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Electrochemistry techniques of reducing salinity in water using aerogel carbon electrodes

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Abstract

One of the most environmental friendly technique for desalination where electricity applied instead of chemicals. Water with different species like anions, metals and other contaminants is introduced to an electrochemical cell to purify it from contaminants including salt. During polarization, ions are electrostatically removed from the water and adsorbed in electric double layers at the surfaces of electrodes. The output of this process is cleaned water without contaminants. The Capacitive Deionization Technology (CDI) with carbon aerogel considered new and famous technique where 80% of saline water transferred to pure water with low energy consumption, and very simple method, without producing pollutants like NO_X, SO_2, and other volatile organics. This experiment based on applying current and the two anions, Na^+ and Cl^- were distributed between the two electrodes of carbon aerogel which they have high surface area. The absorption of NaCl by the aerogel carbon electrodes reached more than 50% by varying the experimental parameters like voltage, pH, concentration, distance between electrodes and flow. The best conditions were using 2V, pH =5, and a 0.4 cm distance between electrodes. When the distance between electrodes decreased (0.4 cm) the absorption of ions increased due to the formation of electrical double layer and increasing potential between electrodes. For the best removal results a flow of 80 mL/min was used. From our results we can conclude that using capacitive desalination technology (CDI) enhanced the removal of salts from brackish water.

Keywords : Desalination; Aerogel; Electrochemistry; Carbon electrode; capacitive technology.

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1. Introduction

Our need for fresh water is ever increasing and the present fresh water resources can't satisfy our needs. At present, by ever-increasing population and cities development, water can't be accessible as the natural purified water with low expense and easily [1]. Today, using of drinking water for industrial and agricultural applications will face humans with water shortage crisis in the near future [2]. Simultaneous with population's increase and fresh water resources decrease or drought, using of unusual water resources such as wastewater, salty water and sea water have been increased all over the world [3].

Water is considered to be basic and vital component of the social, economic, political fabric of Palestine. Its sector represents the basic foundation for sovereignty and attachment to our land. There are limited sources classified as surface and ground water. Depletion of water resources recently and deterioration of it becomes the key of environmental challenges; it requires urgent action to treat water to an appropriate quality and quantity for meeting disposal and beneficial reuses [4].

Different research areas have been used to treat wastewater and saline water in Palestine. Four reverse osmosis plants exist in Jericho for treatment brackish and brackish water. This operation has side product such as generated brackish water. Disposal of it cause salinity of soil, and inhibit plant growth. These waste streams, such as reverse osmosis (RO) concentrates or brine solutions produced from ion exchange, are generally discharge to the sanitary sewer system. This increases to the total dissolved solids (TDS) load of the treated wastewater that is eventually returned to the environment [5]. To minimize effect of brackish water disposal into environment, many researchers have been put into finding economical and effective methods for treatments of it through many feasible processes [6].

Recently some researches proved the effective of phytoremediation technique in soil salinity treatment [7]. Other use to add regular water to balance the salinity of the water which needs a lot of volumes. The problem of evaporation processes (MSF and MED), not only is high energy expense but is high precipitation and corrosion, which they can be controlled by an experienced operator group [8]. In RO and Electro Dialysis (ED) methods, very large expenses of investment in one side and their limitations for sea water desalination in other side have restricted their applications. Development in new water desalination methods for producing fresh water from salty waters and reducing its expenses and using of the nuclear energy is one of the main alternatives against the world water challenges in the 21th century [9]. The use of carbon aerogel electrodes for environmental cleanup is one of the advanced techniques to remove alts like NaCl by applying potential. Electrodialysis with bipolar membranes can be used to separate neutral salt solutions into their acid and base components so that recycle is possible, thereby lowering risk to the environment [10]. However, the electrodialysis process is not 100% efficient and generates a dilute waste stream of NaCl. Carbon aerogel electrodes canbe used to remove NaCl from the effluent, concentrating it for recycle to the electrodialysis cell [11-13]. Brackis water usually passed through a stack of carbon aerogel which have surface are between 700-1200 m^2/g and low electric resitivity of about 0.3Ω.m. During polarization, Na^+ cations and Cl^-anions are removed from the electrolyte by the applied electric field and held in electric double layers made at the surfaces of electrodes. This operation is capable of removal different contaminants like volatiles, colloids and dissolved heavy metals. In these cases, contaminants are removed by electrodeposition and electrophoresis, respectively [14].

In this study, feasibility to make carbon aerogel in order to remove salinity generating factors from saline and brackish waters has been considered. Also, it aims to study the main bilateral and separate parameters' effect such as PH, the primal concentration of salinity factors and the electric current to increase removal efficiency.

Materials and methods

The schematic diagram of our experiment for the carbon aerogel is described as shown in Fig. l. The Na^+ and Cl^- will be gathered in the electric double layer formed at the extensive surface of the carbon aerogel electrodes until the voltage is reduced. The electrodes are made from carbon aerogel composite (CAC) glued using silver epoxy and placed on titanium sheet which used as current collector and at the same time support for the electrodes. Conductive .Each sheet of CAC is 8 X 8 X 0.013 cm. Two holes were made for the cell, one is to supply the salty water and the other is to drain the pure water. Electrical conductivity, pH, individual ion concentrations, and temperature are continuously monitored. The preparation of resorcinol-formaldehyde (ElF) aerogels and their carbonized derivatives has been described before by other researchers [15,16]. In summary, a thin film of graphite-filled epoxy (3:1:3 Epon 828: HY955: graphite) was smeared at the titanium current collectors, and the electrodes were gently compressed into place. The epoxy was further cured for 24 h at 85°C. This will increase the porosity of carbon aerogel and will increase the surface area (735 m^2/g). The surface area is based on Brunauer-Emmet-Teller (BET) analyses. Synthetic samples of saline and brackish waters were passed through these electrodes spirally, and anions were attracted to anode and cations were attracted to cathode. The flow was batch type. The electrical conductivity of feeding storage was measured continually. Feeding storage electrical conductivity was measured continuously.

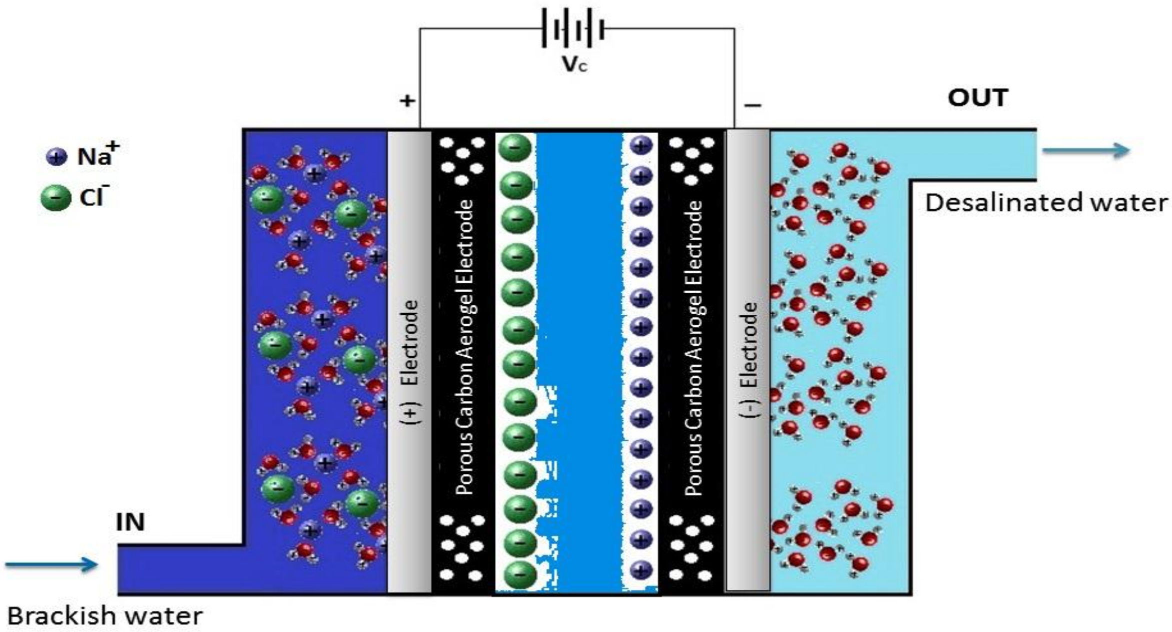

Fig. 1. Scheme for the capacitive deionization capacitor for desalination of water using carbon aerogel electrods.

Constant number showed that carbon aerogel electrodes were saturated. The maximal carbon aerogel absorption capacity was determined by mass balance of absorbed salt with amount of used aerogel, in cell. The effect of concentration, pH, Current intensity, Flow rate and distance between each pair of carbon-aerogel sheets on electro sorption of CDI was examined using the pilot-scale testing unit treating synthetic sodium chloride solutions. By different voltages and pHs and change in electrodes distance, effects of these parameters on system efficiency were considered in the different concentration of saline and brackish waters. The effect of each variable on removal efficiency was measured by changing one parameter and keeping other parameter as constant. Therefore, by comparing the salinity of the input and output waters and computing system's efficiency in all conditions, the best voltage and distance between the electrodes for accessing to high efficiency were determined. In practice, carbon aerogel regeneration was performed by revers current or interruption in current about 15-30 minutes, so this cycle was restated.

Results and discussion

In this Study, carbon aerogel was used to make fresh water from saline waters and several effective parameters on this process were considered by one factor in time method, so, the best conditions for making fresh water and NaCl removal from were determined. The main and effective factors on capacitive deionization which were studied by carbon aerogel, include, input concentration, electric current, pH, flow and distance between electrodes.

To study the removal of sodium chloride from the salty water when introduced to the cell, the concentration of sodium chloride was studied as a function of applied voltage versus conductivity as shown in Fig. 2. When applying voltage between the electrodes, Na^+ cations and Cl^-anions are drawn towards the cathode and anode, respectively. These ions are held in the electric double layers formed at the extensive surface of the carbon aerogel electrodes until the voltage is reduced. Deionization was accomplished during charging, while regeneration was accomplished during discharge. The concentration and conductivity were cycled up and down numerous times by charging and discharging the circuit. The ability of the CAC electrodes to remove ions from water, i.e., the electrosorption capacity, had a strong dependence on cell voltage. The best results were achieved at 1.0V, with relatively poor performance below 0.4V.

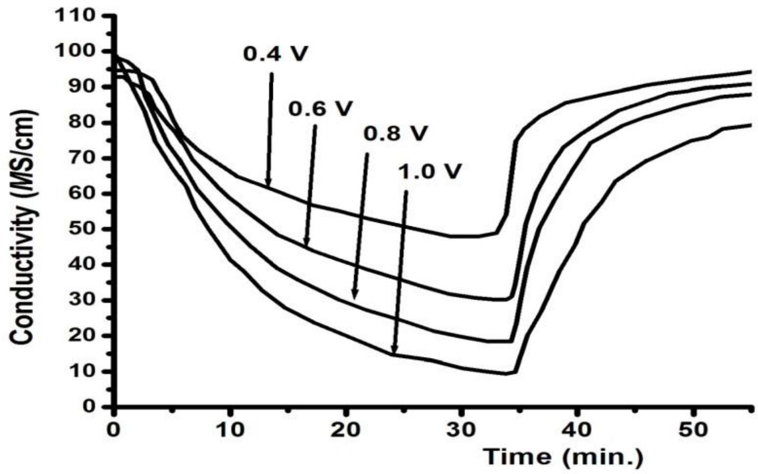

Figure 2. The capacitive mode of carbon aerogel as a function of time and conductivity for removal of NaCl at fixed volume of electrolyte.

Fig.3 shows the SEM for the carbon aerogel attached on both electrodes using silver epoxy and titanium sheets. From the figure we can see the particles have large surface area and this will help both sodium and chlorides to be adsorbed. Since the particles are semi spherical as seen in Figure, this will enhance enlarging the surface area which increase the capacity efficiency of adsorption of ions. In order to study the surface analysis and pores diameter measurement, T-plot, BJH (Barrett, Joyner) and BET (Brunauer, Emmett, Teller) methods were used [17]. The carbon aerogel surface analysis results by BET method showed that the surface is 735.69 m^2/grand results of carbon aerogel surface analysis by BJH and T-plot methods showed that the pore's diameter is between10-120 nm[16].The pores volume according to BJH method was 0.67 cc/g.

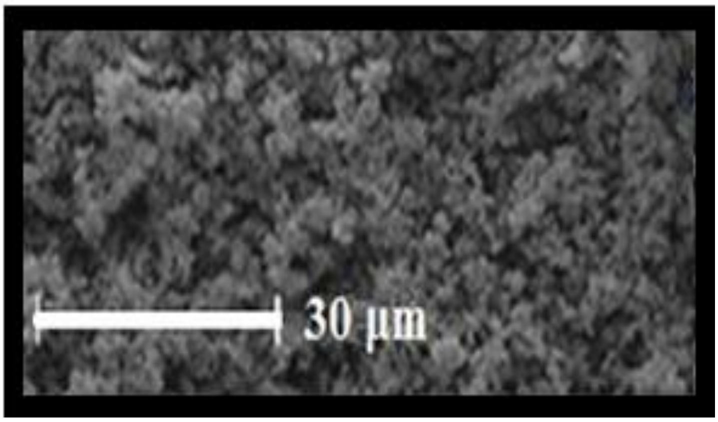

Fig. 3. Scan electron microscopy (SEM) for the carbon aerogel after preperation and pasted on titanium sheet.

In this present research, carbon aerogels which were synthesized in fresh air pressure conditions, were used to remove NaCl ions. As Fig. 4 has shown, by increasing NaCl concentration, the amount of carbon aerogel electrode absorption increases, so that in the concentration of 2500 mg/L, the amount of absorption was 3.75×10^{-3} mole of NaCl pergram of carbon aerogel. This amount is comparable with absorption amount from other studies [1,15]. researches, in which the amount of absorption for capacitive deionization mono-cell system was in the range of 1.2×10^{-4} - 1.95 x 10^{-4}mole NaCl/gr Aerogel, and for multi-cell system was 2.1×10^{-4} mole NaCl/gr Aerogel.

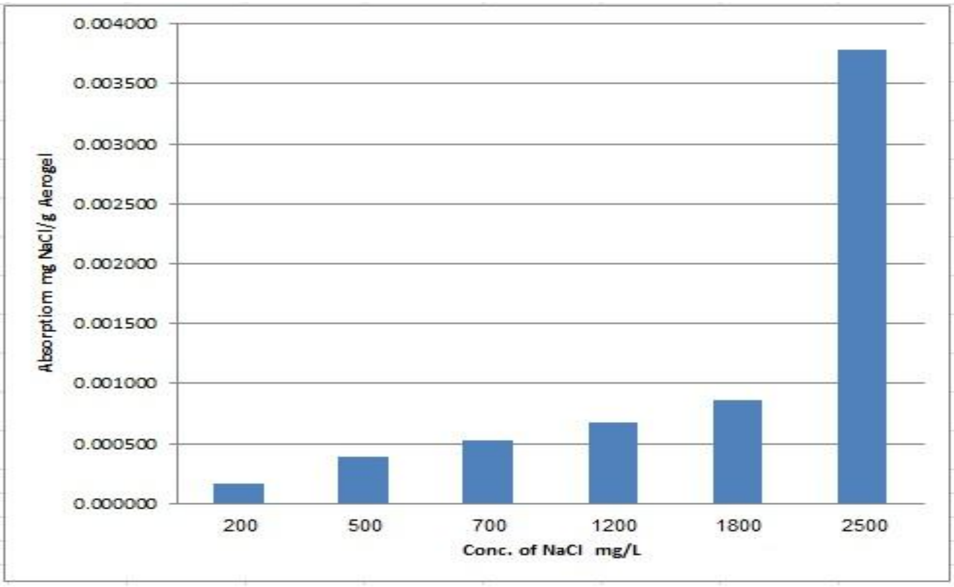

Fig. 4. Shows the behavior of NaCl in solution and the capacity of absorption of carbon aerogel electrodes.(distance between electrodes (D=0.7cm), Flow(Q)=80 ml/min, I=1.7Amp, pH=6.3).

The effect of inlet NaCl concentration on the absorption capacity of carbon aerogel electrodes illustrate in Fig. 4. This study showed that increasing electrolytes concentration could reduce electrical double layer thickness, and consequently, improve electrical capacity of the carbon aerogel. The ability of electrodes with carbon aerogel granules and their absorption capacity inorder to remove ions from water is completely related to electric current. As figs 2 and 5 show, by increasing input electric current to system, NaCl removal efficiency is increased.

Fig. 5 illustrates the effect of electrical current and pH on the desalination efficiency at constant concentration, flow rate and distance between each pair of carbon-aerogel sheets. As is shown in Fig. 5, desalination efficiency increases as the current increases and pH decreases.

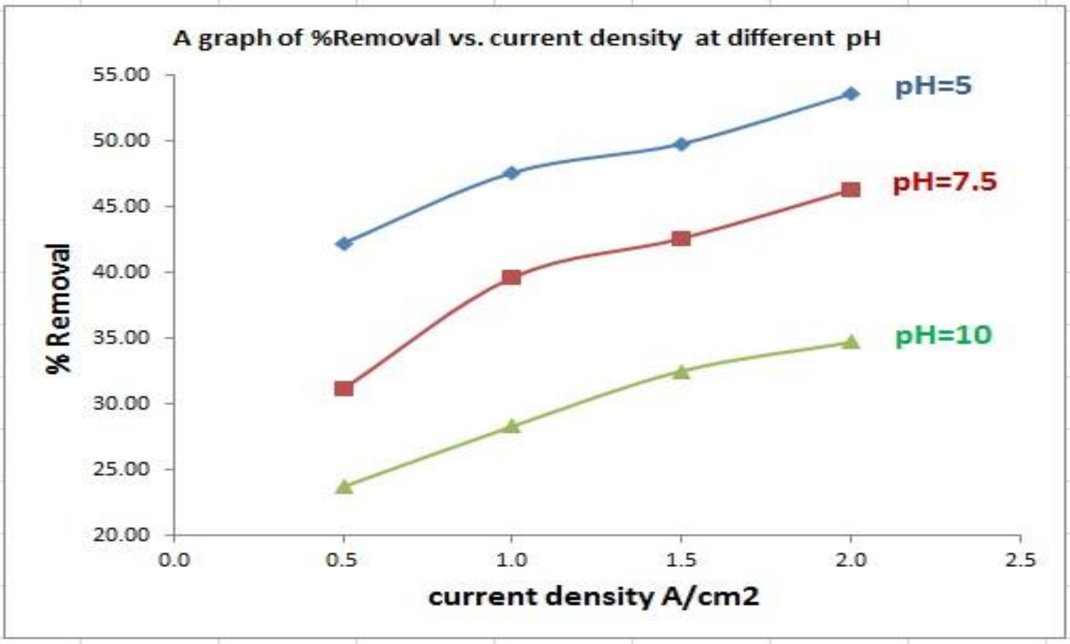

Fig. 5. The % removal of NaCl from solution at different pH and current densities. (Cs=700 mg/L, distance between electrodes (D=0.7cm), flow (Q=80ml/min).

Fig. 6 shows the removal percentage of NaCl at different flows and distance between electrodes at constant concentration, pH and current intensity. Increasing in feed flow rate and distance between electrodes decreased the performance of electrodes electrosorption.

Statistical analysis shows that there is a significant correlation between electric current and the amount of NaCl absorption for each gram of aerogel (p=0.01). In other side, as Figure 6 has shown by decreasing the distance between electrodes, absorption efficiency is increasing due to more potential differences between electrodes and more electrical double layers formation. For flow, statistical analysis shows that there is a significant correlation between NaCl concentration and NaCl removal efficiency [1]. The best results were obtained in 60ml/min flow, and this shows that in less flow, electrodes have more times for ion absorption. The relationship between flow and absorption efficiency is provided in figure 6. Because electrical absorption process is reversible, by reversing or cutting of the current, ions are released rapidly. Therefore, electrodes can be regenerated and be used more and more [15].

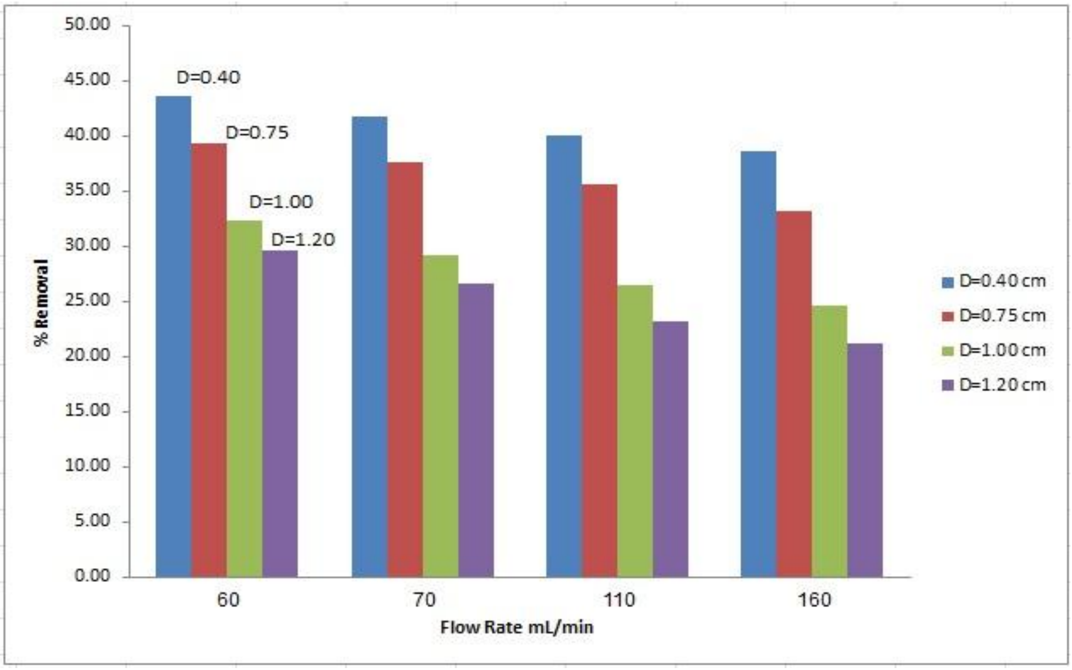

Fig. 6. Percentage removal of sodium chloride at different distances between electrodes and different flow rates.(Cs=700mg/L, pH=6.3, I=2.0 Amp).

Conclusion

In this study, one of the modern methods for making fresh water was considered. The Capacitive Deionization Technology (CDI) to remove salt from saline and brackish waters is a new process in compared with other processes such as reverse osmosis (RO), electro dialyze (ED) and ion-exchange resin.

In this Study capacitive deionization technology (CDI) with carbon aerogels was used to make fresh water from saline waters and several effective parameters on this process were considered by one factor in time method, so the best conditions for NaCl removal from were determined. In this study carbon aerogels which were synthesized in fresh air pressure conditions, were used.

By increasing NaCl concentration the amount of carbon aerogel electrode absorption increases, so that in the concentration of 2500mg/l, the amount of absorption was 3.75×10^{-3}molNaCl/gr carbon aerogel. The ability of electrodes with carbon aerogel and their absorption capacity in order to remove ions from water is completely related to electric current. By increasing input electric current to system, NaCl removal efficiency is increased. As expected, the best performance (salt removal) was achieved at 2 ampere. In other side, by decreasing the distance between electrodes, absorption efficiency is increasing due to more potential differences between electrodes and more electrical double layers formation. For flow analysis shows that there is a significant correlation between NaCl concentration and NaCl removal efficiency. The best results were obtained in 60ml/min. According to the results obtained in this study, it appears that using of capacitive desalination technology (CDI) with Carbon Aerogel electrodes for NaCl removal from saline and brackish waters is a suitable method.

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