

# Electrocapacitive Desalination of Brackish Water Using Biochars

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## ABSTRACT

Electrodes fabricated from porous carbons derived from biomass have been observed to be suitable for high capacity energy storage, and subsequently investigated for their effectiveness in CDI, but there is a dearth of studies to find a relationship between the electrochemical performance of the carbon and the biomass properties and process conditions. Because cellulose, hemicellulose and lignin are the main components in biomass, in this study, we produce carbons from rice hull, switchgrass and poplar wood, each representative of cellulose-rich, hemicellulose-rich and lignin-rich biomass, respectively. The investigation goal is correlating electrochemical performance of the carbon to the nature of the biomass precursor and the processing conditions. This study will aid in identifying and classifying biomass raw materials to develop carbon materials with well-defined pore structures.

**Keywords:** water, desalination, deionization, capacitive, biomass

## 1 INTRODUCTION

Groundwater reservoirs are a possible source of water for irrigation purposes, but brackish groundwater with ~5000 ppm salt makes it difficult to harness these resources. Capacitive deionization (CDI) is a sustainable, energy efficient, and cost effective technology for desalinating moderately brackish water. CDI requires electrodes which have large-ion, accessible specific surface area, fast ion mobility within the pores, high conductivity, good wetting behavior, low cost and scalability. The principle of electro-desalination has been known for some time, as a spin-off of electrochemical capacitance. Instead of storing energy, the purpose of electro-desalination is to store (temporarily) salt, extracted from the water. With ions of opposite charge attracted to and held by electrodes – to which an applied voltage is applied, the dissolved salt is effectively removed from the water – accomplishing desalination. Figure 1 illustrates this concept. It does not require added harsh chemicals, as by conventional precipitation, expensive membranes, as does reverse osmosis, or high-energy inputs, as needed for evaporative

techniques. Relative to distillation, evaporative or reverse osmosis, it offers high-energy efficiency. Advancing this technology with new, biomass-derived carbons as electrode materials is the key innovation proposed here.

## 2 EXPERIMENTAL APPROACH

Our approach is to use carbonaceous material produced through pyrolysis of a biomass mixture of cellulosic and lignin components, along with activated carbon. Using a mixture of components decouples the constraints of porosity and high surface area. Separate materials, mixed and bonded together fulfill both criteria. Moreover all such materials are economical, available in bulk and hence well suited for small- and large-scale implementation. The carbon-based materials, in different forms separately provide porosity and high surface area while enabling independent tailoring of each characteristic by their relative amounts and pre-processing, prior to mixing. An electro-desalination unit will be assembled using electrodes fabricated from these carbons and tested for its effectiveness. Key metrics include the salt removal capacity (per unit mass of carbon), removal rate, and cycle life. The project will progress along two stages of development: material development and testing.

In our tests, the pyrolysis process temperature was varied between 300 °C – 900 °C. Physical and textural properties of carbons that include pore size distribution and specific surface area along with wettability, conductivity and chemical composition will be reported, along with cyclic voltammetry and salt absorption capacity.

Porosity (of the composite carbon) is being gauged by gas adsorption isotherms with BET analysis for surface area and BJH analysis for pore size distribution. Electrical conductivity is being measured using 4-probe electrical conductivity. Target values are 500 m<sup>2</sup>/gram and 0.5 cm<sup>3</sup> pore volume with majority associated with mesoporosity.

## 3 DESALINATION PERFORMANCE

Tests are determining salt removal rates based on electrical conductivity for single component (salt) systems and ion-specific electrodes for mixtures of salts and ionic compounds. The system is based on a 3-electrode setup: the two desalination electrodes and a reference electrode.

Voltage ranges between -1 to +1 Volts, within (below) the electrolysis threshold for water. Results will be reported as follows.

1. Salt removal rate will be gauged by chrono-coulometric tests – measuring the current response upon applied potential, with time. First order kinetic analysis will be applied.
2. Salt capacity measured through this same method. Dependence of capacity upon sweep rate tests transport and mass flow resistance of the material mixture relative to pure single components – serving as baselines.
3. Regeneration rate and capacity preservation of (salt absorption) by galvanostatic charge-discharge cycles.
4. Salt removal rate will be gauged by chrono-coulometric tests – measuring the current response upon applied potential, with time. First order kinetic analysis,

$$-\ln(1 - Q/Q_0) = t/RC$$

will be applied, where  $Q_0$  is the charge of the electrode at the equilibrium,  $t$  is the time, and the product  $RC$  is equivalent to the system time constant,  $\tau$ , being the  $R$  and  $C$  values of the electrode. Voltage ranges will be varied to identify changes in efficiency.

5. Salt capacity will be measured through this same method. Dependence of capacity upon sweep rate will test transport and mass flow resistance of the material mixture relative to pure single components – serving as baselines. (These will be similarly tested).

$$(C_0 - C) \cdot V/M$$

where  $C_0$  is the initial concentration,  $C$  the concentration at time  $t$ ,  $V$ , solution volume and  $M$  the electrode mass, for calculating the normalized capacity (of uptake).

6. Regeneration rate and capacity preservation of (salt absorption) will be evaluated by galvanostatic charge-discharge cycles.
7. From C-V curves, the total energy consumption ( $W$ ) of a purification cycle can be calculated based

$$W = \int V I dt$$

upon,

where  $V$  is the operational voltage and  $I$  the current, integrated over the cycle duration.

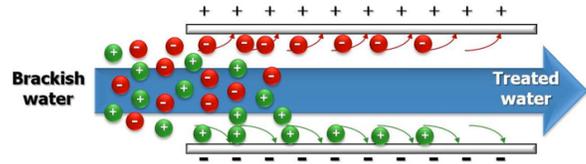


Fig. 1 – Conceptual illustration of the CDI process.