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High-performance capacitive deionization electrodes through regulated electrodeposition of manganese oxide and nickel-manganese oxide/hydroxide onto activated carbon

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ABSTRACT

Capacitive deionization (CDI) can directly produce freshwater from brackish water through electrostatic force which is applied to porous electrodes for ion adsorption. The adsorption capacity can be extended by not only physical surface area but also pseudocapacitive behavior on metal oxide. Here, we enhanced CDI performance of microporous activated carbon (AC) electrode by regulated electrodeposition of Ni and Mn metal hydr(oxide). Metal hydr(oxide) coating increases the electrosorption capacity (Mn only: 6.81 mg g^{-1} and Mn with Ni: 6.46 mg g^{-1}) and CDI performance compared to pristine AC electrode (3.67 mg g^{-1}) due to synergistic influence of an electric double layer-based and pseudocapacitive-based capacitance. By comparing capacitance depending on the ratio of Mn to Ni, we revealed that incorporation of small Ni amount in Mn oxide matrix contributes to increase electrochemical capacitance. Furthermore, Ni also plays a role in improving adsorbed salt desorption, achieving higher long-term stability compared AC and only Mn-coated AC electrodes.

1. Introduction

Several countries, such as United Arab Emirates and Saudi Arabia, have invested in desalination technologies to address water scarcity [1]. Reverse osmosis and thermal distillation techniques have been the primary methods of producing freshwater from saltwater [2]. Despite the maturity of these technologies, they still suffer from high energy consumption and high start-up/operation costs [3,4]. Capacitive deionization (CDI) is an alternative technology that has the potential to mitigate the issues of conventional desalination technologies. It only needs a small energy input for the process and does not require high-pressure pumps or heat generators to facilitate salt removal [5–7]. Unlike the other technologies, CDI directly separates salt from water through electrostatic adsorption of ions on the electrode surface which is polarized by an applied electric field. Once the surface of CDI electrode became saturated with salt ions, the applied potential is reversed or short-circuited to regenerate the electrode for next process cycles [8,9]. CDI is not only used for desalination but also water softening and water remediation if the pollutant has a charge to be electrically adsorbed on electrode [10,11]. Currently, CDI faces challenges in developing electrode materials with high ion capacity and excellent energy/cost efficiency, limiting its commercialization and large-scale application.

Porous carbon has been chosen as traditional CDI electrode materials because of its ability to store electrolyte ions on the electric double layer which is the interface between electrode and electrolyte. Hence, the available area for non-faradaic reaction such as ion adsorption is proportional to only surface area of electrode material [10]. On the other hand, some metal oxides involve faradaic reaction such as metal oxidation/reduction reaction in the range of CDI operation potential, and it leads to increasing CDI performance by forming pseudocapacitive (at or near-surface adsorption) or battery-like (bulk adsorption) capacity [12–15]. Mn-based oxides have been widely used as pseudocapacitive materials for CDI because of their high theoretical capacitance, low cost and environmental friendliness [16]. Recently, Zou *et al.* have fabricated an asymmetric CDI cell with $MnFe_2O_4$-rGO/MnO_2-rGO electrode pair [17]. CDI tests revealed a salt adsorption capacity of 38.28 mg g^{-1}

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