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MODERN METHODS OF PREPARATION OF DEEPLY DESALINATED WATER FOR THE NEEDS OF THERMAL POWER PLANTS. ECOLOGICAL ASPECTS

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The need for water treatment at thermal power plants remains one of the most important aspects in the energy sector. Water is the main source of energy for energy companies. Therefore, very high demands are placed on its chemical composition. The quality of the water supplied to the system has a major impact on its operation. Hard water is a serious problem for steam and gas boiler houses, as well as for steam turbines at thermal power plants that provide heat and hot water. Water hardness creates problems that significantly affect the performance of boilers and boilers, and negatively affect their productivity. Scale builds up on the walls of the equipment, causing excessive levels of magnesium and calcium cations. To improve the performance characteristics and operating time, it is important to use water of high purity, which is the main problem of using steam generation systems.

The main modern methods of water treatment for the needs of thermal power plants are considered: evaporation, reverse osmosis, and electrodialysis.

Evaporation is based on the use of cooling towers. In general use in buildings, cooling towers are connected to water-cooled central chillers that provide cooling for the building. In water-cooled plants, water from the condenser absorbs heat from the chillers and then transfers it to the cooling towers, where it is exposed to the outside air.

The advantages of reverse osmosis are versatility, the ability to purify water from ionic and organic contaminants, high molecular weight compounds, suspensions, bacteria and other impurities simultaneously. The flow of filtrate is directly proportional to the surface area of the membrane and inversely proportional to its thickness.

Electrodialysis (ED) is an established technology for treating industrial wastewater, brackish water, municipal wastewater and is used in the pharmaceutical and food industries, chemical processes, table salt production, electronics, biotechnology, heavy metal removal, and acid and alkali production due to its ability to remove ionic and non-ionic components under the influence of an electric current. This was due to the development of IEMs with improved electrochemical and physicochemical characteristics. *Key words:* thermal power plant, hard water, evaporation, reverse osmosis, electrodialysis.

Сучасні методи підготовки глибокознесоленої води для потреб ТЕС. Екологічні аспекти. Феденко Ю.М., Діденко Д.В., Бурмак А.П.

Необхідність водопідготовки води на ТЕС залишається одним з найважливіших аспектів в енергетиці. Вода для підприємств енергетики – це основне джерело їх роботи. Тому до її хімічного складу висуваються дуже високі вимоги. Якість води, яка подається в систему, дуже сильно впливає на її роботу. Жорстка вода – є серйозною проблемою для парових та газових котелень, а також для парових турбін ТЕС, які забезпечують теплом та гарячою водою. Жорсткість води створює проблеми, що суттєво впливають на продуктивність котелень та котлів, а негативно впливають на їх продуктивність. На стінках обладнання утворюється накип який викликає надлишковий вміст катіонів магнію та кальцію. Для покращення характеристик продуктивності та часу експлуатації актуально використовувати воду підвищеної чистоти, що і є основною проблемою використання систем пароутворення.

Розглянуто основні сучасні методи водопідготоки для потреб ТЕЦ: евапорацію, зворотний осмос, електродіаліз.

Евапорація полягає у застосуванні градирень. У загальному застосуванні в будівлях градирні підключаються до центральних охолоджувачів з водяним охолодженням, які забезпечують охолодження будівлі. На заводах з водяним охолодженням вода з конденсатора поглинає тепло від холодильних установок, а потім передає його в градирні, де ця вода піддається впливу зовнішнього повітря.

Переваги зворотного осмосу – універсальність, можливість очищення води одночасно від іонних і органічних забруднень, високомолекулярних сполук, суспензій, бактерій та інших домішок. Потік фільтрату прямо пропорційний площі поверхні мембрани та обернено пропорційний її товщині.

Електродіаліз (ED) є усталеною технологією обробки промислових стічних вод, солонувату воду, муніципальні стічні води та використовуються в фармацевтичній та харчовій промисловості, хімічних процесах, виробництві кухонної солі, електроніці, біотехнологіях, видаленні важких металів, а також виробництві кислот і лугів завдяки своїй здатності видаляти іонні та неіонні компоненти під дією електричний струм. Це було зумовлено розробкою IEM з покращеними електрохімічними та фізико-хімічними характеристиками. *Ключові слова:* теплоелектростанція, жорстка вода, випаровування, зворотний осмос, електродіаліз.

Introduction. The need for water treatment at thermal power plants (TPPs) remains one of the most important aspects in the energy sector. Water is the main source of energy for energy companies. Therefore, very high demands are placed on its chemical composition. The quality of the water supplied to the system has a major impact on its operation. Hard water is a serious problem for steam and gas boiler houses, as well as for steam turbines at thermal power plants that provide heat and hot water [1].

Water hardness creates problems that significantly affect the performance of boilers and boilers, and negatively affect their productivity. Scale builds up on the walls of the equipment, causing excessive levels of magnesium and calcium cations. To improve performance and operating time, it is important to use high-purity water, which is the main problem with steam generation systems.

To study the problem in detail, it is necessary to understand where scale comes from and how it affects equipment.

The first negative impact becomes apparent after the first few hours of using untreated water. A thin film-like layer, like limescale, forms on the walls and significantly impairs heat transfer. First of all, this is a negative consequence for electric heat exchangers because due to poor heat removal from the heat exchanger, the automatic overheating protection system can be triggered, and the heat exchanger will be shut down [2,3].

The second problem is the difficulty of descaling the equipment. There are two methods of equipment cleaning. The first is mechanical. The second is chemical [4].

Both methods have both positive and negative consequences for the equipment.

On the positive side, the equipment and its surface are restored to their original condition and the productivity and efficiency of the equipment is restored for a while. The negative consequence is that even the mildest mechanical or chemical cleaning of the equipment significantly damages its surface. Micro-cracks are formed that become centers of scale growth, and the surface of metal equipment is also significantly deteriorated, which leads to corrosion. These negative consequences are why it is necessary to use softened water [5,6].

To ensure trouble-free, efficient and long-term operation of equipment, companies need to use water treatment systems.

Review of modern methods of deeply desalinated water treatment for the needs of TPPs

Evaporation. In common building applications, cooling towers are connected to water-cooled central chillers that provide cooling for the building. In water-cooled plants, water from the condenser absorbs heat from the chillers and then transfers it to the cooling towers, where it is exposed to the outside air. Some of the water from the condenser evaporates; the rest is returned to the chiller to repeat the cooling process. Since evaporation is a heat absorption process, the water returning from the condenser is colder than the water supplied from the condenser to the cooling tower [7-10].

The water that evaporates in the condenser must be replaced with cooling tower makeup water, which usually comes from the cooling tower basin using a float valve similar in concept to the float valves in older toilet models. Cooling tower makeup water is usually supplied from the municipal drinking water supply and increases the building's water consumption [11-12].

The continuous evaporation of the condenser water from the condenser water side in the cooling cycle also has another effect: since only pure water evaporates, it leaves behind any mineral content that it carried when it entered the condenser water system. Makeup water contains naturally occurring amounts of mineral impurities (silica, calcium, magnesium, chloride), so the water remaining in the condenser will have increasing amounts of impurities as more water evaporates. These impurities will eventually precipitate (as water can only hold so much), resulting in a solid precipitate [13-16].

Reverse osmosis. The advantages of reverse osmosis are versatility, the ability to purify water from ionic and organic contaminants, high molecular weight compounds, suspensions, bacteria and other impurities simultaneously. The flow of filtrate is directly proportional to the surface area of the membrane and inversely proportional to its thickness. Consequently, when designing a reverse osmosis plant, it is necessary to choose a membrane with the maximum possible area and minimum possible thickness per unit volume of the plant [17].

The reliability of the plants is supposed to be increased by redundancy of equipment by substitution, providing for its multifunctional use, optimization of the number of filter modules in a separate section, as well as by increasing the reliability of filter elements and equipping with a high-speed search system for a failed module or element. Reverse osmosis processes use acetate cellulose and other polymeric membranes, including charged ones. This creates variability of the technology for any pH of the environment, as well as the ionic composition of water [18].

The main advantages of reverse osmosis desalination compared to distillation include operation of plants at normal temperature; lower energy consumption (approximately 2 times); no "thermal pollution" of the environment; no (or little) corrosion; relatively easy achievement of the desired water quality; low capital costs for small capacity plants, no restrictions on the location of plants; no need for further treatment of the resulting water.

In addition to independent use, the reverse osmosis process is well combined with traditional methods of separation (ion exchange, rectification, adsorption, extraction, electrodialysis), which opens wide opportunities for creating fundamentally new, simple and low-energy technological processes and industries with a closed water cycle [19].

Reverse osmosis is one of the most used membrane separation methods. It is widely used for desalination (demineralization) of all types of water in plants of various capacities.

Nanofiltration is a membrane process similar to reverse osmosis. The difference is selectivity for multi- and single-charged ions, as well as for organic substances. Thus, while reverse osmosis membranes have high selectivity for all ions, nanofiltration membranes are highly selective for calcium, magnesium, sulfate ions and other multicharged ions, but relatively permeable to single-charged ions such as sodium, potassium, chloride, nitrate, etc.

The phenomenon of osmosis can be observed if pure water and a solution are placed in a closed vessel on opposite sides of a semipermeable membrane that allows only water molecules to pass through. Under such conditions, water molecules will penetrate the solution, reducing its concentration. Due to the closed nature of the vessel, the pressure in the solution zone will increase, and in the pure water zone it will decrease.

This will continue until the resulting pressure difference compensates for the energy benefits of diluting the solution. The system will come to a state of equilibrium. The difference in pressure (height of the liquid columns) in the two zones is called the osmotic pressure of the solution [19-20].

Electrodialysis. Electrodialysis (ED) is an established technology for treating industrial wastewater, brackish water, and municipal wastewater and is used in the pharmaceutical and food industries, chemical processes, table salt production, electronics, biotechnology, heavy metal removal, and acid and alkali production due to its ability to remove ionic and non-ionic components under the influence of an electric current. This was due to the development of IEMs with improved electrochemical and physicochemical characteristics [21].

The main advantages of ED are higher water recovery rates compared to RO, ease of operation, long membrane life, operation at high temperatures, and, unlike RO, it does not require significant pre- or post-treatment. In addition, it can selectively separate monovalent ions (e.g., NO_3^-, Cl^-, NH_4^+, K^+, Na^+) from multivalent ions (e.g., PO_4^{3-}, SO_4^{2-}, Mg^{2+}, Ca^{2+}) to produce irrigation water, using monovalent permeation-selective IEM. Researchers have reviewed the basic principles of ED in their articles [9, 10], and this has led to significant advances (e.g., electrodeionization EDI). Furthermore, due to the flexibility of the ED process, which can follow the oscillatory behavior of photovoltaic (PV) power generation, it has established a photovoltaic (PV)-ED coupling system. Despite this, many ED developments are still on the laboratory scale. In addition, the global installed capacity of desalination is only 4 %.

The voltage applied between the cathode and anode electrodes passing through the IEM is used inside the ED cell to separate charged particles (i.e., ions) from uncharged substances and aqueous solution. Thus, ED is established as an electrical process. Inside the ED stack, there are several anion exchange membranes (AEMs) and cation exchange membranes (CEMs) placed between the cathode and anode electrodes [22].

A spacer is used inside the ED stack to separate the IEMs and create compartments for concentration and dilution. The electrodes are semi-separated by parallel membranes. The membranes work as a barrier to nutrient migration, preventing or allowing ions to pass according to their electrical charge. The electrolyte solution circulates through the electrode compartments, which are called electrode washing compartments [23].

Electro-dialyzers use chemically resistant electrodes made of platinum titanium, ORTA (ruthenium oxide titanium anodes), and less often alloy steel or graphite [24].

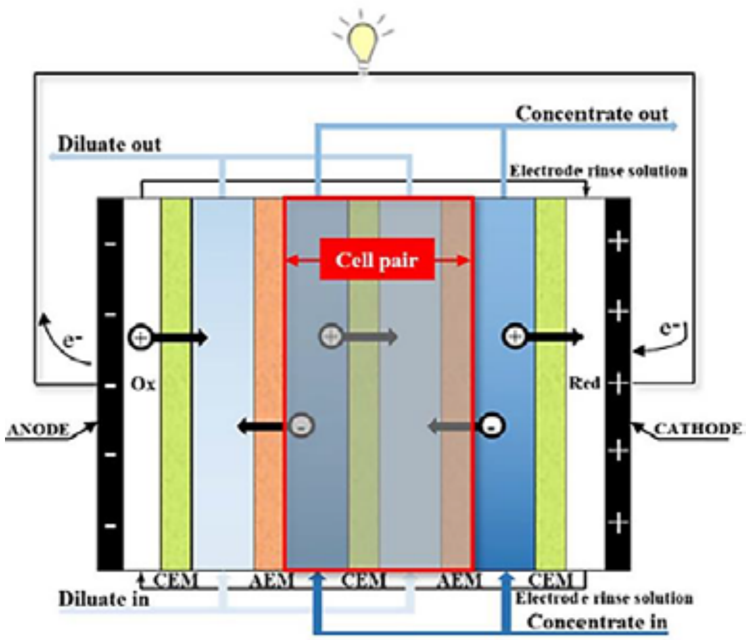

Fig. 1. Scheme of the electrodialysis process

References

1. Taysir A.D. The management of desalinated water. *Desalination*. 2001. Vol. 135. P. 7–23.
2. Rami A.R., Abdallah S., Ratiranjan J. Hybrid deep learning and remote sensing for the delineation of artificial groundwater recharge zones. *The Egyptian Journal of Remote Sensing and Space Sciences.* 2024. Vol. 27. P. 178–191.
3. Poblete R., Bakit J. Water recovery from industrial sludge drying by humidification–dehumidification (HDH) processes: A comparison of condensation systems. *Journal of Water Process Engineering*. 2024. Vol. 67. P. 106–117.
4. Tian S., Zhou Z., Li X. Applications of solar-driven interfacial evaporation-coupled photocatalysis in water treatment: A mini review. *Desalination*. 2024. Vol. 592. P. 118–159.
5. Raza S., Ghasali E., Orooji Y. Two dimensional (2D) materials and biomaterials for water desalination; structure, properties, and recent advances. *Environmental Research*. 2023. Vol. 219. P. 114–124.
6. Chen X., Zhang P. Salt-resistant MXene-charge gradient hydrogel evaporator with boosted water transport for efficient photothermal desalination. *Desalination*. 2024. Vol. 5. P. 118–155.
7. Xie C., Xiao W., Zhang M. Isotopic kinetic fractionation of evaporation from small water bodies. *Journal of Hydrology*. 2021. Vol. 603. P. 126974. DOI: 10.1016/j.jhydrol.2021.126974.
8. Gilson L.N., Cooper C.E., Withers P.C. Two independent approaches to assessing the constancy of evaporative water loss for birds under varying evaporative conditions. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*. 2021. Vol. 261. P. 111041. DOI: 10.1016/j.cbpa.2021.111041.
9. Yuan B. Meng L. Enhancement of pollutant degradation and solar-driven water evaporation by architecting hierarchical 1D/2D TiO_2 @ MoS_2 core–shell networks. *Applied Surface Science*. 2021. Vol. 570. P. 151143. DOI: 10.1016/j.apsusc.2021.151143.
10. Li Y., Hong W., Li H. Solar absorber with tunable porosity to control the water supply velocity to accelerate water evaporation. *Desalination*. 2021. Vol. 511. P. 115113. DOI: 10.1016/j.desal.2021.115113.
11. Wang J.Y., Guo X.X., Chen J. A versatile platform of poly (acrylic acid) cryogel for highly efficient photothermal water evaporation. *Material Advances*. 2021. Vol. 2. P. 3088–3098. DOI: 10.1039/d1ma00119a.
12. Abaker Omer A.A., Liu W. Water evaporation reduction by the agrivoltaic systems development. *Solar Energy*. 2022. Vol. 247. P. 13–23. DOI: 10.1016/j.solener.2022.10.022.
13. Zang L., Finnerty C., Yang Z. An electrospun transporter-assisted evaporator with antifouling water channels for solar-driven desalination and water purification. *Journal of the Taiwan Institute of Chemical Engineers*. 2022. Vol 138. P. 104493. DOI: 10.1016/j.jtice.2022.104493.
14. Shukla A., Bhagat B., Sharma P. Structural features and solar absorption characteristics of sucrose derived spherical carbons: A case study towards solar-thermal water evaporation. *Cleaner Engineering and Technology*. 2022. Vol. 11. P. 100585. DOI: 10.1016/j.clet.2022.100585.
15. Rauter M.T., Aasen A. A comparative study of experiments and theories on steady-state evaporation of water. *Chemical Thermodynamics and Thermal Analysis*. 2022. Vol. 8. P. 100091. DOI: 10.1016/j.ctta.2022.100091.
16. Tesfuhuney W.A., Mengistu A.G. Rensburg L.D. Estimating soil water evaporation as influenced by “dry-and green-mulch” cover beneath maize canopy. *Physics and Chemistry of the Earth, Parts A/B/C*. 2022. Vol. 128. P. 103270. DOI: 10.1016/j.pce.2022.103270.
17. Cui M.Q., Dong X.Y., Wang J.X. Calcium carbonate scaling and seeding induced precipitation in FO treating textile reverse osmosis concentrate. *Journal of Water Process Engineering*. 2022. Vol. 50. P. 103256. DOI: 10.1016/j.jwpe.2022.103256.
18. Tavares T., Tavares J. Assessment of processes to increase the lifetime and potential reuse and recycling of reverse osmosis membranes towards a circular economy. Case of study of Cape Verde and Macaronesia area. *Desalination and Water Treatment*. 2022. Vol. 259. P. 308–314. DOI: 10.5004/dwt.2022.28577.
19. Sun J., Chen S. Simultaneous $Fe(OH)_3$ formation and silicon adsorption removal from reverse osmosis brine wastewater. *Chemical Engineering Research and Design*. 2022. Vol. 188. P. 964–971. DOI: 10.1016/j.cherd.2022.10.042.
20. Shadravan A. Feasibility of thin film nanocomposite membranes for clean energy using pressure retarded osmosis and reverse electrodialysis. *Energy Nexus*. 2022. Vol. 7. P. 100141. DOI: 10.1016/j.nexus.2022.100141.
21. Gu M., Wang Y., Wan D. Electrodialysis ion-exchange membrane bioreactor (EDIMB) to remove nitrate from water: Optimization of operating conditions and kinetics analysis. *Science of The Total Environment*. 2022. Vol. 839. P. 156046. DOI: 10.1016/j.scitotenv.2022.156046.
22. Finklea H., Lin L.S., Khajouei G. Electrodialysis of softened produced water from shale gas development. *Journal of Water Process Engineeri*ng. 2022. Vol. 45. P. 102486. DOI: 10.1016/j.jwpe.2021.102486.
23. Siddiqui M.U., Generous M.M. Explicit prediction models for brackish water electrodialysis desalination plants: Energy consumption and membrane area. *Energy Conversion and Management*. 2022. Vol. 261. P. 115656. DOI: 10.1016/j.enconman.2022.115656.
24. Giacalone F., Catrini P. Exergy analysis of electrodialysis for water desalination: Influence of irreversibility sources. *Energy Conversion and Management*. 2022. Vol. 258. P. 115314. DOI: 10.1016/j.enconman.2022.115314.