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Desalination of Simulated Textile Wastewater by Capacitive Deionization Using Nitric Acid Modified Carbon Electrodes

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Abstract : The dyeing process involves the use of inorganic salts (NaCl) in large quantities during the dye fixation of fabric and here the disposal of saline effluent from textile industries is an increasing problem worldwide. Zero discharge desalination process is the most promising technology to prevent addition of salinity and thermal shocks to ecosystem by effluent streams of desalination unit drained into the water bodies. Multiple Effect Evaporator and Crystallizer are the major equipment involved in conventional method of desalination of textile wastewater which require enormous amount of energy and produces a large quantity of contaminated unusable NaCl crystals that are stored unnecessarily. In order to overcome these complications, Capacitive Deionization (CDI) is one of the methods for treating RO reject. In this work, CDI with an activated carbon (AC) modified by nitric acid has been used as the electrodes for the desalination of simulated textile wastewater. The experimental results showed that the modification could greatly increase the efficiency of salt removal from the solution for various residence time and voltage. It was found that the modification greatly increased the oxygen-containing functional groups on the surfaces of activated carbon, leading to an increase in capacitance and decrease in charging resistance, which might be attributed to the improvement of the desalination.
Key words : Capacitive Deionization, Desalination, Textile wastewater, NaCl, Modified Carbon Electrodes.

Introduction

The increase in exploitation of groundwater around the globe and industrial activities has resulted in several impacts over environment. As a consequence, there is a large interest in the development of economically attractive treatment technologies. Over the years for desalination, a number of methods have been developed among which distillation, reverse osmosis, and electro dialysis are the most commonly known and widespread technologies. A common goal for current research is to make these technologies more energy efficient and cost effective, both for the deionization of seawater and for industrial effluent. The high saline effluents from the industries such as textile, tannery, pulp and paper and several other industries pollute the environment at a larger scale. In conventional textile wastewater treatment process, thermal desalination techniques are followed. The RO reject is taken and desalted by using evaporator, crystallizer and solar pond which is time consuming and uneconomical. There comes a necessity to use most suitable effective methodologies and techniques to treat these effluents

Capacitive deionization (CDI) is an emerging technology for the facile removal of charged ionic species from aqueous solutions, and is currently being widely explored for water desalination applications[1].A CDI cell consists of a pair of porous electrodes, with a separator in-between, which is made of dielectric material as shown in the Fig 1. The electrodes are typically carbon, and the feed water flows either between or through the charging electrodes. The porous electrode pair is charged with an applied voltage difference of typically 1–1.4 V, and salt ions present in the feed migrate into electrical double layers (EDLs) along the pore surfaces at the carbon/water interface, removing salt from the feed water. Positive ions (cations) are attracted by the electrostatic force to the negative electrode while the negative ions (anions) are attracted to the positive electrode. Salt ions are electrostatically held in the double layer until the discharging step, where the external power supply is shorted or its polarity reversed. During discharge, the release of ions results in a brine stream, and the charge leaving the cell can be leveraged to recover energy[2].

1.

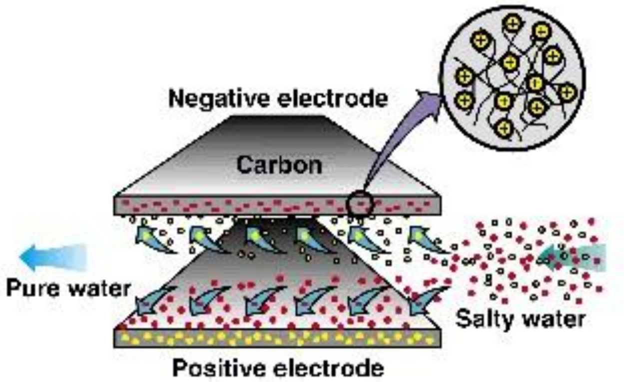

Fig 1. Carbon Deionization process

The energy release during electrode regeneration (ion release, or electrode discharge) in deionization can be utilized to charge a neighbouring cell operating in the ion electro sorption step and in this way energy recovery is possible. The energy efficiency of CDI for water with a salt concentration is due to the fact that the salt ions, which are the minority compound in the water, are removed from the mixture[3]. A cycle of purification (ion removal) and regeneration (ion discharge) is alternated to produce two streams of desalinated water and brine. CDI applies a basic principle of electro chemistry to purify the brackish water and industrial effluents[4]. The carbon electrodes used in different forms such as mesoporous layers[5], asymmetric pairs[6], micro/nano grafted cloth[7], carbon aerogels[8] etc. In the present work, the carbon electrodes are taken in the form of porous layer and the simulated textile effluents are treated by using Nitric acid modified carbon electrodes. The electrosorption studies[9-12]is carried out between ranges of charging current on different NaCl concentrations in the simulated textile effluent.

Experimental

Fabrication of modified carbon electrodes

The activated carbon powder used in this work was initially treated with Nitric acid (HNO_3) and Sodium silicate is used as binder material for the coating of activated carbon over the Graphite sheet. Initially 10 g of raw AC powder and 100 ml of HNO_3 solution (10 mol/l) were mixed together and stirred for 4 h at 90 °C. Then, the activated carbon powder was separated by filtration. The filter cake was washed with distilled water until the filtrate became neutral. After that, the cake was dried at 60 °C, which is referred to as the modified activated carbon. Then the activated carbon slurry was prepared by mixing the powder with Sodium silicate gel which was used as the binder in a magnetic stirrer. After that, the slurry was uniformly casted on a graphite sheet with a blade to form electrodes with the dimensions of 10 × 3.7 cm. The casted electrodes were dried at 50 °C for 2 hours. The weight of the AC electrode was 6 g.

Experimental set-up

The experiment is conducted in a batch process which involves a CDI cell whose dimensions are 30cm x 10cm x 15cm, DC power supply, Total dissolved salts meter (TDS meter), and Multimeter. The CDI cell consists of carbon electrodes in predetermined positions and is connected to DC power supply at desired voltage. The water sample that is to be treated is kept in the cell at a particular voltage for considerable interval of time. The experimental setup is as shown in Fig 2 consisting of four porous carbon electrodes alternately connected in parallel to the power supply. The changes in the salt concentration of the water from the reactor are noted with the help of TDS meter.

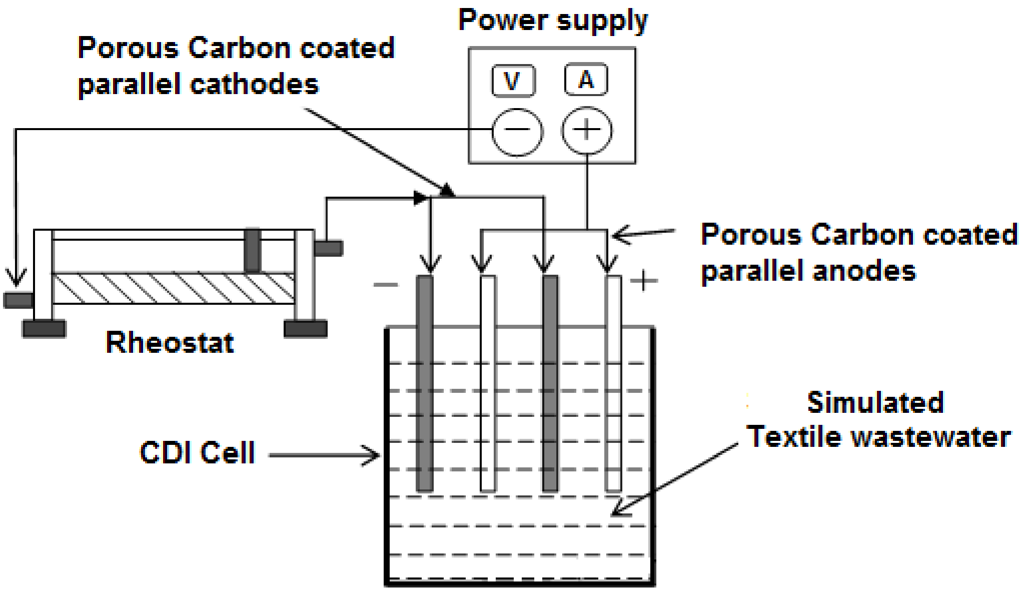

Fig 2. Experimental Setup

Experimental procedure

Experiments were conducted to evaluate the desalination performance based on different operational parameters of the CDI system. The operational parameters are concentration of feed, applied voltage and time. Deionization capacity of modified carbon electrode is initially studied and then it is compared with deionization capacity of normal electrodes. Both studies include same procedure. Initially Modified carbon electrodes are taken in the CDI reactor. The concentration of the feed is taken as 1000 ppm, 2000 ppm and 4000 ppm of NaCl solution. The potential difference of 1.2V, 2V and 4V is applied between electrodes and the respective change in concentration of the feed with respect to time is measured. The concentration is measured using a TDS meter. Different concentrations of the feed solution are taken and the corresponding change in the total dissolved salts is measured with respect to change in time. Same experimental procedure is conducted using normal electrodes. The Salt removal efficiency is calculated by using the formula,

$$\text{Salt Removal Efficiency}(\%) = \frac{\text{Co} - \text{C}}{\text{Co}} \text{X } 100$$

where C_0 - Concentration of Feed and C - Concentration of Treated Water.

The energy consumption of CDI (kW-h) of a purification cycle can be calculated, based on the equation

$W = \varphi \int \text{I dt}$

where

W = total energy Consumption, kW-h

Φ = voltage, V

I = currentsupplied, A

t = time taken for purification cycle, h

Result and Discussion

Deionization using Normal Carbon Electrodes (NCE) and Modified Carbon Electrodes (MCE)

The desalination process was carried out for different initial salt concentrations such as 500, 1000, 2000 and 4000 ppm and it was found that the salt removal percentage decreases with increase in feed concentration. The readings were taken for time interval of 15 min and the cumulative salt removal percentage was calculated till 60 min. The experimental results for treating the simulated effluent of concentration 2000 ppm for different applied voltage of 1.2, 2, 4 V are shown in the Fig 3 which shows that with increase in time the salt removal percentage increases and the maximum removal percentage of 67.4% and 50.9% were obtained by using Modified Carbon Electrodes (MCE) and Normal Carbon Electrodes (NCE) respectively.

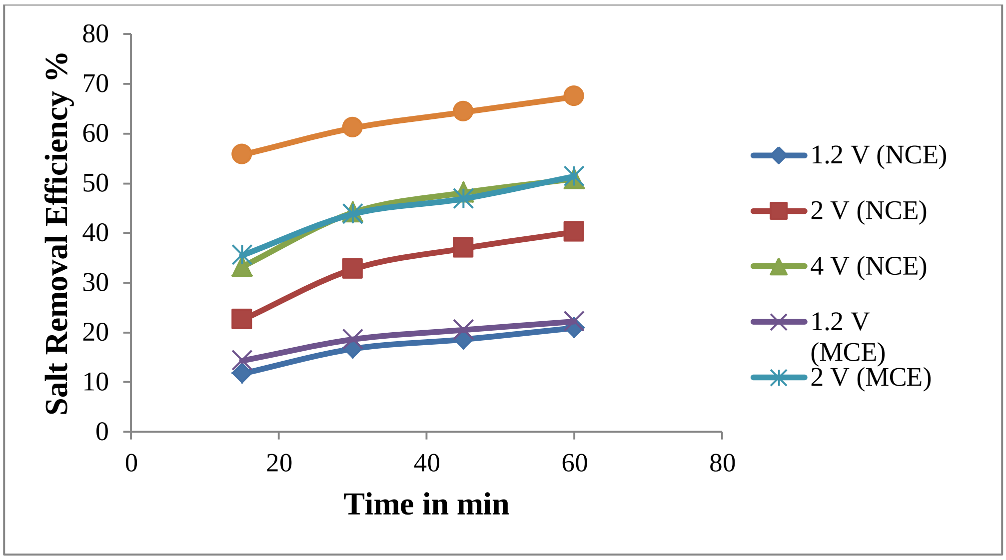

Fig 3. Salt Removal Efficiency v/s Time

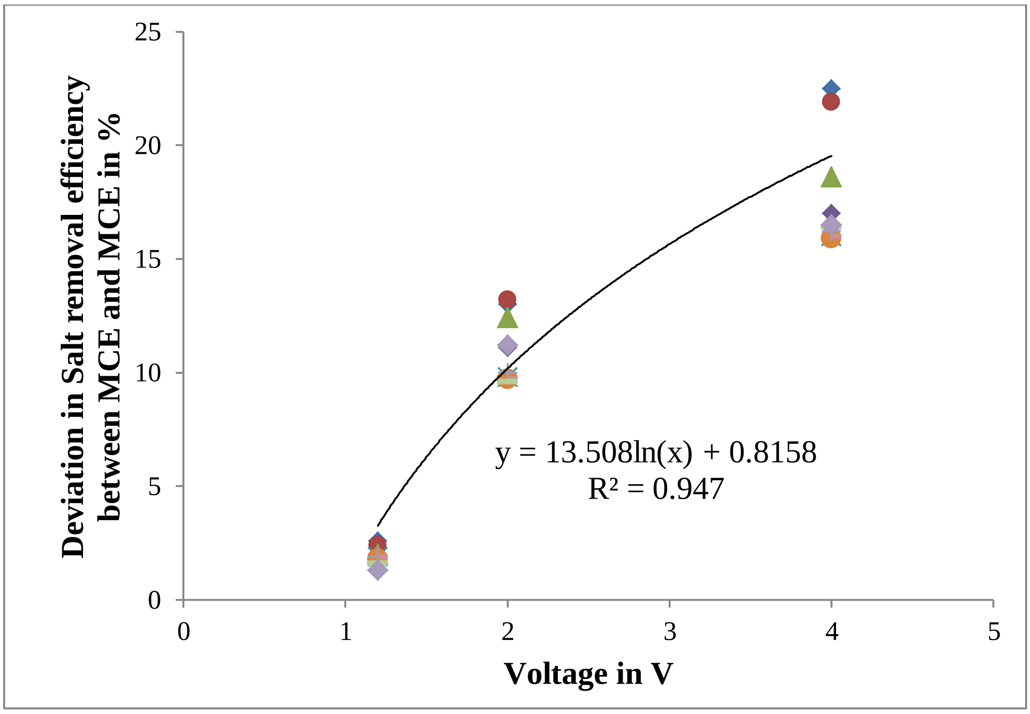

Fig 4. Deviation in Salt Removal Efficiency between MCE and NCE v/s Voltage

It was observed that increase in the applied voltage increased the salt removal efficiency. The relation between the increase in salt removal efficiency compared to that of the NCE and MCE was plotted and found to have a logarithmic relation with the applied voltage as shown in Fig 4.

Energy Consumption of Capacitive Deionization

The energy consumption of CDI varies from 0.15 to 2.4 kWh, when the voltage is increased from the 1.2 to 4 V. For the same capacity of the effluent, the energy consumption for evaporation is found to be 3 -10 KWh. This clearly shows that CDI is far more efficient when compared to evaporation. The impact of voltage on energy consumption using Modified and Normal Carbon Electrodes yields a quadratic relation and are given in the Fig 5. The results show that the power consumption by MCE is less than that of the NCE as more activated sites were created due to treatment of nitric acid.

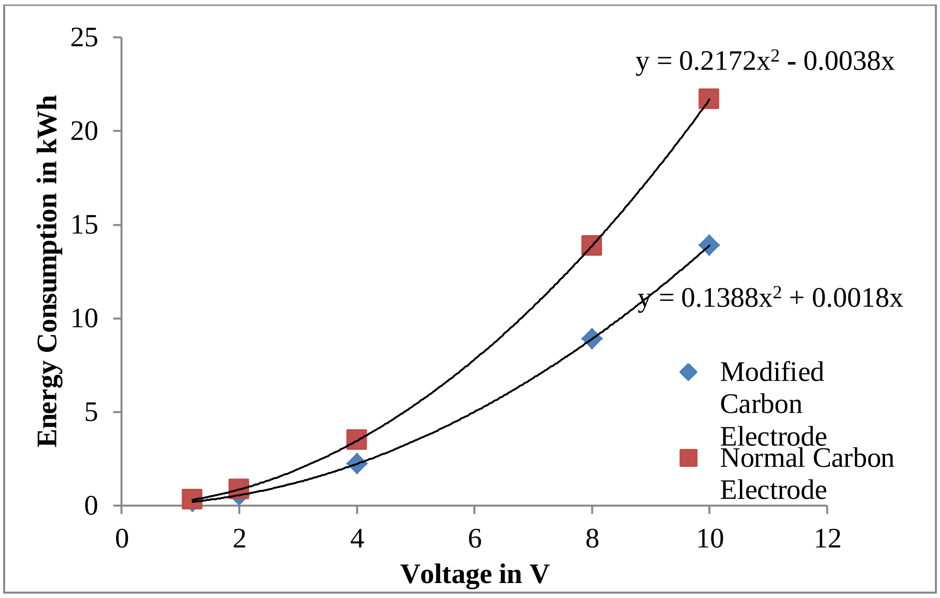

Fig 5. Energy Consumption v/s Voltage

Conclusion

In order to recover water by desalination of textile wastewater, capacitive deionization technique was employed.For improving the effectiveness of the process, nitric acid modified carbon electrodes were developed, fabricated and used. The effects of time of capacitive deionization and applied electric potential on salt removal efficiency were studied. The results showed that the salt removal efficiency increased with increase in both time of capacitive deionization and applied voltage. It was observed that salt removal efficiency was higher for the modified carbon electrode when compared with that for the normal electrode at all the applied voltages. It was also noticed that the energy consumption was lower for modified carbon electrode than for the normal electrode. The results indicated that the capacitive deionization using nitric acid modified carbon electrode could be a promising technology for desalination of textile wastewater and for the recovery of water at considerably low power consumption.

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