SIMULTANEOUS DESALINATION AND WASTEWATER TREATMENT BY ALGAL – MICROBIAL DESALINATION SYSTEM

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Abstract

Owing to the fresh water crisis, one of the solutions to increase the availability of portable water is by desalination of brackish water and sea water. The research is based on green technology that focuses on the development of modified Microbial Desalination Cell (MDC) i.e., algal-microbial desalination. It is found to be energy-efficient saline water desalination with self-sustainability. The designed MDC for the study consists of three compartments anode, middle chamber and cathode. The middle chamber consists of salt solution with ions that moves towards the anode and cathode by electric field leading to desalination process. The degradation of organic matter results in the simultaneous wastewater treatment and energy production present in the anode chamber. In this study bio-cathode consisting of *Scenedesmus* species is tested for desalination process. Exploitation of the biomass of *Scenedesmus* is expected to yield high lipid content. The successful rate of desalination and waste water treatment is evaluated by essential parameters. This study integrated desalination with wastewater treatment, bioenergy and biofuel production in a microbial desalination cell (MDC) by utilizing the communal benefits among the above functions.

Keywords: Algal-microbial desalination, *Scenedesmus*, bioenergy

Introduction

The Social and economic development are searching for the sustainable supply of water and energy. Especially, water security is an urgent global issue faced by many regions of the world and or expected to face the shortage in supply. More than one in six people globally are water stressed, in that they do not have access to safe drinking water (United Nations, 2006).About 97% of the earth's surface is covered by sea water. The removal of salt helps to reduce the fresh water crisis. Many conventional techniques such as thermal and membrane technologies, distillation help in desalination process .The major problem with the techniques is energy intensive, high operating cost. Many steps have been taken in past years and succeeded in reducing the capital cost yet the high energy requirement remain a concern. This led to the development of new technology called Bio-Electrochemical systems (BESs) for generation of clean energy and water. The new type of BES called Microbial Desalination Cell was developed for the simultaneous desalination, waste water treatment and Power generation.

Microbial Desalination Cell

Water desalination using MDC process was first introduced in 2009 by Cao et al., which is a new platform technology. Desalination occurs by utilization of electric potential generated across cathode and anode that avoids the usage of external energy. MDC comprises of three chambers that are separated by anion exchange membrane and cation exchange membrane. Bacteria in the anode chamber oxidize organic wastes present in it and generate current that releases protons in the solution. Positive charges are restricted to move through anion exchange membrane and therefore the movement of negatively charged species occurs from middle chamber to anode. The protons generated are consumed in cathode chamber leading to the movement of positively charged species towards it. Thus the movement of ions towards anode and cathode chamber leads to the desalination of water and generation of bio-energy.

Role of algae in desalination

The application of algal species to desalinate water started 5 years ago and it provided successful promising results. Algae are heterogeneous group of organisms that grows either in salinity water in seas or fresh water in rivers and lakes and different climatic conditions. The advantage of cultivating algae when compared with land based alternative such as terrestrial plants constitutes; they require less space (1/7 th less surface area), have higher growth rates and do not compete with food production. *Chlorella* and *Scenedesmus* species are tested in previous research in wastewater treatment and stated that it reduced the cost of operation and maintained efficiency. Scenedesmus growth is successfully seen in saline water as it consumes salts and makes use of them in metabolism. The species proven promising results and that paved the development of desalination process up to 95% removal efficiency. The major drawback of using algae is harvesting the biomass (Nadi et al., 2010).

General MDC Set up

A general MDC consists of anode, anode chamber, anion exchange membrane, desalination chamber, cathode, cathode chamber and cation exchange membrane. The anode is placed within the anodic chamber containing mixture of organic components with pure culture or mixed bacterium consortium for degradation of organic compounds. The cathode is directly exposed to air. The desalination chamber is

Table 1: Summary of MDC literature
(Katie Guerra, 2013)

Citation	**MDC Configuration**	**Desalination Chamber Salt Type/ Concentration**	**Key Findings**
(Cao, Huang et al. 2009)	3 Chamber	Nacl, 5, 20,35 g/L	1. First literature mention of MDCs, 2. 90% salt removal even at high concentrations over 24 hr period in batch mode
(Mehanna, Saito et al, 2010), received February 2010	3 Chamber	Nacl, 5, 20 g/L	1. First use of air cathode, 2. Equal volumes of anolyte and desalination chamber solutions, 3. Showed partial desalination proposed MDC as pretreatment for RO, 4. 60% reduction of saline water conductivity
(Mehanna, Kiely et al. 2010), reveived July 2010	3 Chamber with added voltage (Microbial electrodialysis desalination cell, MEDC)		1. Applied 0.55 V using external power supply, 2. Increased desalination capactiy, 3. Reduced saline water conductivity by 68%, 4. Produced hydrogen gas
(Jacobson, Dreww et al.2011), received March 2010	Upflow Microbial Desalintion cell (UMDC)	Nacl, 30 g/L	1. 99% Nacl removal, 2. Saline water HRT = 4 days, 3. Max power density = 30.8 W/m^2, 4. 81% to 99% of electrons used for desalination process
(Chen, Xia et al. 2011), received October 2010	Stacked microbial desalination cell (SMDC)	Nacl 20 g/L	1. Total desalintaion rate = 0.0252 g/h
(Jacobson, Drew et al. 2011), received January 2011	Continuously operated, UMDC	Nacl, 30 g/L	1. 99% Nacl removal, 2. Saline water HRT = 4 days, 3. Current production = 62 mA, 4. Power density = 30 W/m^3
(Luo, Xu et al. 2012), received November 2011	3 Chamber	100 mM Nacl and 100 mM $NaHCO_3$	1. 4 times higher energy production for MDC compared to MFC (Microbial Fuel cell w/no desalination), 2. Used feed with multiple ionic species rather than single solute solutions
(Forrestal, Xu et al. 2012), received January 2012	3 Chamber MDC compared to microbial capacitive deionization (MCDC)	10 g Nacl, 0.49 g $NaH_2PO_4H_20$, 0.92 g Na_2HP0_4	1. Improved performance of MCDC compared to MDC, 2. Used additional AEM to minimize pH fluctuations caused by ion imbalances

placed in the middle and is separated by anion exchange membrane and cation exchange membrane. The whole set up is completed by connecting to an external resistance. The MDC chambers are made of materials such as glass, metal, plastic or suitable materials.

In photosynthetic microbial desalination cell, algae is used as biocathode in cathodic chamber.

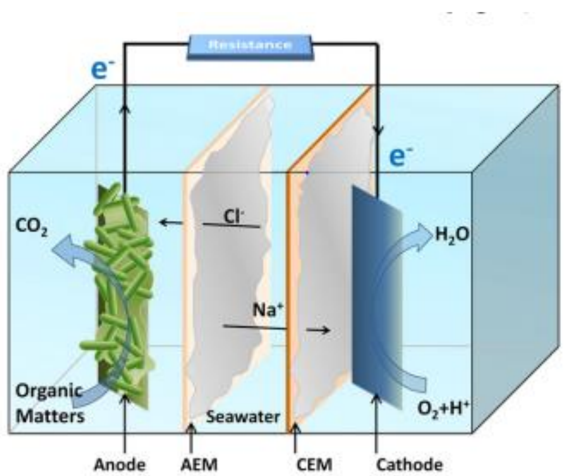

Fig 1. Schematic representation of Microbial Desalination Cell

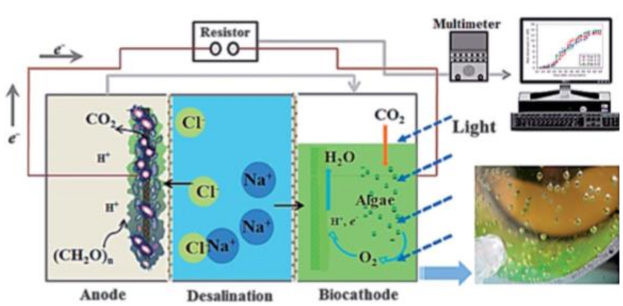

Fig 2. Schematic reperesentation of Photosynthetic Microbial Desalination Cell (Bahareh kokabian, 2013)

Anode and Microorganism

The anode compartment comprises of microorganisms such as exoelectrogens, electricigen or anode respiring bacteria that are either used in pure culture or in mixed cultures (Logan 2009). Anodophilic bacteria refer to bacteria that transfer electrons to an electrode, either directly or by endogenously produced mediators. In general, anodophilic bacteria are obligate or facultative anaerobes. The anode used provides a surface for transfer of electrons produced when microbes oxidize a substrate (Logan, 2004). MDC anodes may be formed of granules, mesh or fibers of a conductive anode material, (e.g., such as graphite, carbon, metal, etc.) Anion exchange materials may include quaternary ammonium-functionalized poly (phenylsulfone); and quaternary ammonium-functionalized divinylbenzene cross-linked poly (styrene). Specific examples include AMI ion exchange membranes (e.g., AMI-7001). The substrates used include synthetic waste water, industrial waste water, and domestic waste water.

The microorganisms oxidize the substrate and releases electrons to produce electricity leading to simultaneous treatment of wastewater. The different parameters such as pH, BOD removal, COD removal, Total dissolved solids, alkalinity, Chloride are determined to justify the treatment process.

Cathode and Algae

In general MDC, air cathode is used ie., one side of surface is exposed to air or gases. Materials that may be used for the cathode include carbon paper, carbon cloth, carbon felt, graphite, porous graphite, activated carbon, etc. Electrode coated catalyst such as platinum, nickel, copper, tin, iron and alloys of such metals provides additional conductivity. Cation exchange materials may include ion-functionalized polymers exemplified by perfluorinated sulfonic acid polymers such as tetrafluoroethylene and perfluorovinylether sulfonic acid copolymers, and derivatives thereof; sulfonate-functionalized poly(phenylsulfone); and sulfonic acid functionalized divinylbenzene cross-linked poly(styrene). Specific examples include NAFION, such as NAFION 117 and CMI-7000.

Algae as sustainable biocathode were first reported by bahareh et al., in photosynthetic microbial desalination cell. Usage of algae is considered to be environmentally beginning approach. Insitu oxygen generator and COD removal is seen. Finally after the desalination process, the obtained biomass can be used for biodiesel production.

Desalination

Desalination occurs in the middle chamber of MDC. Dissociation of ions occur leading to desalination process. Salinity removal in MDC is dependent on many factors such as salt solution volume, wastewater volume, hydraulic retention of waste water and salt solution concentration, membrane surface area, microbial oxidation and oxygen reduction rates (Jacobson, 2011). Parameters such as pH, conductivity, TDS, Nacl concentration, resistance, temperature, desalination rates can be determined in order to rate the efficiency of desalination process.

Power generation

Production of current depends on the ability of the bacteria that oxidizes substrate and transfer of electrons. Water bodies containing higher organic matter were able to generate higher power output. At present, power generated is low from the view of large scale wastewater treatment. Microbial catalyzed bio cathodes produce stable voltage for longer periods when compared with chemical catalyst like ferricyanide was used as a catholyte (Cao, 2009)

Conclusions and future aspects

MDC is found to be promising technology for desalination and wastewater treatment. Low strength of wastewater can be successfully treated due to the improved conductivity in the anodic chamber, that enhance the electricity generation. Usage of algal biocathode in photosynthetic microbial desalination cell showed simultaneous removal of salt, wastewater treatment and algal biomass production.

Innovation in the MDC technology is further necessary in order to increase the power amplification and reduction in capital cost. Next aspect to be concentrated is the technical problems in scale up process. Different substrates, electrodes, wastewater can be used to increase the efficiency of the process. In some cases, MDC is used as a pre-treatment of RO.

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