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Desalination and disinfection of inland brackish ground water in a capacitive deionization cell using nanoporous activated carbon cloth electrodes

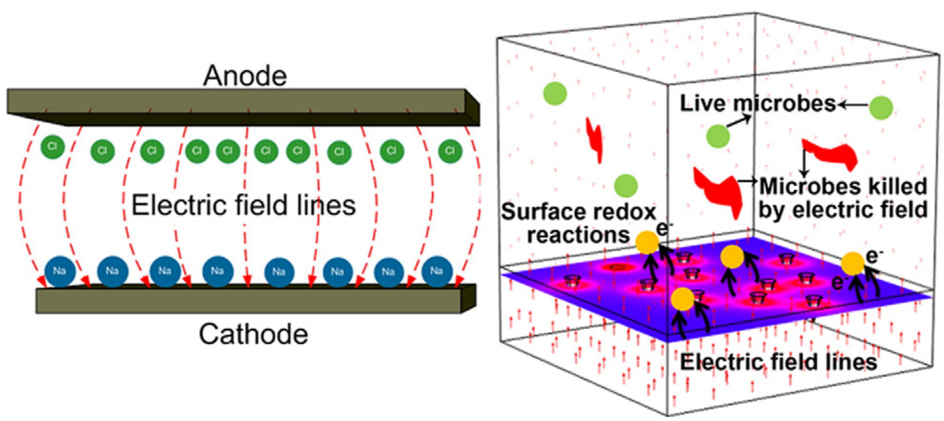
Karthik Laxman [a,b], Myo Tay Zar Myint [a], Mohammed Al Abri [c], Priyanka Sathe [a,d], Sergey Dobretsov [d], Joydeep Dutta [a,*]

[a] Chair in Nanotechnology, Water Research Center, Sultan Qaboos University, PO Box 17, Al-Khoudh, Muscat 123, Oman
[b] Department of Electrical and Computer Engineering, College of Engineering, Sultan Qaboos University, PO Box 33, Al-Khoudh, Muscat 123, Oman
[c] Department of Chemical and Petroleum Engineering, College of Engineering, Sultan Qaboos University, PO Box 33, Al-Khoudh, Muscat 123, Oman
[d] Department of Marine Science and Fisheries, College of Agricultural and Marine Sciences, Sultan Qaboos University, PO Box 34, Al-Khoudh, Muscat 123, Oman

HIGHLIGHTS

- Inland ground water desalination and disinfection using capacitive deionization (CDI)
- Electrical characterization of porous activated carbon cloth (ACC) electrodes for CDI
- Study of ACC electrosorption and desorption dynamics in a multi-ionic matrix
- A three-fold reduction in the microbial biomass of well water after desalination
- Comparison of ion adsorption characteristics of synthetic water with ground water

GRAPHICAL ABSTRACT



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ABSTRACT

Desalination of brackish water using capacitive deionization (CDI) poses unique challenges attributed to the microbial, organic and other contaminants in water. By using chemically inert and high surface area activated carbon cloth electrodes, the desalination of water from wells in Oman's Al Musanaah wilayat is demonstrated. The ion adsorption characteristics for well water are compared to that of synthetic water (sodium chloride) and their dependence on the charge, size and concentration is investigated. Disinfection properties of the CDI unit were also demonstrated with a 3-fold decrease in viable bacterial cells upon desalination of well water. The power consumption for well water desalination was lower than that of synthetic water with similar salt concentrations and was calculated to be 0.78 kWh/m^3. The stated desalting capabilities and small footprint make CDI a viable option for remote ground water desalination.

* Corresponding author.
E-mail address: dutta@squ.edu.om (J. Dutta).

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1. Introduction

It has been estimated that by 2025, close to half the world's population will be living in regions of water scarcity [1]. Presently, more than a fifth of the world population lacks access to clean water, while another fifth faces an economic water shortage [1,2]. Fresh water which constitutes less than 1% of the entire world's water resources is fast depleting due to need based overdrawing and sea water intrusion in water stressed regions [3,4]. The trend has reached acute levels in the Middle East, where recent reports have suggested that the region has less than 500 m^3 of water per person, well below the world average of more than 1500 m^3 per person on an annual basis [3]. The ever depleting ground water table in the region has accelerated sea water intrusion, rendering the available fresh water sources brackish in nature, with average salt concentrations of ~5 g/l [4]. Needless to say, the region, like other water stressed countries has opted for sea water desalination to support its water requirements.

The common desalting techniques used are reverse osmosis (RO) and multi-stage flash (MSF), which are suitable for sea water, but prove uneconomical for the often remote and low salinity brackish water sources in the region. New stand-alone desalting techniques like capacitive deionization (CDI) have addressed the issue by specifically operating in the brackish water salt regimes [5–20], which are predicted to be present even offshore beneath the continental shelf [21]. CDI involves the potential mediated separation of salt from water, rather than water from salt, as practiced in traditional desalting techniques like RO and MSF [22,23]. CDI typically uses high surface area and electrically conductive activated carbons as the electrode materials, upon the surface of which ions of salt are adsorbed [24–29].

Although considerable research has been conducted on desalination of lab scale brackish water (sodium chloride) and industrial waste water using CDI [20,30], few reports have been presented on the desalination of brackish water [31–33], which can contain several organic and microbial contaminants that could hamper the desalting efficiency and electrode integrity. Recent studies have explored the effect of water flow rate and its hardness and organic content on the power consumption and desalting efficiency, revealing that dissolved organic content is the main cause for electrode fouling and performance degradation over time [34,35]. However, the studies also showed that electrode regeneration could be carried out by a simple cleaning process, making CDI a viable option for brackish water desalination [35].

This work focuses on the desalination of brackish water collected from a well in Oman's Al Musanaah wilayat, where sea water intrusion has led to a dramatic increase in the salt abstraction rate in recent years [36,37]. A CDI cell using activated carbon cloth (ACC) as electrodes with an area of 100 cm^2 was fabricated for the experiments and as-received brackish well water was used as the feed at 5 ml/min (0.3 l/h). To observe the effect of microbial and other contaminants on the desalting capacity, adsorption trends for brackish water are compared with that of synthetic saline (sodium chloride in water) of similar salt concentrations. The relative ion adsorption capacities, power consumption and anti-microbial activity of the process were also studied to substantiate the viability of using CDI for brackish well water desalination.

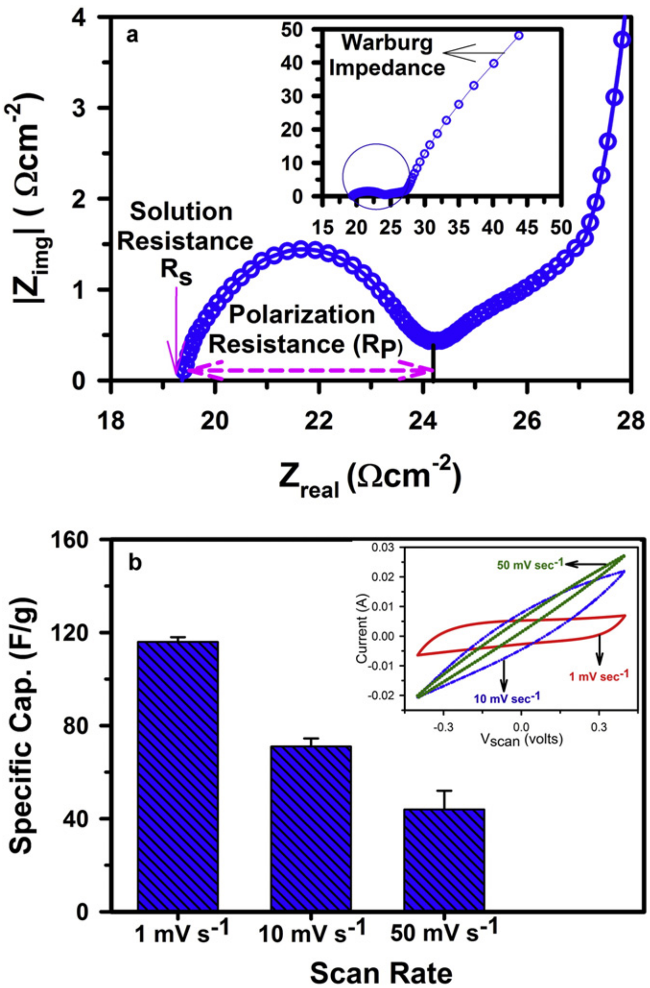

Fig. 1. (a) Nyquist plot for activated carbon cloth (ACC) showing low resistance to charge flow and a reasonably high capacitance and (b) specific capacitance of ACC as calculated from cyclic voltammetry curves (inset of figure b) at scan rates of 1 mV s^{-1}, 10 mV s^{-1} and 50 mV s^{-1}.

2. Experimental

2.1. Chemicals and materials

Brackish ground water was collected from a well in Oman's Al Musanaah wilayat (north western Oman, GPS coordinates 23.48.21 N, 57.34.10 E). Ground water in the wilayat experienced a high increase in salinity in recent years due to dropping ground water tables leading to seawater intrusion. The well water pH was 8.0 (at 28 °C) with a TDS content of 2500 mg/l. Analytical grade hydrochloric acid 34% (HCl) and sodium chloride were purchased from MERCK, Germany and used without any further purification. Activated woven carbon cloth (Zorflex FM-100) was used as electrode substrates. Activated carbon cloth (ACC) of ca. 1.0 mm thickness and specific surface area of about 1200 m^2/g [38,39] (as specified by the manufacturer) was cleaned with 2 M hydrochloric acid (HCl) heated to 115 °C (slightly above the boiling point of HCl solution) for 12 h to remove mineral contaminants. Subsequently, samples were thoroughly rinsed with deionized water and dried in a vacuum oven at 150 °C for 12 h and then stored in a desiccator until further use.

2.2. Capacitive deionization (CDI) cell

The CDI device (cell) used for the desalination consists of two 10 × 10 cm ACC electrodes separated by a spacer having a thickness of

Table 1
ACC electrical parameters extracted from the rebar electrical fitting model.

Material	Series resistance (R_s 'Ω')	Pore resistance (R_{po} 'Ω')	Charge Trf. resistance (R_{ct} 'Ω')	Double layer capacitance (C_{dl} 'F')	Coating capacitance (C_c 'mF')	Warburg component
ACC	19.82	4.600	411.0	4.1	0.012	0.7