Application of Electro-Sorpton Desalination Technique in Water Treatment

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Abstract. Electro-Sorption Technology (EST) is also known as Capacitive Deionization (CDI). It originated in the late 1990s. Electro-Sorption desalination technology is a new water treatment technology that uses the phenomenon of ions and charged particles adsorbed on the surface of charged electrode to enrich and concentrate dissolved salts and other charged substances in the water on the surface of electrode to realize water purification/desalination. As a new water treatment technology, Electro-Sorption technology (EST) has the characteristics of low inlet water quality, reliable operation, low energy consumption, convenient operation, high water yield and low comprehensive operation cost. The electrode material with high activity is the key to obtain its high performance. According to different water quality conditions, the electrode material which is good for ion adsorption in solution should be studied. The application of this low-energy water purification technology in real life has become a new research hotspot.

1. Introduction
In order to alleviate the serious shortage of fresh water resources in China, it is urgent to develop the deep treatment and reuse technology of sewage. At present, many kinds of water treatment technologies have been developed. The main technologies are reverse osmosis (RO)[1,2], electrodialysis (ED), ion exchange (IE), multistage flash distillation (MSF), multi-effect distillation (MED), steam compression (MVC), NF and EDI. However, the above-mentioned methods have problems such as complex equipment, difficult material regeneration and secondary pollution. Advanced, green and cost-effective deionizaton technology has become a research hotspot[3]. Electro-Sorption Technology (EST) is also known as Capacitive Deionization (CDI). Based on the electrical conductivity and adsorption of activated carbon electrodes, the ions in the solution move towards the electrodes on both sides under the action of electric field, forming a compartmentalized ion zone in the middle for desalination.
2. Overview of desalination methods of water
The desalination of water is partial desalination and complete desalination (depth desalination). Partial desalination occurs when only part of the salt is removed from the water. Desalination is complete when the salt concentration in water is 1 ~5 mg/L. Currently, common desalination technologies for waste water reuse include ion exchange, electrodialysis, ultrafiltration, nanofiltration, reverse osmosis, etc.[4-9]. Electro-Sorption technology (EST) combines theory of electrochemistry with adsorption and separation technology, which can be used for desalination, hardening and desalination of water, deep treatment of drinking water, and treatment of heavy metal waste water. EST is a new water treatment concept with unique advantages in treatment efficiency, adaptability, energy consumption, operation and maintenance, and environmental friendliness. It has a wide range of applications and development prospects[10,11].

3. Principle of Electro-Sorption technology
Most salts in water treatment are ions (positively or negatively charged). The basic idea of Electro-Sorption desalination technology is to apply applied voltage to form electrostatic field and force ions to move towards the electrode with opposite charge, so that ions are enriched in the double electric layer and solution body concentration is greatly reduced, so as to realize desalination of aqueous solution.

Figure 1. Working process diagram

The principle of electric adsorption is shown in the figure 1. Raw water enters the space separated by two electrode plates at one end and flows out at the other end. When raw water flows between anode and cathode, it is affected by electric field. Ions in the water migrate to the electrode with opposite charge, which absorbs them and stores them in the double electric layer. With the increase of ions absorbed by the electrode, the ions are enriched and concentrated on the surface of the electrode, and the separation from water is finally achieved to obtain purified/desalinated product water[12].

In the process of electric adsorption, the storage/release of electric quantity is realized through the absorption/desorption of ions rather than chemical reaction, so it can be quickly charged and discharged. Moreover, since only the absorption/desorption of ions occurs during the charge and discharge, the electrode structure will not change, so the number of charge and discharge is not limited in principle.

When raw water containing a certain amount of salt passes through an electroadsorption module composed of high-functional electrode materials, ions are stored in the double-layer of electrode surface under the action of direct current electric field until the electrode reaches saturation. At this point, remove the dc power supply and short connect the positive and negative electrodes shown in the figure 2.
Due to the disappearance of the dc electric field, the ions stored in the double electric layer return to the channel and discharge with the water flow, and the electrode is regenerated[13].

The treatment effect of electrical adsorption module mainly depends on the adsorption performance of electrode.

4. Application

According to the statistical analysis of the experimental and practical data at the present stage, EST requires the conductivity≤500μS/cm, COD≤100mg/L, turbidity≤5 NTU, SS≤5 mg/L, oil≤3mg/L, and after treatment the conductivity can be reduced by 60%–95%, COD removal rate by 20%–80%, turbidity≤2NTU, SS≤2mg/L, oil≤2mg/L. The treatment effect is related to the comprehensive factors affecting water quality and the combination of EST equipment technology[14].

Depending on the quality, source, and process of the incoming water, EST may be used for:
- water replenishment pretreatment of circulating cooling water system. Reducing the salt content of the replenishment water by electric adsorption method can improve the water quality and further increase the concentration ratio of circulating water and reduce the replenishment and sewage water.
- recycling and reuse of waste water from circulating cooling water system. After desalination, the discharged sewage is used in the circulating cooling water system instead of fresh replenishment, which can reduce the consumption of new water and sewage discharge, and further improve the recycling utilization rate of circulating water. Gao yuan et al. conducted a pilot test to remove salt from the water outside the cooling circulating water of electronic group by using the electric adsorption desalination technology, and achieved a good effect. The water production has been relatively stable in the case of large fluctuation of raw water[15].
- municipal and industrial sewage treatment. For COD and industrial waste water with high salt content, the traditional water treatment technology affects the removal of salt due to high COD, and the electric adsorption can remove the high salt in the waste water, which makes the biochemical method feasible. The sewage after secondary biochemical treatment can be used as the replenishment of circulating water system or the reuse of water in production process. MOON et al. prepared thermal peel GO (TEGO) after 2 min of GO at 250℃, and stirred the material in KOH solution of 7mol/L and then let it be washed and dried. After that, three-dimensional porous graphene was activated in tube furnace. This material was used as the EST electrode material to conduct desalination experiments on low-content waste water. The research results showed that: under the condition of voltage 2.0v and NaCl solution with mass concentration of 74 mg/L, after 25 min of electroadsorption test, the electrode desalination amount was 11.8 mg/g[16].
- the microbial fuel cell (MFC) is assembled with the equipment of electric adsorption and desalination. Although MFC has a low energy output, it can be used as an external power
source to meet the low potential requirements of electric adsorption desalination equipment. Therefore, MFC-driven electric adsorption and desalination device coupling technology is a green technology that drives the electric adsorption and desalination device generated by MFC to achieve ion removal[17].

- industrial water treatment. Textile printing and dyeing, light industry and paper making, electric power and chemical industry, metallurgy and other industries all need a lot of desalination or pure water as process water. According to different water quality standards, electro-adsorption water treatment technology can be combined with traditional desalination technology to reduce operating costs.
- purification of drinking water. Electroadsorption technology can be used for deep treatment of drinking water to remove excessive inorganic salts, such as calcium, magnesium, fluorine, arsenic, sodium, nitrate, sulfate, chloride and even make effective use of some water sources due to excessive inorganic salts. Ma aipeng et al. successfully applied activated carbon fiber as the electrode material for desalination of drinking water. The results showed that the desalination rate reached 90% when the voltage was 2V, the flow rate was 0.56 m/min and the flow length was 330 cm[18].
- desalination of brackish water. Electro-Sorption technology has the characteristics of resistance to scaling of calcium, magnesium, sulfate and other substances, and has an attractive application prospect in brackish water, especially mine water with high salt content and desalination of organic water.
- desalination of seawater. Although the current Electro-Sorption desalination technology is not mature, the electro-adsorption desalination technology has simple equipment, low voltage, low energy consumption and no pollution to the environment. Therefore, if the electro-adsorption desalination technology is applied to seawater desalination, problems such as large energy consumption and complex equipment will be solved[19]. DREWES et al. successfully desalinated the artificially prepared seawater and extracted iodine by electric adsorption desalination technology[20]. Muhammad Wajid Saleem et al. integrated the electrochemical CDI process with the PRO system for high water recovery and salinity power generation with low brine discharge. It has a great potential in military and domestic applications where more energy intensive water purification technologies are not viable[21].

5. The development trend of Electro-Sorption Technology

5.1. With other desalination technology combination, complementary advantages

Due to the low requirements of this technology on raw water pretreatment, in terms of market application, in addition to desalination treatment as an independent operation unit, it can also cooperate with other existing desalination technologies to meet higher water quality requirements.

- in terms of desalination treatment of sewage (waste) water, electro-adsorption pretreatment can be combined with ultrafiltration to conduct in-depth treatment of complex raw water, which can further improve the removal effect and reduce the workload of module cleaning.
- the boiler's make-up water is different according to different water quality standards of different pressure and temperature grades, and has certain desalination requirements; Some process water must be water containing metal ions or extremely low amount of silicon, chlorine and carbonate ions. Electric adsorption water treatment technology can be combined with traditional desalination treatment technology to achieve these purposes in a very low operating cost[22]. High pollution surface water is used as water source to prepare deep desalination, electric adsorption is used as pre-desalination, and then mixed bed desalination system is adopted. The effluent can meet the requirements of boiler make-up water. Reduce acid - base consumption of mixed bed regeneration by 90- 95%.
- considering the reuse value of primary reverse osmosis concentrated water, some low-concentration reverse osmosis concentrated water can be recycled by electroadsorption...
desalination, so as to reduce the amount of concentrated water, improve the water yield of the whole desalination system, and achieve zero discharge of industrial waste water.

5.2. To develop the depth and breadth of Electro-Sorption Desalination Technology
Mainland coastal islands, especially in the northwest, north China's fresh water is lack in mainland China, had to use desalination to solve the water and underground brackish water desalination, the electric adsorption technology has the characteristics of the materials such as calcium, magnesium, sulfate resistance, has unique advantages in brackish water desalination, especially for high salt content and organic matter content such as mine water, brackish water desalination by electric adsorption technology will fully display its advantages. With the gradual reduction of the cost of desalting brackish water by Electro-Sorption water treatment technology, this technology will have stronger market competitiveness[23]. Muhammad Wajid Saleem et al. successfully combined EST with reverse electrodialysis (RED) to use EST for water purification and RED for energy production. It provides a new way to reduce the energy consumption of desalination[24].

At the same time of market operation, the electric adsorption and desalination technology is constantly innovated and improved to meet higher water quality treatment requirements at a lower cost, so as to realize the dream of low cost and high efficiency desalination of seawater.

5.3. Develop new electrode materials
The treatment effect of electrical adsorption module mainly depends on the adsorption performance of electrode. According to different water systems, the electrode materials which are beneficial to ion adsorption in different solutions are studied and developed. It is beneficial to extend the electric adsorption desalination technology to more engineering practice.

6. Conclusion
EST is a green water treatment technology with low energy consumption, high efficiency, easy maintenance, low cost and no secondary pollution formed by rational design and construction of active electrode based on the theory of double electric layer, which is in line with the economic development of modern science and technology. Due to its outstanding advantages such as being free from geographical restrictions, EST has been widely used in many water treatment fields such as hard water softening, seawater desalination and waste water treatment. After comprehensive analysis on the application of electric adsorption desalination technology found in the country is still in its infancy, but electric adsorption desalination technology is a kind of requirements on water quality is not high, reliable operation, low energy consumption, easy operation and high water production rate, low running cost of the new water treatment technology, suitable for further in municipal and industrial sewage (waste) water desalination field intensify popularization, the electric adsorption desalination technology in chemical, petrochemical, metallurgy, electric power, papermaking contour of water industry and nuclear industry waste water treatment and so on has a great potential for application. It is hoped that this low-energy water purification technology will be applied to real life as soon as possible.

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References

[1] Greenlee, L. F., Lawler, D. F., Freeman, B. D., Marrot, B., & Moulin, P. (2009). Reverse osmosis desalination: water sources, technology, and today's challenges. Water Research, 43(9): 0-2348.

[2] Fritzmann, C., L?Wenberg, J., Wintgens, T., & Melin, T. (2007). State-of-the-art of reverse osmosis desalination. Desalination, 216(1-3), 1-76.

[3] Zhang Xumei, Wang Shuang, Gao Juanjuan, Zhang Shupeng, Xie Kangjun, Song Haiou. (2018) Application of capacitive deionizing technology in water treatment. Water Treatment Technology, 9: 16-21.

[4] Cui Yuchuan, Li Siming, Li Fuqin. (2003) Design and calculation of industrial water treatment facilities. Chemical Industry Press, Beijing.

[5] A Buguangxiong. (1991) Modern ion exchange technology. Chemical Industry Press, Beijing.

[6] Zhao Ruilhua. Lin Kaicheng. (2000) Electrodialysis waste water treatment technology. Journal of taiyuan university of technology, 31(6): 721-724.

[7] Feng Yixian, Yang Shichun. (2000) Reverse osmosis water treatment project. China Electric Power Press, Beijing.

[8] Jiang Zhongying, Xia Minfang. (2003) Application of reverse osmosis in water pollution control. Pollution Prevention Technique, 16(1): 21-23.

[9] Tan Yongwen. Zhang Weirun. (2003) Application and development trend of reverse osmosis engineering. Membrane science and technology, 23 (4): 110-115.

[10] Anderson, M. A., Cudero, A. L., & Palma, J. (2010). Capacitive deionization as an electrochemical means of saving energy and delivering clean water. comparison to present desalination practices: will it compete?. Electrochimica Acta, 55(12), 3845-3856.

[11] Zhao, R., Satpradit, O., Rijnaarts, H. H. M., Biesheuvel, P. M., & Van, d. W. A. (2013). Optimization of salt adsorption rate in membrane capacitive deionization. Water Research, 47(5), 1941-1952.

[12] APA Mossad, M., & Zou, L. (2012). A study of the capacitive deionisation performance under various operational conditions. Journal of Hazardous Materials, 213-214(none), 491-497.

[13] Porada, S., Zhao, R., Van, d. W. A., Presser, V., & Biesheuvel, P. M. (2013). Review on the science and technology of water desalination by capacitive deionization. Progress in Materials Science, 58(8): 1388-1442.

[14] Han Han, Chen Xinchun, Shang Haili. (2010). Development and application of electroadsorption desalination technology. Industrial Water Treatment, 30(2): 20-23.

[15] Gao Yuan. (2013). Application of electroadsorption technology in treatment of circulating cooling water. Water Supply and Drainage, 39(3): 51-53.

[16] Li, Z., Song, B., Wu, Z., Lin, Z., Yao, Y., Moon, K. S. (2015). 3d porous graphene with ultrahigh surface area for microscale capacitive deionization. Nano Energy, 11: 711-718.

[17] Feng, C., Tsai, C. C., Ma, C. Y., Yu, C. P., Hou, C. H. (2017). Integrating cost-effective microbial fuel cells and energy-efficient capacitive deionization for advanced domestic wastewater treatment. Chemical Engineering Journal, 330: 1-10.

[18] Ma Aipeng. (2011). Experimental study on electroadsorption and desalination of activated carbon fiber electrode. New technology and new products in China (05).

[19] Georgiadis, J. G., Mari As, B. J., Mayes, A. M., Shannon, M. A., Bohn, P. W. (2008). Science and technology for water purification in the coming decades. Nature, 452(7185): 301-310.

[20] Xu, P., Drewes, J. E., Heil, D., Wang, G. (2008). Treatment of brackish produced water using carbon aerogel-based capacitive deionization technology. Water Research, 42(10-11): 0-2617.
[21] Saleem, M. W., Im, B. G., & Kim, W. S. (2018). Electrochemical cdI integration with process for water desalination and energy production: concept, simulation, and performance evaluation. Journal of Electroanalytical Chemistry.

[22] Ahmed, M. A. & Tewari, S. (2018). Capacitive deionization: processes, materials and state of the technology. Journal of Electroanalytical Chemistry, S1572665718301085.

[23] Xiaoping, L., Xiaoping, F., Bengao, L. (2008). Progress in the preparation of the desalination water technology. Industrial Water Treatment, 28(4): 6-9.

[24] Saleem, M. W., Jande, Y. A. C., & Kim, W. S. (2017). Performance optimization of integrated electrochemical capacitive deionization and reverse electrodialysis model through a series pass desorption process. Journal of Electroanalytical Chemistry, S1572665717302655.