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Note

Brackish Water Desalination by Capacitive Deionization using Nanoporous Carbon Aerogel Electrodes

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Abstract

Capacitive deionization or otherwise called electrosorption is a collection / discharge process which relies on the formation of double-layer supercapacitor at the solution/electrode interface. The process needs micro- or nano-porous electrodes with very high specific areas and high salt sorption capacities, such as carbon aerogel, activated carbon cloth, carbon nanotubes and nanofibres.

The objective of this study is to elucidate the efficiency of capacitive deionization on desalination of a brackish water sample containing 1000 mg/L NaCl using nano-structured carbon aerogel electrodes. Experiments showed that the removal efficiency of NaCl increases with increasing applied voltage, higher concentration gradient and less double-layer overlapping effect. At the optimum applied voltage of 1.5 Volt, pH 7 and initial NaCl concentration of 1000 mg/L the electrosorption capacity was found to be 14.22 mg NaCl/g carbon aerogel. The proposed process is reversible, as the electrode charge/discharge procedure can be repeated many times without any significant loss of salt sorption capacity in all cycles.

Keywords: Brackish, Desalination, Nanoporous Carbon Aerogel Electrodes

1. Results and Discussion

Continuous electrodeionization CEDI is the removal of ions and ionisable species from water or organic liquids, which uses ion exchange membranes and an electric potential to create diluate and concentrate compartments [1]. Electrostatic shielding electrodeionization uses ionic current sinks instead of ion exchange membranes [2]. Capacitive deionization CDI or otherwise called electrosorption [3,4] is a membrane-less batch wise operated electrodeionization process, where ions are forced to move towards to the opposite charged electrodes, resulting in deionization of the treated solution. Capacitive deionization is the most economic and energy efficient method for water deionization.

Experiments were carried out in a 100 ml rectangular glass vessel serving as undivided cell with dimensions 10 cm in length, 10 cm in height and 1 cm in width. Four sheets of porous carbon aerogel electrodes (Marketech Int. USA) with dimensions 10 x 8 x 0.1 cm each were connected in parallel as two anodes and two cathodes. The electrodes were placed vertically parallel to each other at a distance of 0.2 cm between them. The solution volume was 80 ml. A saturated calomel electrode (SCE) was used as a reference electrode. Proper provisions were made in the lid of the glass vessel for fixing the anodes, the cathodes and the bridge of the reference electrode. The NaCl concentrations were determined by measuring the electrical conductivity of the treated NaCl solution. A linear relationship existing between NaCl concentration and conductivity via a calibration curve was made prior to electrosorption experiments.

The main properties of carbon aerogel electrodes, as supplied by the manufacturer, are listed in Table 1.

Table 1. Main characteristics of nanoporous carbon aerogel electrodes

Surface area	600 m^2/g
Average pore size	75 - 80 nm
density	0.4 - 0.5 g/cm^3
Capacitance	28 – 30 F/g
Resistivity	0.01 – 0.04 ohm.cm

A DC power supply (Agilent E3612A, USA) was used for measuring the electrode potential and current. Conductivity was measured by means of a conductometer (WTW). pH and temperature were determined using a pH-meter (Hanna) connected to a combined electrode comprising a temperature sensor.

2. Effect of applied voltage

To study the effect of applied voltage on NaCl removal experiments were conducted under varying voltages of 0.5, 1.0 and 1.5 V at fixed

NaCl concentration of 1000 mg/L, neutral pH=7 and 30 minutes run time. Results are shown in Figure 1. The initial conductivity of 2000 μS/cm of the treated brackish solution decreased to 1605, 1012 and 680 μS/cm for the applied voltages of 0.5, 1.0 and 1.5 V respectively. Higher removal efficiency of NaCl was achieved at higher voltages as

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increased voltage increases the flow velocity of electrons and the electrostatic attraction of ions by the opposite charged electrodes.

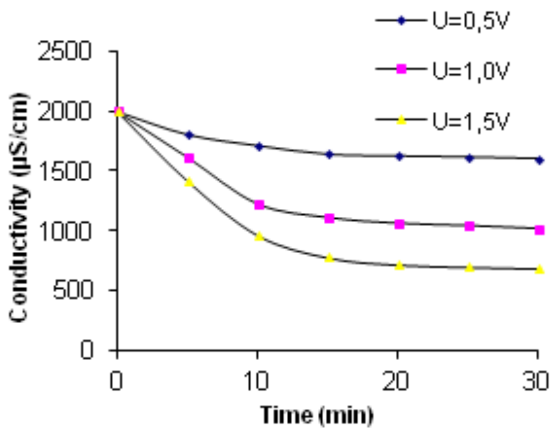

Fig. 1. Conductivity variation versus time at various applied voltages.

3. Effect of initial NaCl concentration

All experiments were conducted at the optimum voltage of 1.5 V. The NaCl concentration ranged from 0 to 1000 mg/L. According to Figure 2, the electrosorption capacity of NaCl increases sharply with increasing initial NaCl concentration in the region 50-500 mg/L. Higher electrolyte concentration causes higher concentration gradient and enhanced ion transport, resulting in compression of the electric double-layer and the known overlapping effect [5]. Therefore, more surface area of the porous electrodes is available for electrosorption of ions. The amount of NaCl electro-adsorbed on carbon aerogel electrodes was almost saturated about 12.67 mg/l NaCl per g of carbon aerogel at the initial concentration of 500 mg/l NaCl. Furthermore, it increased only slightly to 14.22 mg/L at 1000 mg/L.

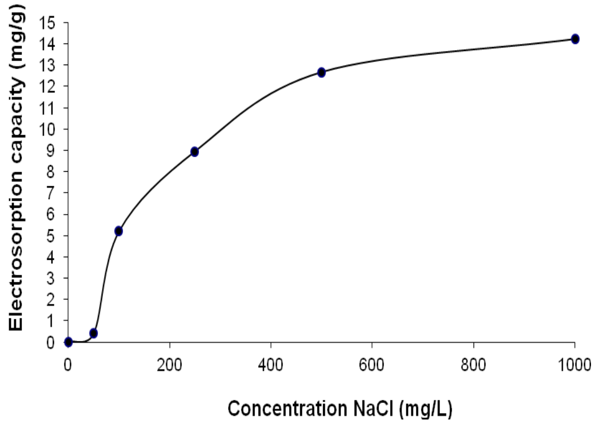

Fig. 2. Effect of initial NaCl concentration on electrosorption capacity

4. Electrodesorption and regeneration of the electrodes

The electrodesorption process helps to regenerate the electrodes and recover the adsorbed NaCl in a concentrated brine solution. The charged carbon aerogel electrodes were sort-circuited and depolarized to 0.0 V. Almost 100 % of NaCl could be recovered by the electrodesorption /regeneration step. The electrosorption /electrodesorption procedure is a rapid and reversible process which can be repeated innumerable times without any significant loss of salt sorption capacity in all cycles.

5. Conclusions

Based on the experimental results it can be concluded that capacitive deionization with nanoporous carbon aerogel electrodes is a safe, fast and efficient method for brackish water desalination.

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