Enhanced Capacitive Deionization by Dispersion of CNTs in Activated Carbon Electrode

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Supporting Information

ABSTRACT: Energy-effective, ecofriendly desalination is a technology in universal demand due to global water scarcity. Capacitive deionization (CDI) is a promising method that has those advantages, but it is still necessary to enhance desalination performance to desalinate high-concentration raw salt water. In this work, carbon nanotubes (CNTs) are used as a conductive agent of the CDI electrode. To use CNTs as a conductive agent, we examine the effect of the dispersion status of the CNTs within activated carbon active material on the CDI performance. Acid treatment-functionalization of CNTs created a better dispersion status than CNTs without any treatment. Homogeneously dispersed CNTs showed enhanced electrochemical and desalination performance. Interestingly, desalination tests with highly concentrated raw salt water achieved a more notable improvement with 13.9% at only 1 wt % of CNT dispersion. The improvement mechanisms with dispersing CNTs such as increment of surface area and decrement of electrode resistivity are analyzed.

KEYWORDS: Capacitive deionization, CDI, Carbon nanotube, Activated carbon, Desalination, Functionalization

INTRODUCTION

Because of increasing water evaporation due to global warming, the drastic increase in population, and the increase in water needed for industrial use, desalination of saline water has become one of the most demanded technologies. Existing technologies such as thermal evaporation or reverse osmosis (RO) have advantages for large-scale desalination of seawater. However, they are associated with high energy consumption. An ion-exchange technology is a widely used technique for desalination. It separates ionic matter in saline water, but after the process, it is necessary to regenerate the resins, which creates more energy and waste fluid.1

Capacitive deionization (CDI) has been proposed as a promising alternative method for the desalination process, due to its good performance.2 Furthermore, it has been proposed to be of low-energy consumption and an environmentally friendly process due to its regenerative electrodes. This process uses electrical double layers (EDLs) to adsorb ions of the saline water. Carbon materials, such as activated carbon, carbon aerogels, carbon nanotubes, carbon nanofibers, and graphenes are promising materials due to their high specific surface area, high electrical conductivity, and hydrophilicity.3–5

Therefore, recent papers on CDI have focused on the carbon nanomaterials as electrode materials. They have a large number of mesopores and a large specific surface area. Furthermore, they possess extraordinary electrical conductivity due to their sp2 carbon structure. Li et al. fabricated a carbon nanotube (CNT) and reduced graphene oxide (RGO) composite, and used it as an electrode for the CDI system.6 They made an interesting theoretical analysis of CNT and RGO composites and their use in the CDI system. Wilimlasiri et al. also studied the CNT/graphene composite for the CDI electrode, and it was demonstrated that it had an extraordinary electrochemical and desalination performance.7 The Dengsong Zhang group has been actively analyzing the effects of nanostructures and surface properties on the desalination properties through the use of graphene, CNT, and meso-/microporous carbon. These efforts have been expanding the possibilities of future CDI electrodes using carbon nanomaterials.8–10 There are many other research studies of emerging carbon nanomaterials such as...
as CNTs, graphenes, graphene aerogels, carbon nanofibers, nitrogen-doped graphene sponges, and porous carbon spheres, for use as CDI electrode active materials (electrosorption materials), and those ideal nanomaterials are showing promising desalination performances.\textsuperscript{11−22}

However, regardless of great performance of carbon nanomaterials, only the activated carbon is generally used for commercial CDI systems, since it is much cheaper than other ideal carbon nanomaterials. It is abundant and can be obtained from nature. Although the theoretical efficiency of the material has more disadvantages than other carbon materials, the commercial advantage of activated carbon is overwhelming. The activated carbon CDI system is already being briskly commercialized for the water and sewage industry, ultrapure water, and household water softeners. However, it still needs more improvement of efficiency to be used in high-concentration desalination areas such as seawater or factory wastes.

In this research, we focused on combining those two advantages of the ideal properties of carbon nanomaterials and the extremely low cost of activated carbon. The goal of this research was to enhance the commercially existing activated carbon CDI system by adding a limited amount of carbon nanomaterial, CNTs. We used CNTs as the conductive agent for the CDI electrode. The typical CDI electrode contains active materials, binders, and conductive agents. Even some of the studies using carbon nanomaterials as electrode active materials included a small amount of graphite powder or carbon black as the conductive agent.\textsuperscript{3,4,18} However, we believe that CNTs have more potential for use as a conductive agent due to their excellent electrical conductivity and unique 1D structure. In this research, we used CNTs as a conductive agent to reduce several kinds of resistance of the electrode, namely, resistance between each activated carbon powder and the contact resistance between activated carbon slurry and a graphite foil.

Low-dimensional nanomaterials like CNTs have unique properties due to their extremely high aspect ratio. They also suffer from agglomeration due to their high aspect ratio. The van der Waals force plays a more crucial role in low-dimensional materials on a nanoscale.\textsuperscript{23,24} For prevention of agglomeration problems, the CNTs require a functionalization process. In this research, CNTs were functionalized by an acid treatment process.\textsuperscript{25,26} A small amount of CNTs with and without the functionalization process were dispersed in the activated carbon active material as a conductive agent. To determine the improvement mechanism of the CNTs in the CDI electrode, we determined the electrochemical properties with a cyclic voltammetry (CV) test and electrochemical impedance spectroscopy (EIS) test. Desalination properties at low and high concentrations of saline water were characterized to interpret the effect of the dispersion stability of the CNTs on the CDI system.

\section*{Experimental Section}

\textbf{Fabrication and Characterization of a CNT/Activated Carbon Composite Slurry.} Multiwalled CNTs fabricated by chemical vapor deposition were obtained from Hanwha Nanotech (CM-95). The CNTs were acid-treated with $\text{H}_2\text{SO}_4$ and $\text{HNO}_3$. For the 0.2 g of CNT, 75 mL of $\text{H}_2\text{SO}_4$ and 25 mL of $\text{HNO}_3$ were used to generate functional groups on the surfaces of the CNTs. After a 12 h sonication process in the acid, the functionalized CNTs were centrifuged and washed for neutralization. The functionalized CNTs were sonicated for 12 h in 20 g of $\text{N, N}$-dimethylacetamide (DMAc, anhydrous, 99.8\%, Sigma-Aldrich). The amount of the CNTs was varied between 0.01 g (0.1 wt %) and 0.1 g (1 wt %). The same amount of CNTs without acid treatment was also dispersed in DMAc for a control experiment. After a 12 h sonication process in the acid, the functionalized CNTs were centrifuged and washed for neutralization. The functionalized CNTs were sonicated for 12 h in 20 g of N,N-dimethylacetamide (DMAc, anhydrous, 99.8\%, Sigma-Aldrich). The amount of the CNTs was varied between 0.01 g (0.1 wt %) and 0.1 g (1 wt %). The same amount of CNTs without acid treatment was also dispersed in DMAc for a control experiment. After the dispersion of the acid-treated CNTs, 10 g of activated carbon and 0.437 g of PVDF were dissolved in the solution as an active material and a binder. The solution was mixed with a planetary centrifugal mixer (THINKY, ARE-310) at a 2000 rpm rotation speed and 30 min holding time.

The microstructure and surface-area measurement of the slurry were characterized by scanning electron microscope (Hitachi S-4800,
were calculated from the CV curves according to di working electrode material loaded on the graphite foil (g), and scan rate (V/s) of the test.3

Graphite electrodes were dipped for 10 s and dried in hot air at 80 °c for 30 min. Graphite electrodes were dipped for 10 s and dried in hot air at 80 °C for 30 min.

Both coating solutions were maintained at a temperature and 1000 cP viscosity. Activated-carbon-coated graphite electrodes were dried at 80 °C for 1 h in air. Electrochemical characterization of the electrodes was performed by Zive SP1 (Wonatech) and a plate test cell (PTC1) with a 1 cm² working area. All electrochemical measurements were done with a three-electrode method. A CNT/activated-carbon-coated graphite electrode served as the working electrode, while a Ag/AgCl electrode and a graphite rod were used as a reference and a counter electrode, respectively. The characterizations were carried out in a 0.5 M KCl aqueous electrode. EIS measurements were performed in a frequency range from 10 kHz to 0.01 Hz. A cyclic voltammetry test was done between −0.5 and 0.5 V (versus Ag/AgCl reference electrode) at different scan rates of S and 50 mV. The specific capacitance (in F/g) was calculated from the CV curves according to

\[
C = \frac{\int i \, dt}{Mv}
\]

where \(i\) is the average current (A), \(M\) is the measured mass of the working electrode material loaded on the graphite foil (g), and \(v\) is the scan rate (V/s) of the test.

Contact angle of the activated carbon electrode without ion-selective binder coating was measured by an SEO Phoenix300 instrument, to confirm the hydrophilicity change of CDI electrodes. Contact angles of 0, 3, 5, and 10 s were measured.

CDI Characterization and CDI Experiments of CNT/Activated Carbon Electrode. For characterization of the CDI performance of the electrodes, the prepared electrodes were dip-coated in an ion-selective binder synthesized by Innochemtech Co., Ltd. (negative-ion-selective binder, INC-ITA (aminized); positive-ion-selective binder, INC-ICS (sulfonated); both based on poly phenylene oxide). Positive- and negative-ion-selective activated carbon electrodes were fabricated by a dip-coating process. Both coating solutions were maintained at a 25 °C temperature and 1000 cP viscosity. Activated-carbon-coated graphite electrodes were dipped for 10 s and dried in hot air at 80 °C for 30 min.

As shown in Figure 1, two electrodes were connected to a potentiostat and placed against each other. Furthermore, for effective recovery of the electrodes, each electrode was dip-coated with the aforementioned ion-selective binders. The saline water was supplied to the cell using a pump with a flow rate of 30 mL/min. The NaCl concentrations of saline were 250 and 1000 ppm. A voltage of 1.2 V was applied to the electrode system during the saline water flow. A conductivity measurement system was connected to the outlet of the cell, to characterize the NaCl concentration of the desalinated solution.

RESULTS AND DISCUSSION

In this study, two kinds of CNTs were inserted as conductive agents for the activated carbon electrode. One was pristine CNTs without any functional treatment (NCNT); the other was nitric- and sulfuric-acid-treated CNTs (functionalized CNT, FCNT). Although the FCNTs were covalent-functionalyzed and had many defects which can lower the electrical conductivity of the CNT,27 this research suggests that the dispersion status of the conductive agents is more important than their intrinsic property (conductivity). Figure 2 shows the scheme of the structure of the electrode that was used in this research. The CDI electrode contained three layers, the current collector, the active layer, and the ion-selective polymer layer. Graphite foil was used as a current collector. For the active layer, activated carbon was used as the active material. The two kinds of CNTs were dispersed in the active layer to enhance the conductivity of the active layer. Finally, positive- or negative-ion-selective (sulfonated or aminized, respectively) polymer layers were coated on the activated carbon active layer. Without the CNTs, the electrode consisted of a commercialized CDI system from Siontech Co., Ltd.

First, we conducted acid treatment of the CNTs. Acid treatment was processed using sulfuric and nitric acid, and a following ultrasonication process. For precise control of the test parameters, the CNT length before and after the acid treatment should not be significantly different. From the SEM image, it might be confirmed that our acid-treatment conditions did not change CNT length significantly (Figure S1).

For determination of the result of the acid treatment of CNTs, FT-IR, Raman, and ζ potential analysis were conducted. The CNTs that we used (CM-95, Hanwha Chemical) already contain a small amount of functional groups such as the C=O...
(1715 cm$^{-1}$) peak during the fabrication process (Figure S2). After further acid-treatment-functionalization was conducted, some characteristic peaks appeared. The newly appeared C—H (around 620 cm$^{-1}$) and C—O (around 1075 cm$^{-1}$) peaks show that CNTs were further functionalized. More evidence for functionalization is obtained from Raman analysis (Figure S3). Raman spectroscopy from the CNT has two characteristic peaks, which are the G band and D band. The G band generally indicates the graphitization and crystallinity of the CNT, and the D band shows the defect of the CNT. Defect of the CNT is usually related with the functionalization of the CNT. The $I_D/I_G$ ratio of NCNT and FCNT was calculated. After acid treatment, the $I_D/I_G$ of the CNT is increased from 0.92 to 0.97. These results clearly show that the acid treatment of CNT using sulfuric and nitric acid has been successful. Dispersion stability and status of the CNTs in the DMAc solution was determined by $\zeta$ potential analysis. The absolute value of the $\zeta$ potential before and after acid treatment increased from $-24.90$ to $-43.76$ mV. Through the acid treatment, entangled CNTs became untangled, and dispersion stability was increased because of newly formed functional groups. It is expected that the acid-treated CNTs which have high dispersion stability can cause a higher electric conductivity improvement of the electrode than the pristine CNTs.

Figure 3a shows the microstructure of activated carbon powders with a size of around 10 μm and porous structures.

After the mixing process with the activated carbon, with DMAc, PVDF, and CNTs using the planetary centrifugal mixer, the slurry was coated on a graphite foil. The graphite foil had a 300 μm thickness, and the coated slurry formed a 150 μm uniform thickness. Figure 3c,d shows SEM microstructure images of 1 wt % NCNT- and 1 wt % FCNT-dispersed activated carbon slurry. Figure 3c shows the activated carbon slurry, which contains CNTs without any treatment and has agglomerated CNTs on the surface of the activated carbon. However, FCNT-dispersed slurry does not have entangled CNTs because of their covalent functional groups. Homogeneously dispersed FCNTs might have connected to activated carbon particles in the slurry, and this phenomenon would increase the electrical conductivity of the electrode.

The change of hydrophilicity of the activated-carbon-coated electrode by CNT addition was evaluated with contact angle measurement (Figure S4). However, there was no significant change in contact angle with or without CNTs and with or without the acid-treatment process. It is considered that the small amount of CNT (0.1–1 wt %) does not contribute significantly to change of the contact angle.

**Electrochemical Behavior of the CNT-Dispersed Activated Carbon Electrodes.** On the basis of the above suggestion, it is expected that the FCNT-dispersed activated carbon electrode would show enhanced conductivity. The superior electrical conductivity of the electrode indicates that it possesses easy electrolyte (saline water) penetration and low diffusion resistance of cations and anions to the pores. From these characteristics we might expect an enhanced CDI performance in the activated carbon electrode with homogeneously dispersed CNTs. For confirmation of the electrical conductivity enhancement of the CNT-dispersed electrode, EIS tests were performed (Figure 4). In this research, electrochemical properties were characterized with a fragment of the commercial electrode without an ion-selective binder-coated
layer. EIS results of the CNT-dispersed electrodes show significantly reduced resistivity.

Because of the unstable interface property of the electrode material (activated carbon or CNT-dispersed activated carbon) and the current collector (graphite film), the EIS results did not show the typical shape of other EDL capacitors. However, the EIS results of the electrodes with or without CNTs are still powerful enough to confirm the effect of dispersion status of the CNTs on the resistivity of the electrodes. In this research, the initial point of the EIS graph (at 10^4 Hz) was assumed as the resistivity of each electrode.

Without any functionalization process, the enhancement of the conductivity of NCNTs was limited because of their agglomeration and entanglement. Nevertheless, because of the high intrinsic electrical conductivity of CNTs, electrodes with NCNTs have still shown an increase in conductivity, but the effect was only marginal (Figure 4a).

For the 0.1 wt % functionalized CNT-dispersed electrodes, 1/3 of the resistivity was decreased compared to the intrinsic activated carbon electrode. However, when the amount of functionalized CNTs increased up to 1 wt %, the resistivity changed slightly from 9.7 to 9.4 Ω (Figure 4b). It seems that 0.1 wt % is a sufficient amount of CNTs in the activated carbon electrode to achieve efficient reduction in resistance.

The specific capacitance measurement was conducted by using a CV charge–discharge experiment with a 3-electrode method (Figure 5). At a 50 mV/s scan rate, it seems that the effect of reduced resistivity on specific capacitance of the electrode takes dominance over that of the surface area. When 1 wt % of FCNTs was added, the specific capacitance was increased by 13%, and when only 0.1 wt % of FCNTs were dispersed, the specific capacitance increased by 10.2% over the pure activated carbon electrode. However, for a low scan rate (5 mV/s), the specific capacitance was not drastically enhanced by adding CNTs. Furthermore, for the 1 wt % NCNT-added electrode, the specific capacitance was decreased by 3.4% even though it had enhanced electrical conductivity. Figures 2 and 3c, which indicate an agglomerate microstructure of the NCNT-added activated carbon electrode, can show this specific capacitance drop. Homogeneously dispersed FCNTs can enhance not only the electrical conductivity but also the surface area. However, in the NCNT-added electrode, CNTs were entangled, and they could be blocking the pores which can act as electrochemically active sites.

Those suppositions which explain the relativity of the dispersion status of CNTs and capacitance can be interpreted by the BET specific surface-area measurement. The BET surface-area results of the activated-carbon-based electrodes show the expected data. The total specific surface area of the electrode was not drastically increased or decreased (Figure 6).

The CNTs were agglomerated, and they clogged the micropores, which reduced the specific surface. When the CNTs were homogeneously dispersed, the electrodes showed an increased specific surface area due to the added “surface” by the CNTs.

Those results of electrochemical properties can be related to the performance of CDI. From the results, we suggest a few mechanisms of CNTs in the CDI electrode as conductive
agents. With homogeneously dispersed CNTs, electrochemical properties and pore structure improve. First, the EIS test revealed that the resistivity of the electrode had been drastically decreased. Although the shape of the curves was not clearly analyzed due to the irregular surface of the graphite current conductor, it is confirmed that the resistivity of the electrode would decrease, and the effective voltage which can be applied to each part of the activated carbon active material would be higher. 

Second, which can be related to the first mechanism, because of the reduced resistivity of the activated carbon powders, the ions can easily penetrate the inner mesopores of the activated carbon powders. For a low scan ratio (5 mV/s), the ions have sufficient time to be adsorbed into the inner mesopores of the activated carbon powders; however, for a high scan ratio (50 mV/s), the existence of homogeneously dispersed highly conductive CNTs plays a greater role than that for a low scan ratio. Last, the increased specific surface area due to dispersed CNTs could be positively affected by the adsorption property of the electrode. However, for the NCNT-dispersed electrode, which has saturated NCNTs, the NCNTs could then be aggregated, which would lower the specific surface area and the electrochemical properties. Those enhancing or degrading mechanisms of FCNTs and NCNTs are summarized in Figure S5.

Desalination Properties and the Mechanisms of the FCNT-Dispersed Electrodes. For measuring desalination properties of CNT-dispersed electrodes, the pure activated carbon electrode and 1 wt % CNT-dispersed electrodes were used. Two types of characterizations were performed: One was 250 ppm of NaCl dissolved deionized (DI) water which was at a relatively low concentration, and the other one was 1000 ppm of NaCl solution which was chosen for highly concentrated saline water to be desalinated. The experiments were conducted at Siontech Co., Ltd. Photographs and a schematic description of the desalination system are shown in Figure 1. Interestingly, unlike the other CDI desalination electrode system, we did not use the ion-selective membrane but the positive- and negative-ion-selective polymers which were dip-coated on the surface of the electrode. (The schematic image of the ion-selective binder-coated electrode is depicted in Figure 2.) As the saline water penetrates between the negatively and positively charged electrodes, the sodium and chloride ions attach to the electrode, and the desalination property is measured via checking the conductivity of the outlet.

Figure 7 indicates the desalination property of the electrodes in 250 ppm of NaCl solution. The CNT-dispersed electrode showed enhanced desalination. In this research, 5–180 s was set as one cycle. In this research, removal capacity of the electrodes was calculated by the following equation:

\[
\text{percentage of salt removal} = \frac{C_i}{C_0} \times 100
\]

where \(C_0\) is an initial saline water concentration, and \(C_i\) is an average value of desalinated salt during the given time (5–180 s). 

Average values of 5–180 s after the voltage was applied to pure activated carbon and 1 wt % FCNT-dispersed electrodes were 46.5 and 28.8 ppm, respectively. They show 81.4% and 88.5% desalination. Only 1 wt % of CNTs can enhance about 7% desalination for 250 ppm of NaCl solution. However, 1 wt % of an NCNT mixed electrode, which has a poor dispersion status, had a 42.1 ppm average concentration, which limited enhancement on CDI.

The result can be compared to other results, and it is summarized in Table S1. Novel carbon-based nanomaterials such as CNTs and graphene have extraordinary specific surface area, electric conductivity, and easily controllable hydrophilicity. Therefore, some previous results, which used carbon-based nanomaterials as the active material, show higher removal capacity than the current result. However, the important point of this study is that the addition of a very small amount of CNT (0.1 wt %) to the activated carbon electrode, which is being commercialized because of its low cost, greatly improves desalination performance.

The result with 1000 ppm of NaCl solution, which is high-concentration saline water, shows a more significant finding (Figure 7b). If the desalination is calculated the same way as 250 ppm saline water (average of 5–180 s), desalination performance of the 1 wt % FCNT-dispersed electrode was not significantly enhanced and was from 34.1% to 34.4%. However, the desalting performance around the first 30 s was significantly enhanced. The average desalination between 5 and 30 s was increased from 66.8% to 80.7% by adding FCNTs. This graph gives a clear demonstration of the effect of homogeneous dispersed CNTs on desalination. The improvement mechanisms of the CNTs for desalination are similar to those of the electrochemical property. Because of reduced resistivity of the electrode, sodium and chloride ions can easily penetrate into the small mesopores of the activated carbon. Furthermore, there are more enhancing mechanisms by the distribution of CNTs.

S. Porada et al. minutely explained that there are several important electrochemical reactions and processes in CDI electrodes. They are capacitive ion storage, ion kinetics, and...
chemical surface charge which are classified as non-Faradaic processes, and carbon redox reactions, water chemistry, and carbon oxidation, which are classified as Faradaic reactions. Of course, the main reaction of the mechanism of CDI is capacitive ion storage, which is determined by the surface area and pore distribution. As mentioned earlier, CNTs can increase the surface area of the electrode. Acid-treated functionalized CNTs had carboxyl functional groups on their surfaces. Because of them, a “chemical surface charge” mechanism might occur, and they accelerate H/OH transport rates around the micropores; it can also influence the flux of sodium and chloride ions. This process can explain the drastically enhanced desalination performance in high-concentration raw water.

A durability test of two electrodes was also performed with 250 ppm saline water. The FCNT-dispersed electrode showed enhanced desalination performance during the repetition (Figure 8). After 10 cycles of tests were repeated, desalination performances did not decrease after the first cycle. Our experiment confirmed that the addition of a small amount of homogeneously dispersed CNTs into commercially available electrodes can improve desalination performance without any side effects such as reduction in durability of the electrodes.

A charge efficiency ($\eta$) is a useful tool to show the correlation between the amounts of charge applied and the amount of ion actually adsorbed. However, there was no significant difference in charge efficiency with and without CNTs (from 97.4 to 97.6). In this study, ion-selective positive and negative binders were coated on electrodes to control external factors including dissolved oxygen. Therefore, it is considered that most of the applied current is used for the adsorption of ions because there are very few external elements that can reduce charge efficiency. The detailed calculation process about the charge efficiency is demonstrated in the Supporting Information (Figure S6).

### CONCLUSION

In this research, we determined the effect of the dispersion status of CNTs as a conductive agent in the CDI electrode on the desalination property of the CDI process. Electrochemical properties of agglomerated (NCNTs) and homogeneously dispersed functionalized (FCNTs) CNTs containing an activated carbon electrode were compared to interpret the effect of the dispersion effect. Homogeneously dispersed CNTs reduced the resistivity of the electrode and increased the specific surface area of the electrode. However, without the functionalization process of the CNTs, they easily agglomerated and blocked the internal pores which could adsorb the ions. Specific capacitances of dispersed FCNTs were increased 6.6% (at 5 mV/s) and 13.3% (at 50 mV/s) by adding 1 wt % FCNTs. We suppose that homogeneously dispersed CNTs reduce the resistivity and increase the specific surface area of the electrode.

Furthermore, the FCNT-dispersed electrode showed an enhanced desalination performance. Two kinds of measurements were conducted: One was low-concentrated (250 ppm), and the other was high-concentrated (1000 ppm) saline water. Above all, the highly concentrated desalination more drastically improved the performance by 13.9% at 1 wt % of FCNTs. With increased surface areas due to homogeneously dispersed FCNTs, their surface functional groups and reduced electrode resistivity can upgrade the existing activated carbon electrode by adding a small amount of CNTs.

The bottom line of this research is based on the commercial activated carbon electrode. With grafting by a small amount of nanomaterial (CNTs), desalination can be conspicuously improved. This concept will affect the future application of CDI technology.

### ASSOCIATED CONTENT

* Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acssuschemeng.7b01750.

- SEM images, FT-IR, and Raman spectroscopy of CNTs; wettability of activated carbon electrodes; schematic illustration; current change during the desalination tests; and comparison of salt removal with the literature (PDF)

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![Figure 8. Durability test of the electrodes. Part b is an expanded graph of part a.](image)
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