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# Water deionization with renewable energy production in microalgae - microbial desalination process

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ABSTRACT

Photosynthetic microbial desalination cells (PMDCs) using microalgae biocathode (*Chlorella vulgaris species*) were evaluated under three different process configurations. Static (fed-batch, SPMDC), continuous flow (CFPMDC) and a photo-bioreactor MDC (PBMDC), were developed to study the impact of process operation and design on wastewater treatment, water deionization, electricity generation, nutrient removal, and biomass production capacities. The effect of TDS concentration in desalination compartment on the overall performance of SPMDC was also studied. TDS and COD removal rates and power densities have increased with increase in TDS concentrations in the desalination compartment. TDS removal rates were 21.4%, 29%, and 32.2% with corresponding COD removal of 58%, 63%, and 64% at 5 g/L, 20 g/L and 35 g/L respectively. The power densities at these TDS concentrations were 285 mW/m$^3$, 550 mW/m$^3$ and 675 mW/m$^3$ respectively in SPMDCs. Although the electricity production was lower, a higher biomass growth rate of 7 mg L$^{-1}$ h$^{-1}$ was recorded for CFPMDC. The COD removal and nutrient removal potentials were similar in all three experimental configurations. Experimental studies show that SPMDCs are more appropriate for bioelectricity production due to biofilm formation while the continuous flow or photobioreactor PMDCs are suitable for microalgae biomass production.



## 1. Introduction

Energy - water nexus has been highly pronounced recently and the issues related to their production cannot be addressed in isolation [1,2]. Conventional water and wastewater treatment and desalination processes are energy and resource demanding with negative effects on the environment [1,2]. Novel platform technologies utilizing wastewater sources to generate energy for freshwater production are ideal for addressing current energy and water issues. In this context, bioelectrochemical systems have evolved as a novel technology platform to convert wastes into valuable energy and chemical forms [3]. Bioelectrochemical systems can be employed to generate clean electricity, or high value energy or chemical products from various wastewater sources and organic or inorganic wastes that can serve as fuel feedstock for electroactive bacteria [4]. Microbial desalination cells (MDCs) are based on an integrated bioelectrochemical configuration which allows for simultaneous wastewater and saline water treatment without any external power input or mechanical energy or pressure application [5]. This process offers multiple benefits of energy and resource (water and nutrients) recovery while eliminating environmental pollution.

In a microbial desalination cell, electrons released from oxidation of organic wastes by electroactive (or electrogenic) bacteria in the anode compartment flow through an external circuit towards the cathode to be taken by an electron acceptor. Saline water in the middle chamber is deionized through ion exchange membranes due to the potential difference in the dissolved solids as well as the ionic concentration and migration generated between anode and cathode chambers [4,6]. Oxygen is a cheap and common electron acceptor used in bioelectrochemical systems [7]. To improve oxygen-reduction reaction (ORR) in cathodes, expensive catalysts such as platinum were used or external aeration was provided. To address this issue, biological cathodes can be considered [8–10]. Oxygen production through photosynthetic reactions of microalgae has been shown as a viable alternative for aeration of cathode chamber in microbial fuel cells (MFCs) which has been reported recently [10–13]. Besides providing oxygen, use of microalgae in the cathode chamber helps in $CO_2$ scavenging through photosynthesis [14], removal of pollutants (e.g. nitrate, phosphate) from

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agricultural and domestic wastewaters and production of useful biomass used for extraction of biofuels [15]. Application of microalgae *Chlorella vulgaris* in MDCs was recently reported by the authors [4,16,17]. Microalgae can be grown in the cathode compartment in MDCs due to several advantages. Residual organic and inorganic carbon compounds in the anode effluent can be scavenged by microalgae along with high nutrient uptake for biomass production suitable for various energy and high value product recovery purposes [16–21]. Above all, in-situ oxygen production provides an effective electron-acceptor for bioelectricity production [4].

Microalgae can be used in PMDCs for accomplishing various purposes as mentioned before. Their role in PMDCs can be further controlled specifically for bioelectricity production or biomass production by changing the PMDC configuration. Microalgae can be introduced into the cathode chamber either in the form of a biofilm or a cell suspension maintained by a continuous flow configuration. This study focuses on the effect of different modes of operation as well as the effect of TDS concentration on electricity generation in PMDCs. Static, continuous flow and a photo bioreactor MDC (PBMDC) were developed to compare and determine the best application of photosynthetic microalgae in the cathode chamber. Microbial community analysis of biofilms and biosolids in anode chamber is also presented in supporting information.

## 2. Materials and methods

### 2.1. Microbial physiology and electrolyte composition

A mixed consortium acquired from the aerobic sludge of the local wastewater treatment was used as initial inoculum (biocatalyst) in the anode of MDCs after enriching it with synthetic wastewater under anaerobic condition. The synthetic wastewater in the anode chamber was prepared to have the following composition: Glucose 468.7 mg/L, $KH_2PO_4$ (4.4 g $L^{-1}$), $K_2HPO_4$ (3.4 g $L^{-1}$), $NH_4Cl$ (1.5 g $L^{-1}$), $MgCl_2$ (0.1 g $L^{-1}$), $CaCl_2$ (0.1 g $L^{-1}$), KCl (0.1 g $L^{-1}$), $MnCl_2$*$4H_2O$ (0.005 g $L^{-1}$), and $NaMoO_4$*$2H_2O$ (0.001 g $L^{-1}$) (Cao et al., 2009a). The microalgae *C. vulgaris* used in the cathode compartment was grown in the following mineral solution: $CaCl_2$ (25 mg$L^{-1}$), NaCl (25 mg$L^{-1}$), $NaNO_3$ (250 mg$L^{-1}$), $MgSO_4$ (75 mg$L^{-1}$), $KH_2PO_4$ (105 mg$L^{-1}$), $K_2HPO_4$ (75 mg$L^{-1}$), and 3 mL of trace metal solution with the following concentration was added to 1000 mL of the above solution in water: $FeCl_3$ (0.194 g $L^{-1}$), $MnCl_2$ (0.082 g $L^{-1}$), $CoCl_2$ (0.16 g $L^{-1}$), $Na_2MoO_4$*$2H_2O$ (0.008 g $L^{-1}$), and $ZnCl_2$ (0.005 g $L^{-1}$).

### 2.2. Experimental setup and studies

Three-chamber MDCs (7.2 cm diameter) were made using plexiglass. Anion exchange membrane (AEM, AMI7001, Membranes International) separated the anode and the desalination chambers, while cation exchange membrane (CEM, CMI7000, Membranes International) separated the cathode and the desalination compartments. Both membranes were preconditioned by immersing in 5% NaCl solution at 40 °C for 24 h and rinsed with distilled water (DI) water prior to use to allow for membrane hydration and expansion as recommended by the supplier. Carbon cloth covered with stainless steel mesh were used as electrodes with 16 $cm^2$ surface area. Prior to use, both electrodes were washed first with 1 N HCl solution and then with 1 N NaOH and finally rinsed with deionized water. The electrodes are then soaked in DI water over a night prior to use to remove any excess residues [22]. Anode and cathode electrodes were connected through a titanium wire. The working volume of anode, desalination, and cathode chambers after inserting the electrodes were 37, 28, and 37 mL respectively. Three different operational modes, namely, static (SPMDC, Fig. 1A), continuous flow (CFPMDC, Fig. 1B), and photobioreactor (PBMDC, Fig. 1C) were used for the photosynthetic MDC to assess its performance in terms of electricity generation, biomass production and nutrient removal capacities. SPMDC was run in batch cycles. In each test, new wastewater, fresh microalgae medium and fresh salt solution were used in PMDCs. In the continuous mode, the algae

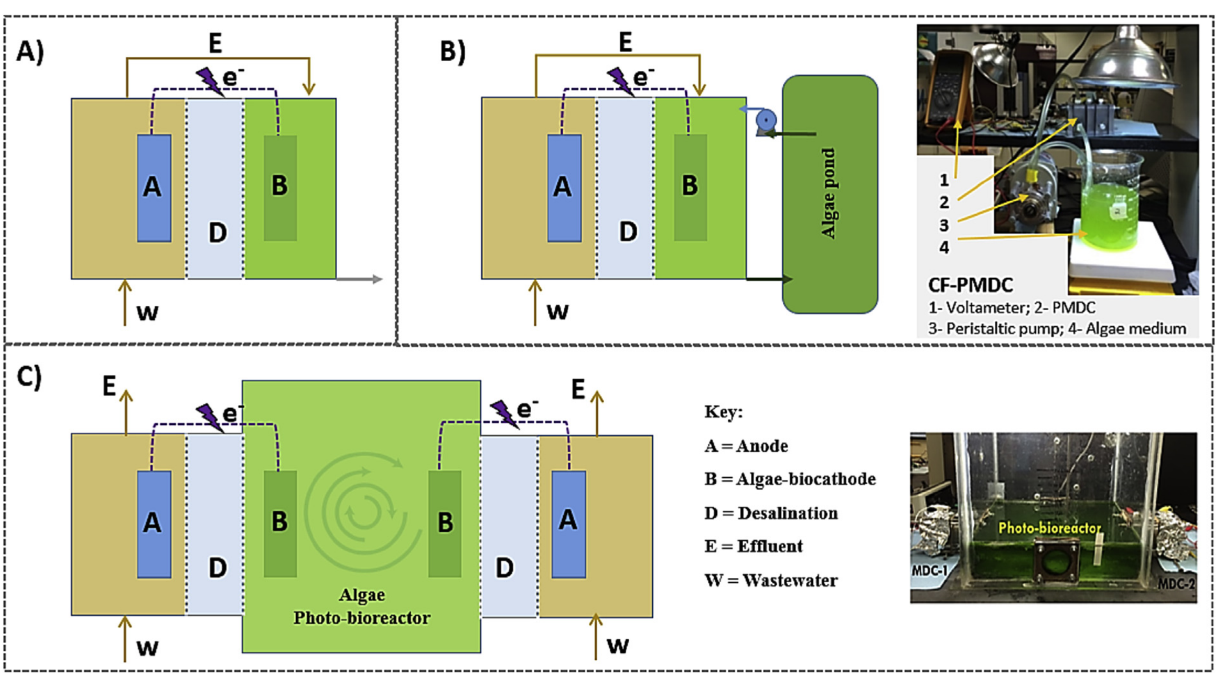


**Fig. 1.** PMDC process configurations: A) PMDC with a microalgae biocathode under fed-batch (static) operational mode (SPMDC); B) PMDC with a microalgae biocathode under continuous flow operational mode (CPMDC); C) PMDC with a microalgae biocathode connected to a photo-bioreactor (PBMDC).