals from water, such as electrodialysis and ion exchange, are well studied and widely used, while EDI technology has not yet been sufficiently researched in such processes. The proposed design of the electrodialysis unit used a cell with two compartments – with anion- and cation-exchange membranes, the dilution compartment was filled with either pure anion resin (Amberlite IRA-67) or mixed-type resin (Amberlite IRA-67 anion- exchange resin and Dowex Mac-3 cation-exchange resin in a 1:1 ratio). The use of an ion exchange unit showed an efficiency of Cr^{6+} removal at 50%, while the method using electrodialysis achieved an efficiency of Cr^{6+} removal at 98% in approximately 6.2 hours (energy consumption – 1.21 kWh/m³). The electrodeionization unit with anion resin achieved a Cr^{6+} removal efficiency of 97.55% in approximately 6.25 hours (energy consumption was 0.91 kWh/m³). The best Cr^{6+} removal results (99.8%) were achieved by an electrodialysis unit with mixed resins in just 1.3 hours with ultra- low energy consumption – 0.167 kWh/m³. Thus, the studies showed that the presence of mixed-bed resin provides a higher ion exchange rate, and therefore a higher Cr^{6+} removal rate as

well as lower energy consumption (Dexiang, 2024).

A wide range of possibilities for removing ions of toxic metals (Cr, Ni, Co, Cu, Pb, Cd), arsenic, radioactive isotopes of cesium and strontium, nitrate and ammonium ions is presented in work (Senthil, 2020), which summarizes the mechanisms of water dissociation and ion transfer, the influence of membrane types and ion exchange resins on the efficiency of the process. The article compares different CEDI configurations (conventional, membrane, wafer), membrane types (homogeneous, heterogeneous), and resin types (cation and anion exchange, mixed action). The results of the research showed the possibility of effective removal of Cr^{6+}, Ni^{2+}, Co^{2+}, Cu^{2+}, Pb^{2+}, Cd^{2+}, As^{5+} at a level of 99 %, as well as the removal of NaCl up to 99.8 % with a sufficiently low energy consumption of 0.03 kWh/m^3.

A not entirely traditional use of EDI is proposed in article (Guangming, 2016), which analyses the use of electrodeionization as a promising eco-technology for concentrating biomethane and capturing and storing CO_2 from seawater and flue gases. The study emphasizes the advantages of EDI as a reagent free method that can be an alternative to classical ion exchange and membrane technologies. The research focused on aspects of water dissociation, ion transfer and various stack configurations. The possibility of using RW-EDI (Resin Wafer EDI) wafer ion exchange electrodeionization units for CO_2 extraction from biogas by conversion to bicarbonate ions, followed by the production of pure methane, was demonstrated. The concept of an electrochemical acidification cell for the separation of CO_2 and H_2 from seawater by shifting the equilibrium of HCO_3^- towards CO_2 at a pH of less than 5 is presented.

Therefore, we can conclude that the use of channel spacers and a multi-stage sequential connection scheme for EDI modules leads to a uniform hydrodynamic regime and high electrochemical selectivity, which allows water with low specific resistance to be obtained. Varying the ratio of ion exchange resins and using them in the form of wafers increases ion transfer and reduces energy consumption. At the same time, the main technological challenges of using the EDI method include chlorine corrosion and fouling, which can be eliminated by preliminary disinfection/dechlorination, the use of adsorbent filters and "protective chambers" in the stack, which will also extend the life of the membranes and stabilize operation without resin regeneration for a long time.

5. Modification of ion-exchange materials

The efficiency of electrodialysis units can be increased by modifying the ion-exchange materials used in EDI units, for example, by adding water dissociation catalysts to ion-exchange resins, changing the proportions of ion exchange resins within a single stack, combining layers of ion exchange resins, etc.

The study (Jun, 2010) presents a simulation of the electrodeionization process using a 2D stationary mathematical model to analyze the effect of the water dissociation mechanism on the efficiency of the EDI system, with particular attention paid to the effect of water dissociation on pH, current efficiency and ion removal rate. The authors show that the asymmetry of dissociation

intensity on anion-exchange and cation-exchange membranes is the main reason for the difference in the efficiency of cation and anion removal. The catalysis of water dissociation on the surface of an anion-exchange membrane is significantly more efficient than on a cation-exchange membrane, which leads to uneven removal of cations and anions, with cations being removed more efficiently. Water dissociation is also a key mechanism contributing to the regeneration of ion-exchange resins. The addition of water dissociation catalysts to the cation-exchange membrane improves the ion balance and increases the efficiency of the process. Tertiary ammonium groups, which are formed as a result of the degradation of quaternary ammonium groups on the surface of anion-exchange membranes, were used as a water dissociation catalyst. It is these tertiary groups that significantly increase the rate of H^+ and OH^- formation. In their modelling, the authors also suggest that tertiary amines can be artificially introduced onto the surface of the cation-exchange membrane to improve the balance between cation and anion removal. The authors determined the effect of the catalytic effect of quaternary ammonium groups in anion-exchange membranes, evaluated the pH distribution and the effect of H^+ and OH^- on the transformation of ion-exchange resins. Excessive H^+ formation on anion- exchange membranes was detected, leading to uneven removal of cations and anions (Na^+ is removed more efficiently than Cl^-). Thus, the study demonstrates the importance of controlling water dissociation and concentration polarization to improve the efficiency of electrodeionization and reduce energy consumption.

The importance of modifying and improving ion-exchange materials is also demonstrated in the work (Jordan, 2020), which presents a new class of symmetric and asymmetric bipolar ion-exchange resins ("Janus bipolar resin wafers", Janus RWs) that have additional functionality for the dissociation of water into protons and hydroxide ions. The synthesized bipolar resins contained nanoparticles of a water dissociation catalyst – aluminium hydroxide ($Al(OH)_3$), which was immobilized in a porous layer of ion-exchange resin. This is an innovative achievement in obtaining symmetric and asymmetric bipolar Janus RW resins to reduce energy consumption and increase EDI productivity.

The initial layer synthesis method was used to apply aluminium hydroxide by mixing cation-exchange and anion-exchange resins with: sulfonated poly (arylene ether ether ketone) (SPEEK) SPEEK) and quaternary benzyl n-methyl pyrrolidinium poly (arylene ether sulfone), QAPSf) in combination with a binder. The high ionic conductivity of the created symmetrical and asymmetrical structures of Janus RWs resins in the range of low salt concentrations indicated a potential reduction in energy consumption in industrial EDI systems. Such new materials can replace classic bipolar membranes in pH regulation processes without the need for high electrolyte concentrations, which simplifies their use in water purification and the removal of organic acids and silicates (Rukowicz, 2023).

The study (Varada, 2020) presents a new class of ion-conducting wafers using ion-exchange binding materials, known as ion-exchange ionomers (IEI), which improve ion conductivity by 3–5 times compared to traditional analogues. Unlike polyethylene, these ion-exchange ionomers have fixed functional groups with a specific charge that

are directly involved in ion transport, increasing the overall ionic conductivity of the material. Thus, the ion-exchange resin matrix ceases to be merely an inert mechanical structure and participates in the chemical process of ion transport, while forming additional functional exchange zones. Three types of linear ion-exchange ionomers were synthesized: sulfonated poly (ether ether ketone) (sodium sulfonate poly (ether ether ketone), SPEEK) as a cation- exchange ionomer (CEI) and quaternary benzyl-N-methylpyrrolidinium poly (arylene ether sulfone (Quaternary benzyln-methyl pyrrolidinium chloride poly (arylene ether sulfone), QBMPSf) and quaternary poly (ammonium sulfone) (quaternized ammonium polysulfone, QAPSf) as anion- exchange ionomers (AEI). The use of an ion-conducting matrix in the form of cation-exchange and anion-exchange ionomers instead of traditional polyethylene significantly improved the ionic conductivity of ion-exchange wafers in NaCl solutions (concentration less than 500 mg/L). The work shows that their use allows for a 25% acceleration of the EDI process and a 5% energy saving compared to typical EDI units, demonstrating significantly better water dissociation capacity. Thus, it has been shown that electrodeionization units with ion-exchange wafers using an ion-conductive matrix allow 99% removal of sodium chloride at a concentration of 5000 mg/L, demonstrating a significant reduction in energy consumption and improved performance.

Article (Fasuyi, 2019) also presents studies on optimizing the composition of ion-exchange wafers by replacing the polyethylene binder with poly (ionic) liquids that have high electrical conductivity, resulting in liquid film ion-exchange electrodeionization. Phosphonium compounds, namely triacetyl (4-vinylbenzyl) phosphorus (trifluoromethanesulfonyl), were used to synthesize the poly (ionic) liquid. It was shown that the poly (ionic) liquid significantly reduced the electrical resistance of the ion-exchange wafer, and the ionic conductivity of the liquid film ion-exchange electrodeionization was 10 times higher than that of a traditional ion-exchange wafer.

At the same time, the degree of ion removal increased by 5%, and the specific energy consumption decreased by 20% in liquid film ion- exchange electrodeionization (from 0.4 to 0.32 kWh/m^3) compared to typical electrodeionization. The use of liquid film ion exchange electrodeionization with 2.5 g of poly (ionic) liquid content provided an optimal balance between the mechanical strength and electrical conductivity of the membranes. Thus, the introduction of poly (ionic) liquids in liquid film ion-exchange electrodeionization allows for increased water purification efficiency and reduced energy consumption. This technology has the potential for large-scale industrial application in water desalination and wastewater treatment.

Article (Ji-Min, 2023) proposes a new approach to the manufacture of heterogeneous anion-exchange membranes using an ion-conducting matrix based on poly (2,6-dimethyl-1,4-phenylene oxide). The study presents heterogeneous anion-exchange membranes modified by a combination of polyvinyl ethanol, which provided good film-forming ability and maintained the mechanical integrity of the membrane; polyethylene, which was used as an inert matrix to create a mechanically strong framework; polyethylene oxide, which

contributed to improved anion transport due to the presence of ether groups; poly (2-methylaminoethyl methacrylate) as a cationic polymer that provided fixed positive charges in the membrane structure; inorganic nanofillers (titanium oxide TiO_2) to improve chemical stability, oxidation resistance and increase hydrophilicity, silicon oxide (SiO_2) to increase the thermal and mechanical stability of the membranes, zirconium oxide (ZrO_2) to increase the acid resistance of the membranes and prevent swelling (Senthilkumar, 2024).

The rationale for this membrane composition is to create composite materials with an optimized ratio of polymer and inorganic components, which significantly improves their performance without compromising selectivity. The membrane with 30% anion exchange resin content had an electrical resistance of 4.6 mOhm·cm², which is significantly lower than that of a widely used commercial membrane (13.6 mOhm·cm²). The additional introduction of nanofibres provided a mechanical tensile strength of about 9.7 MPa while maintaining low electrical resistance.

The degree of salt removal using the obtained heterogeneous anion- exchange membranes was 99.86%, which exceeded the efficiency of commercial membranes (99.76%). The advantages of the obtained heterogeneous anion exchange membrane also include reduced energy consumption of 0.35 kWh/m³ compared to 0.4 kWh/m³ for traditional membranes. Electrodeionization units with upgraded anion exchange membranes demonstrated lower energy consumption and more efficient ion removal, making this method promising for high-degree demineralization water purification in the pharmaceutical, electronic and energy industries (Fasuyi, 2023).

Thus, as shown above, modifying traditional ion-exchange materials increases the efficiency of electrodialysis units, where the introduction of water dissociation catalysts is the most promising direction for the development of the EDI process.

6. Major innovations in the development of the electrodeionization process

Table 1 highlights several of the most common and widely reported innovative developments in the scientific literature in the field of EDI unit design and improving the functional efficiency of ion exchange materials, which demonstrate improvements in the parameters of electrodeionization processes in terms of increasing EDI productivity, reducing electricity consumption and other equally important factors.

As can be seen from Table 1, the productivity and electrical resistance of water purified by electrodeionization significantly depend on the energy consumed and the width of the spacers. The rate of ion removal and the efficiency of their transport increase with the use of wider spacers. When using a spacer configuration with a "protective chamber", the concentration of Ca^{2+} and Mg^{2+} decreases in the anion exchange membrane zone and the formation of $Mg(OH)_2$ decreases.

Table 1. *Major innovations in the design of EDI devices and the modification of ion-exchange materials*

Innovation in design	Spacer width, mm	Electrical resistance, MΩ·cm²	Energy consumption, kW·h/m³	Productivity, L /hour	Reference
Spacer structure	8–10	>17	0.7	0.17	(Xu, 2021)
Structure of the spacer	-	16	0.03	6	(Aiman, 2011)
Liquid film ion exchange EDI	2.5	8.64	0.32	9	(Jordan, 2020)
Heterogeneous ion-exchange Membranes	3	13.6	0.35	-	(Fasuyi, 2019)
Ion exchange Wafers	3.8	-	0.354–0.657	20.1–41.3	(Varada, 2020)
Modular Design	-	18	-	2800–3900	(Yiqing, 2010)
Combination of RO, EDI and mixed-bed filters	3	-	0.28	3	(Po-Chih, 2022)
Combination of RO and EDI	-	17.5	0.21	400	(Shu-Yuan, 2017)
Mixed layers of ion exchange Resins	6	-	0.167	0.72	(Ying, 2019)
Bipolar ion exchange Resins	2.5	18.9	1.0	1.1	(Guangming, 2016)
Ion exchange Ionomers	3	34.6	1.02	50	(Jun, 2010)

The use of liquid film ion exchange EDI allows for a 5% higher degree of ion removal and 20% specific energy consumption compared to a classic EDI unit, while heterogeneous ion exchange membranes reduce electricity consumption by 8.75%. At the same time, the use of ion exchange wafers allows for an even greater reduction in energy consumption, namely by 15–30%.

Mixed layers of ion-exchange resins make it possible to increase the number of electro- regeneration zones and accelerate the rate of ion exchange, while the use of symmetrical and asymmetrical bipolar ion-exchange resins reduces energy consumption. The use of ion-exchange ionomers improves ion conductivity by 3–5 times compared to traditional analogues due to the formation of additional functional exchange zones in the ion-exchange material matrix.

The use of a modular design for the EDI unit, in which the modules are connected in series as in reverse osmosis systems, significantly reduces the flow rate of the concentrate and lowers maintenance costs. The combination of reverse osmosis units, electrodeionization and mixed-bed filters reduces the electrical conductivity of purified water (less than 0.06 μS/cm) and the degree of silicic acid removal, which will increase the operating life of EDI without regeneration of ion- exchange resins.

7. Conclusions

The use of only traditional methods of water desalinate ion, such as ion exchange and reverse osmosis, is insufficient to obtain water with a high level of desalination.

The use of liquid film ion exchange EDI allows for a 5% higher degree of ion removal and 20% specific energy consumption compared to a classic EDI unit, while heterogeneous ion exchange membranes reduce electricity consumption by 8.75%. At the same time, the use of ion exchange wafers allows for an even greater reduction in energy consumption, namely by 15–30%.

The use of ion-exchange ionomers improves ion conductivity by 3–5 times compared to traditional analogues due to the formation of additional functional exchange zones in the ion-exchange material matrix.

The technological approaches to improving the design of electrodeionizers and the prospects for modifying ion-exchange resins, which will increase the efficiency of the installations, namely, reduce energy consumption, increase selectivity and productivity, etc., are analyzed in the literature. In particular, the use of channel spacers and a multi-stage sequential connection scheme for EDI units will increase electrochemical selectivity, reduce energy consumption, and the use of adsorbent filters and "protective chambers" in the stack will extend the life of the membranes and stabilize operation without resin regeneration for a long time. It has also been shown that modifying traditional ion- exchange materials will increase the efficiency of electrodialysis units, where the introduction of water dissociation catalysts is the most promising direction for improving EDI efficiency.

Electrodeionization is expected to become the predominant technology for industrial water demineralization in the near term, effectively replacing traditional ion-exchange systems across the energy sector and beyond.

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АНАЛІЗ ВИКЛИКІВ ТА ПРОБЛЕМ ЗАСТОСУВАННЯ ЕЛЕКТРОДЕОНІЗАЦІЇ ДЛЯ ОТРИМАННЯ ГЛИБОКОЗНЕСОЛЕНОЇ ВОДИ

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У статті представлено аналіз викликів та проблем, які обмежують широке використання методу електродеіонізації для знесолення води. Тим не менш, ця технологія вже успішно зарекомендувала себе в фармацевтичній сфері, у виробництві мікроелектроніки та на теплоенергетичних об'єктах, таких як атомні та теплові електростанції. Але вона має перспективи і для більш ширшого розповсюдження, наприклад, в хімічній, харчовій та переробній промисловості, теплоенергетиці, біотехнології, для виробництва водню тощо. А в поєднанні з попередньою очисткою води з використанням методу двостадійного зворотного осмосу в перспективі має змогу повністю замінити використання класичних катіоно- та аніонообмінних фільтрів змішаної дії для знесолення води. Метою роботи є огляд та аналіз фундаментальних основ та практичних аспектів застосування електродеіонізації, особливостей конструкцій та роботи установок електродеіонізації і можливих підходів для покращення ефективності їх роботи для отримання води високого ступеню знесолення. Для цього детально розглянуто технологічні підходи до вдосконалення конструкцій установок електродеіонізації та можливість модифікування іонообмінних смол з метою зменшення енергоспоживання, збільшення селективності та продуктивності тощо. Визначені основні параметри режимів проведення процесів електродеіонізації та проведено оцінку впливу модифікування іонообмінних матеріалів каталізаторами дисоціації води та варіювання співвідношення катіоно- та аніонообмінних смол на ефективність роботи модулів. Проаналізовано вплив вищевказаних факторів на продуктивність, селективність, енергоспоживання, термін безперервної роботи установок електродеонізації, ступінь регенерації іонообмінних смол, ступінь очищення води, зменшення фоулінгу іонообмінних мембран та ступеню корозії електродів.

Ключові слова: *електродеіонізація, електричний опір води, знесолення, іонообмінна мембрана, канал концентрування, модифікування, спейсер*