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Research progress of EDI in water treatment and Membrane fouling

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ABSTRACT

In Electrodeionization is used in various water treatments due to its low energy consumption, high efficiency and cleanliness. The application of EDI in various water treatments, including heavy metal wastewater, ammonia nitrogen wastewater, salty wastewater, and organic wastewater purification, are reviewed. Ion exchange resins and membranes are important factors influencing the performance of EDI. The research progress on ion exchange resins and membranes in EDI is described, focusing on the solution to the membrane fouling problem in EDI process. Reducing and preventing membrane pollution in EDI is the focus of current research. Solving membrane pollution problem will greatly promote the development and application of EDI.

Key words: Electrodeionization; Ion exchange resin; Membrane fouling

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1. Introduction

Electrodeionization (EDI) has received more and more attention due to its environmental protection and high efficiency, and has been tried in various wastewater treatments. EDI is essentially a technique that combines ion exchange and electrodialysis. The working principle includes ion exchange, directed migration of anions and cations under electric field, and electrical regeneration of resin[1]. The target ions are transported to the surface of the membrane by the ion exchange resin under the action of the electric field force, and the ion transfer is achieved due to the selective permeability of the ion exchange membrane. At the same time, the water is continuously cracked into H^+ and OH^- under the action of electric field force, thereby realizing resin regeneration. Ion exchange membranes and resins are important components in EDI device components, and their performance characteristics are one of the main factors affecting EDI efficiency.

2. Application of EDI in water treatment

With the continuous development and improvement of EDI technology, EDI has gradually become the mainstream technology in the ultra-pure water preparation process[2],and many researchers use EDI to treat low-concentration metal wastewater.

Xu[3] In the study of EDI treatment of nickel-containing heavy metal wastewater, when the influent concentration was 50.3 mg / L, the final concentration of Ni^{2+} in fresh water and concentrated water was 0.85 mg / L and 1267 mg / L, respectively. The concentration factor reached 25.2 and the process current efficiency was 23.2%. Feng et al.[4] studied EDI treatment of copper-containing simulated electroplating wastewater, and studied the effect of pH and applied potential on copper ion removal rate. The results show that the proper removal of PH value and appropriate increase of applied voltage can achieve better removal efficiency, the removal rate is above 99.5%, and the final effluent Cu^{2+} ion concentration is less than 0.23 mg/L, and the enrichment factor is 5~14. Alvarado et al.[5] used ion exchange and EDI combination process to remove and recover Cr(VI) in wastewater, and 98.5% Cr(VI) was continuously removed by EDI technology. Taghdirian et al.[6] used the EDI method to selectively separate Ni^{2+} and Co^{2+} from dilute solution and used EDTA as a complexing agent. The results show that the EDTA:Ni molar ratio and feed flow rate are the most important parameters affecting process performance. Under the operating conditions, the Ni^{2+}/Co^{2+} ion molar ratio increased from an initial value of 3 to a final value of 154.6.

At present, EDI technology is not only used in low-concentration heavy metal wastewater, but also more and more researchers are widely used in the treatment of other wastewaters such as salt, ammonia nitrogen, high hardness and organic matter.

Yan[7] studied the removal of phosphate and ammonia nitrogen ions in water by EDI technology. The maximum ammonia nitrogen removal rate was 95.0% and the concentration was 1.36 times. The highest phosphate removal rate was 94.5% and the concentration was 1.15 times. It also verified that EDI technology can simultaneously remove and concentrate both phosphate and ammonia nitrogen ions in solution. Zhang et al.[8] studied the simultaneous removal of nitrate and hardness ions from groundwater by EDI technology. The experimental results show that under the optimal parameters, EDI has good separation and recovery of nitrate and hardness ions in actual groundwater. The results showed that NO^{3-} (96.25%), Ca^{2+} (96.69%), and Mg^{2+} (96.13%) had higher removal rates. Jiang et al.[9] studied the continuous treatment of high boric acid solution by EDI technology. When the boron concentration in the aqueous solution is 60mg/L, the boron removal rate can reach 44.8%. When the boron concentration in the aqueous solution reaches 400 mg/L, boron is removed. The rate dropped to 16%. Zheng [10] in the use of EDI technology to concentrate the recovery of ammonia nitrogen, in the 15 mg/L low concentration ammonium ion artificial domestic sewage, the concentration of single-stage concentrated nitrogen up to 12 times, ammonia nitrogen removal rate of more than 90%.

In recent years, studies on the purification of purified solutions by EDI have been used by researchers in the purification of organic solvents and the recycling of organic materials. Yu et al [11] purified 30% caprolactam aqueous solution by continuous EDI. The study showed that the conductivity of the solution after treatment was less than 10 μS/cm and remained stable. After treatment with EDI, 5-ethyldihydro-2 in caprolactam aqueous solution (3H)-furanone, aniline,4,5,6,7-tetrahydrobenzofuranpyrimidine, N-(N-acetyl-l-ananyl)-glycine butyl ester and other organic impurities are reduced in concentration and the adsorption value is lowered. The amplitude is always greater than 20%. It can be seen that EDI technology has certain effects on removing impurities in 30% caprolactam solution. Sun et al.[12] applied a continuous electrodeionization (CEDI) device to the purification of non-aqueous organic solvent N, N-dimethylformamide (DMF) and explored the effects of different voltages and flows on CEDI performance. Since the DMF does not contain water, the resin cannot be regenerated during operation of the EDI unit. Under the experimental conditions, the technical grade DMF was used to remove formic acid (FA), dimethylamine (DMA) and inorganic salts. The results showed that the removal rate of FA can reach 99.1% and the salt rejection rate can exceed 95%. This study shows that CEDI is also feasible for the treatment of non-aqueous solutions.

A large number of experimental studies have shown that EDI technology has good performance in both simulated wastewater and actual water samples. Its high efficiency and low energy consumption make it have broad application prospects.

3. Correlation Study of Ion Exchange Membrane and Resin in EDI

During the EDI process, the applied electric field causes the ions to pass through the ion exchange resin and the membrane in different compartments, and continuously collects and releases ions, thereby forming mass transfer between the membrane and the ion exchange resin [13]. The choice and use of ion exchange resins and membranes have a major impact on the performance of EDI in water treatment.

3.1 Ion exchange resin

In EDI, the quality of the final produced water also depends on the transport of ions from the dilute chamber to the concentrated chamber. The resin not only has the function of ion exchange, but also transports the ions to the surface of the ion exchange membrane. The mixed ion exchange resin is in the electric field. Acts as a conductive medium [14]. The material and filling method of the ion exchange resin will affect the efficiency and performance of the EDI operation.

Liu et al.[14] studied the selective separation process of different ions by the traditional electric double layer theory and Donnan theory, and explained the mass transfer between ion exchange resin and membrane. He investigated the ion transport behavior of different configuration fluids under different operating parameters. It was found that the ion balance analysis of EDI process can help to determine whether EDI is in steady state or in regeneration stage. The order of selective separation rate of different monovalent ions is obtained. Ca^{2+}, Mg^{2+}, K^+ > NO^{3-} > Cl^- > Na^+, consistent with the relative order of conventional ion exchange. Ion balance analysis in EDI process can be used to determine the steady-state of the operating system and select the optimal operating voltage, so as to improve the current efficiency in the water treatment process Wang et al.[15] selected three different types of macroporous strong acid strong alkaline anion exchange resin for concentration, separation and simultaneous purification of low concentration $NiSO_4$ solution. The effects of resin resistance, exchange capacity and water content on the separation performance of EDI were investigated. Studies have shown that the particle diffusion control mechanism has an important influence on the mass transfer of the process. The higher the water content of the resin, the faster the migration of Ni^{2+} ions. The experimental results show that the relatively high resin moisture content is more conducive to the migration of target ions.

In the work of Yeon et al.[16], a layered installation was used for the resin bed in EDI, the bottom layer was filled with cation exchange resin for removing metal ions, the middle layer was filled with anion resin for removing anions, and the top layer was filled with a mixed bed for controlling pH.Such layered filling can effectively prevent metal ions from combining with hydroxide ions to form precipitation, and can remove more than 99% of the ions and achieve a current efficiency of 30%.

Pan et al.[17] fixed the loose ion-exchange resin beads used in the traditional electrodeionization in the experiment to make a porous resin wafer material. The resin wafer was deionized desalination as a research object, and the resin wafer was inspected. Energy efficiency, salt removal rate, current efficiency and yield of electrodeionization seawater desalination. The influence of key operating factors such as processing time, application voltage and feed flow on EDI performance was determined, and the prediction model of productivity and energy consumption was established by using the response surface method. The results show that the deionization of the resin wafer can reach more than 99% of the salt removal rate at 120 min, and finally the energy efficiency of seawater desalination is increased to more than 35%.

3.2 Membrane fouling

EDI has received extensive attention in the purification of various types of wastewater. However, due to the precipitation of metal ions and hydroxide ions in the EDI process, the precipitation of metal hydroxides is caused, which makes the EDI process very restrictive in practical application. At the same time, membrane fouling also exists in the treatment of high-concentration ion wastewater by using EDI technology. Since the ion concentration in the solution is too high, the ion exchange membrane (or resin) will be polluted to some extent. So far, there is very little use of EDI technology. An example of good results in the treatment of high-concentration ion wastewater.

Solving the problem of contamination of ion exchange membranes and resins in EDI operation is the focus of current research on EDI.

The fouling problem in membrane fouling mainly occurs in the side of the concentration chamber close to the anion exchange membrane. Related studies have shown that [1819], the si- de of the rich chamber close to the anion exchange membrane is easily deposited due to OH-ion accumulation. The metal ions combine to produce a precipitate, which causes the surface of the anion to be easily fouled, thereby causing contamination of the membrane. The acid may be appropriately added to the concentration chamber to keep the environment of the concentrated chamber acidic, or a scale inhibitor, thereby inhibiting scale formation of the membrane stack.

Tessier et al.[20] proposed adding a scale inhibitor to the concentrated water and electrode water of the EDI unit. The addition of scale inhibitor can inhibit the growth of precipitation and prevent scale formation. Although concentrated water is added with acid and scale inhibitor to prevent scaling, the use of chemicals is increased, which may reduce the quality of the water and increase the operating cost.

Some researchers have taken the goal of preventing membrane fouling from the perspective of improving the structure of the membrane stack. In the experimental study of Yang [21], a selective ion exchange membrane was added to the middle concentration chamber to divide the concentration chamber into two chambers. The membrane has selective permeability to monovalent anions, preventing Ca^{2+} and Mg^{2+}. The convection of ions to the surface of the yin membrane avoids scaling and achieves separation and recovery of some ions. According to reports [22], filling the cation exchange resin or the anion-cation mixed resin in the rich chamber can effectively prevent fouling of the membrane stack. Xu[3] filled the cation exchange resin in the fresh water chamber to increase the transfer rate of Ni2+; the concentrated water chamber was filled with anion-cation exchange resin of different volume ratio to reduce the stack resistance, increase the stack current, and adjust it. Thick room acid-base environment. The results show that the EDI membrane stack of this structure can be effectively used for the removal of nickel ions in heavy metal wastewater, and at the same time, it can ensure the acidity of the fresh water chamber solution and eliminate the hidden danger of scaling in the fresh water chamber. Dong[2324] introduced a bipolar membrane in EDI and constructed a "bipolar membrane-electrodeionization" (BMEDI) process for the purification of low-concentration NiSO4 solution while concentrating and recovering valuable metal ions. After 19 h, the concentration factor is about 31, and the internal hydrolysis of the product can achieve pre-acidification and inhibit the surface hydrolysis of the resin, and also dissolve a part of the formed metal hydroxide precipitate. No Ni^{2+} was detected in the fresh water effluent, and no $Ni(OH)_2$ precipitated inside the membrane pile.

During EDI ion exchange, periodic reversal of the power supply electrode has been shown to prevent or reduce membrane fouling and scaling due to the pulsating effects on the membrane surface [25]. The electrodeionization reversal method (EDIR), which has been developed in recent years, utilizes the periodic variation of electrode polarity during EDI operation to achieve the goal of reducing and preventing membrane fouling during EDI operation.

Lee et al.[26] studied the performance of divalent cations in hardness materials by divalent cations in experiments. The scale powder for- med on the surface of the membrane was analyzed by SEM (electron microscopy). It was found that the scale material was calcium and magnesium in the form of carbonate, which was mainly formed on the surface of the cation exchange membrane. When the polarity inversion period was less than 40 min, it was confirmed that no scale occurred and the removal effect of divalent cation was high. In another work, Lee et al.[27] also studied the effects of influent concentration, influent flow rate and polarity reversal period on the removal of groundwater hardness by EDIR process. Under the experimental conditions, the removal rate of Ca^{2+} and Mg^{2+} in groundwater can reach More than 60%, and no scaling occurred. 33 Studies clearly show that the electrodeionization inversion system is feasible in a water softening process with no scaling and a reasonable concentration range.

Lu et al.[28] used an EDIR device to remove and recover nickel ions from simulated electroplating rinse water and studied the effect of polarity reversal cycle on EDIR performance when the superimposed voltage was 30V.When the voltage is 30V, the polarity reversal cycle is 4h, and the stepwise stream switching mode is adopted, (namely,the concentrate stream is switched with a short delay of 3 min over the dilute stream) the nickel ion removal rate and concentration coefficient reach 97% and 79.2 respectively with only one unit.

4. Conclusion

Due to its simple process and low energy consumption, EDI has received more and more attention in water treatment and has been applied to various types of wastewater treatment. The actual wastewater has two characteristics of complex ion species and concentration changes. EDI should be widely used in practical engineering. At present, a large amount of mechanism research and experimental data are still needed to provide theoretical basis and feasibility estimation. At the same time, the problem of membrane fouling is still one of the main problems hindering the promotion and application of EDI.

To promote the development of EDI, the focus of future research should be on reducing and preventing membrane fouling. The research direction includes selection of resins or membranes with special properties, modification of membranes, and improvement of membrane stack structure.

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