Applications of Electrosorption Technology in Water Treatment

Subjects: Electrochemistry

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The salt removal from water by using electrosorption has been studied since 1960s, and the application of this technology began in the mid-1990s when Lawrence Livermore National Laboratory developed the first set of electrosorption application devices in 1996.

electrosorption water treatment adsorption mechanism

1. Removal of Salt Ions from Water by Electrosorption

To ensure the safety of industrial and domestic water supply, desalination technology has attracted the attention of many researchers. This concept of “electrochemical desalination” was put forward by Evans and Hamilton [1]. Compared with reverse osmosis (RO) and multi-stage flash (MSF), the electrosorption desalination technology shows low energy consumption, easy operation, and so on. To improve the electrosorption desalination ability of graphene, Ahmed’s group prepared graphene/SnO2 NPs composite materials by microwave method as CDI electrodes, and this ability was significantly better than that of original graphene [2]. In addition, Zhang et al. prepared graphene/carbon aerogels (GCCAs), which achieved the best salt adsorption capacity (SAC) of 26.9 mg/g under the condition of 500 mg/L NaCl [3]. Furthermore, carbon aerogels were also prepared by carbonizing the composite of PANI and GO, whose adsorption capacity was 15.7 mg/g under the conditions of 500 mg/L NaCl and 1.2 V applied voltage [4]. Wang’s group prepared graphite porous carbon nanosheets (GPCSs) by activating and graphitizing straw waste as the electrode material, and the electrosorption capacity of the sample for 500 mg/L NaCl solution is 19.3 mg/g when 1.2 V voltage was applied [5]. Due to the low cost of biomass derivatives, Lu’s team synthesized porous carbon nanoflakes (PCNs) by using xylose as the carbon source through the carbonization, and the maximum SAC of PCNS CDI electrode for 1000 mg/L NaCl solution reached to 16.29 mg/g when the voltage of 1.2 V was applied [6]. Additionally, Li et al. obtained phosphorus (P)-doped carbon nanofiber aerogel (P-CNFA) by using bacterial cellulose as the raw material via freeze-drying and heat treatment, and the SAC of P-CNFA reached 16.20 mg/g for 1000 mg/L NaCl solution under working voltage of −1.2 V [7]. Therefore, salt ions will be removed efficiently via electrosorption technology.

2. Removal of Heavy Metal Ions and Other Harmful Ions from Wastewater by Electrosorption

The rapid development of industry leads to the increasing water pollution caused by heavy metals, which not only poisons aquatic organisms in water, but also endangers human health. The traditional treatment methods for heavy metals in wastewater mainly include chemical precipitation, coagulation–flocculation, flotation, ion exchange, membrane filtration and adsorption [8]. However, the above methods have some limitations. In 1997, Farmer et al. utilized the capacitive method to remove Cr^{6+} efficiently [9]. Subsequently, Oda's group investigated the removal effect of Cu^{2+} and Zn^{2+} by using AC electrode, and then successfully introduced CDI technology into the field of heavy metal ion removal [10]. To research the influences of surface modification on the capacity of ACF cloth for heavy metal ions adsorption/electrosorption, Huang et al. conducted the adsorption and electrosorption of Cu^{2+} in wastewater by using different modified ACF cloth electrodes [11]. The results showed that the removal degree for the electrosorption was 2.2 times higher than that for the adsorption. In addition, Dai's group used AC as an electrode for the electrosorption of As (III) in an aqueous solution, and found that the electrosorption capacity increased with the increase in voltage, initial As (III) concentration, and pH [12]. Furthermore, Huang's group investigated the removal rate of Cd^{2+}, Pb^{2+}, and Cr^{3+} as well as the mixture by using CDI system and found that the electrosorption can effectively remove these metal ions and the removal rate was positively correlated with the applied voltage [13]. To our knowledge, MnO_2/carbon composites have a high adsorption capacity for heavy metal ions in wastewater. Thus, Hu's group prepared MnO_2/CF composite materials via an electroplating method as the electrical adsorption electrode [14]. The adsorption capacity of Cu^{2+} for MnO_2/CF composite electrode reached 172.88 mg/g under a working voltage of 0.8 V, which was more than two times for ordinary MnO_2 adsorbent in the absence of an electric field. Moreover, Liu and co-workers fabricated activated carbon cloth/graphene oxide composite (ACC/GO) by vacuum filtration process, which was used as the CDI electrode to remove Co^{2+} and Cs^{+} in water. When 1.2 V voltage was applied to the composite electrode, the maximum adsorption capacity of Co^{2+} and Cs^{+} can reach 16.7 mg/g and 22.9 mg/g, respectively, under the condition of the $CoCl_2$ solution concentration and CsCl solution concentration of 20 mg/L [15]. Due to the low cost and high capacitance of MnO_2, Li's group synthesized α-MnO_2 nanoparticles by the hydrothermal method, combined with carbon fiber paper (CFP), to obtain α-MnO_2/CFP as CDI electrode material [16]. The results show that the removal capacity of nickel ion for the composite reached 16.4 mg/g more than twice that for activated carbon under the same electrosorption conditions. Therefore, the electrosorption behaviors for different metal ions and harmful ions by the CDI system exhibit an obvious difference.

3. Removal of Various Organic Compounds from Wastewater by Electrosorption

Due to the demand of the agriculture, various herbicides and fertilizers used in this field have caused water pollution. In addition, methylene blue (MB), other colorants and urea phosphorus compounds are widely used in the printing and dyeing industry, and these organics will cause damage to the water environment. Therefore, the electrosorption method is also applied in the removal of various organic compounds in wastewater. Yue and co-workers reported a kind of rGO/SWCNTs film as the CDI electrode for removing MB [17]. For this system, PS was used as a template to introduce GO sheets for creating large pores and SWCNTs were distributed between the films for generating efficient pathways of ion diffusion. Consequently, the maximum adsorption capacity of

rGO/SWCNTs film reached to 13,014.3 mg/g when applying −1.2 V voltage, and the capacity retention kept nearly 100% after five recycles. Furthermore, this group synthesized porous MXene/SWCNTs film as a CDI electrode for the removal of organic dyes in wastewater, and the maximum adsorption capacity was as high as 28,403.7 mg/g when applying −2.4 V voltage [18]. In addition, the researchers prepared carbon foam electrodes derived from waste cigarette filters/zeolitic-imidazolate frameworks-8 (ZIF-8) composites [19][20][21][22][23][24], and found that the maximum electrosorption capacity of MB for these carbon foams reached to 1846.7 mg/g when applying −1.2 V voltage. Under most conditions, the adsorption time of methyl orange (MO) solution using most water treatment methods is more than 1 h. Whereas, Liu and co-workers used the holey graphene hydrogel (R-HGH) prepared by one-step hydrothermal method as the CDI electrode [25]. When 0.6 V voltage was applied to the R-HGH, the electrosorption capacity for 100 mg/L MO solution was 57 mg/g, and the adsorption equilibrium time could be within 200 s. Therefore, electrosorption can provide an effective route for the removal of typical organic compounds.

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