Microbial electrochemical cell for simultaneous water desalination, energy production, and wastewater treatment

Zhiyong (Jason) Ren* and Haiping Luo
Department of Civil Engineering
University of Colorado Denver, Denver, Colorado 80204
*Corresponding author; Email: zhiyong.ren@ucdenver.edu

Abstract
A multifunctional microbial electrochemical system was developed to concurrently desalinate salt water, produce hydrogen gas, and potentially treat wastewater. The reactor is divided into three chambers by inserting a pair of ion exchange membranes, with each chamber serves one of the three functions. With an added voltage of 0.8V, lab scale batch study shows the microbial electrochemical cell (MEC) achieved the highest H₂ production rate of 1.5 m³/m³ d (1.6 mL/h) from the cathode chamber, while also removing 98.8% of the 10 g/L NaCl from the middle chamber. The anode recirculation alleviated pH and high salinity inhibition on bacterial activity and further increased system current density from 87.2 to 140 A/m³, leading to an improved desalination rate by 80% and H₂ production by 30%.

Introduction
Water and energy are two most pressing technological issues facing the world. The social and economic developments are driving the search for sustainable supply of both water and energy. Recently developed microbial electrochemical cells (MECs) represent one of the newest approaches for generating clean water and energy. MECs use microorganisms to catalyze the oxidization of organic and inorganic electron donors in the anode chamber and deliver electrons to the anode. The electrons can be captured for current and hydrogen gas generation, or used to produce...
value-added chemicals and remediate groundwater contaminants (1-3). Most recently, researchers developed an additional function of desalination by inserting a middle chamber in current two-chamber MEC systems (4). This system has significant advantages compared to traditional desalination processes, such as reverse osmosis or electrodialysis, as it does not require intensive energy inputs or high water pressure. We recently developed an integrated MEC system to simultaneously desalinate salt water, produce hydrogen gas, and treat synthetic wastewater (5).

Materials and Methods

The MEC reactor was divided into three chambers by placing an anion exchange membrane (AEM) between the anode and middle desalination chamber and a cation exchange membrane (CEM) between the middle and cathode chambers (Fig. 1). Heat treated graphite brushes were used as the anode and a stainless steel mesh was selected as the cathode material. The reactors were inoculated from a mixed culture by transferring the bacterial pre-acclimated anodes of active acetate-fed microbial fuel cells. The anodic medium contained synthetic wastewater containing sodium acetate and mineral solutions as previously described, and the cathode chamber was filled with 50 mM phosphate buffer solution. The middle chamber was filled with 10 g/L NaCl solution for desalination (5).

Figure 1 Schematic diagram of the MEDC system (5)
The generated voltage was continuously monitored using a data acquisition system. Current (I = V/R), power (P = IV), and coulombic efficiency (CE, based on COD) were calculated as previously described. To collect hydrogen gas, a fixed voltage was added to the circuit of MEC reactor using a programmable power source, and the gas produced at the cathode bubbled into the cathode chamber and was collected using a sealed anaerobic tube glued to the top of the reactor. Salt concentrations were evaluated by conductivity measurements using a conductivity meter, and the procedure of energy recovery calculation was described previously (4-5).

Results and Discussion

Desalination efficiency and hydrogen gas production were characterized in both fed-batch and continuous flow MECs. With an applied voltage of 0.8 V, the fed-batch reactor achieved a maximum H\textsubscript{2} production rate of 1.5 m\textsuperscript{3}/m\textsuperscript{3} d (1.6 mL/h) and a maximum desalination rate of 0.42 mS/cm h. More than 98.8% of the 10 g/L NaCl was removed from the middle chamber within 4 batch cycles. The anode recirculation alleviated pH and high salinity inhibition on bacterial activity and further increased system current density from 87.2 to 140 A/m\textsuperscript{3}, leading to an improved desalination rate by 80% and H\textsubscript{2} production by 30% (Fig. 2). The energy efficiency obtained in the H\textsubscript{2} producing MECs varied in a range of 170%-181%, suggesting that sufficient H\textsubscript{2} could be produced to power the system with extra energy output for additional uses.

The integration of desalination, H\textsubscript{2} production, and potentially waste removal in the reactors provides new applications for the microbial electrochemical cells. But as a new multifunctional process, the MEC research is facing many challenges that remain to be solved, such as pH variation in the anode and cathode chambers, increased ohmic resistance, and stack system development. In practice, the MEC can be used as pretreatment of downstream RO processing to reduce energy consumption and membrane fouling, or being directly applied for direct beneficial uses such as agricultural irrigation or groundwater recharge, where higher salt limits are allowed.
(TDS 500-2000 mg/L).

Figure 2. Accumulated H₂ production and desalination efficiency in MEC during batch and continuous (CSTR) operation with an applied voltage of 0.8 V. (Arrows indicate electrolytes replacement.) (5)

References


* This extended abstract was adapted from reference 5.