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Microbial desalination cell technology: Contribution to sustainable waste water treatment process, current status and future applications

A. Carmalin Sophia[a,*], V.M. Bhalambaal[a], Eder C. Lima[b], M. Thirunavoukkarasu[a]

[a] National Environmental Engineering Research Institute (NEERI), Chennai Zonal Laboratory, CSIR Campus, Taramani, Chennai 600113, India
[b] Institute of Chemistry, Federal University of Rio Grande do Sul (UFRGS), Av. Bento Gonçalves 9500, P.O. Box 15003, 91501-970 Porto Alegre, RS, Brazil

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ABSTRACT

Microbial desalination cell (MDC) has been developed for removing water salinity, electricity generation, and wastewater management. MDC emerged from the microbial fuel cell (MFC) and electro-dialysis had recently received a significant consideration for desalination and wastewater treatment as an environmentally friendly technology. The above process can be combined with regular desalination systems or can perform individually. The current paper explains the potential applications of MDCs viz. sea water and brackish water desalination, hydrogen gas generation, hardness removal and ground water remediation. The present article outlines the principle behind the functioning of a standard MDC arrangement with a short introduction to the bacteriological media. The effect of experimental conditions in enhancing the MDC operation is optimized. This review highlights the importance of research efforts towards the current status, progress and commercialization of MDCs.

Contents

Abbreviations: AEM, anion exchange membrane; CEM, cation exchange membrane; BPM, bipolar membrane; FO, forward osmosis; MDC, microbial desalination cell; MFC, microbial fuel cell; MEC, microbial electrolysis cell; CMDC, capacitive microbial desalination cell; SMDDC, submerged desalination denitrification cell; CNT, carbon nanotube; MEDC, microbial electrodialysis cell; MRC, microbial reverse electrodialysis cell; MODC, microbial osmotic desalination cell; MEDIC, microbial electro-deionization cell; C-MDC, control microbial desalination cell; COD, chemical oxygen demand; DGGE, density gradient gel electrophoresis; OCV, open circuit voltage; UMDC, up flow microbial desalination cell; SMDC, stacked microbial desalination cell; DR, desalination rate; VFA, volatile fatty acids.

* Corresponding author.
E-mail addresses: ac_sophia@neeri.res.in, sophizz@gmail.com (A. Carmalin Sophia).

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1. Introduction

Clean water is 3% of total water on earth, of which only 1% is accessible. There is always a great demand for clean water since major portion of the water has been locked in glaciers and snow. Desalination technologies are becoming more common for the production of potable water from sea water. Most of these technologies are energy and cost intensive. Since energy demands of traditional desalination procedures such as solar desalination, thermal desalination, reverse osmosis (RO) etc., is a major challenge; alternative techniques are required for desalination of brackish water. It is therefore important to develop desalination technologies supported by renewable energy [1].

Microbial desalination cells (MDCs) is growing technology developed to accomplish saline-water desalination and wastewater treatment in a single reactor [2,3]. It is a bio-electrochemical system and an addition to modified microbial fuel cell (MFC) technology. MFC includes positive and negative charged electrodes with selective proton-exchange membrane mediated by a peripheral circuit to maintain the oxygen and oxygen-less environment at the respective electrodes. To discuss the differences among fuel cell and MDC, the former operates with or without a mediator and involves supplementary microbial input to metabolize the substrate. MDCs do not require superfluous bacteria as a mediator source while; it relies on the internal sludge which is electro-active. The waste water containing the organic matter enters the anodic side where bio-film is formed due to the proliferation of the bacteria and electricity is produced [4]. The biofilm clings to the anode surface and initiates the bio-catalysis process by oxidizing the bio-pollutants present in watery sludge to release protons and electrons.

These routed electrons are captured by anode and cathode, via an external circuit. The positive chamber of MDC is either aerobic or anaerobic. The MDC produces the bioelectricity due to the potential difference across the electrode chambers. The positively charged ions traffic to the cathode by a specific cationic membrane, where it combines with electrons and oxygen species to produce clean water (Fig. 1). Some of the important key points need to be addressed in the case of MDCs for practical applications are (1) knowledge about organic loading (2) cost-effective electrodes with low potential losses (3) pH gradients (4) scalable and cost-effective MDC design.

The overall ionic flow in anodic and cathodic compartments of MDC was represented by the following equations (Eqs. (1) and(2)).

$$2\ CH_3COO^- + 4\ H_2O \rightarrow 4\ CO_2\ (g) + 14\ H^+ + 14e^- \quad (1)$$

$$14\ H^+ + 14\ e^- \rightarrow 7\ H_2\ (g) \quad (2)$$

MDCs can produce energy of about 180–231% in the form of H_2 [5] during the desalination of NaCl solutions from 30 g L^{-1} to 5 g L^{-1} [6,7]. Comparatively, other desalination methods need about 6–68 kW h to desalinate 1 m^3 of saltwater from the sea. In the MDC, chlorides and sulfates move from the middle chamber across the AEM into the anode. The sodium and calcium ions move across the CEM into the cathode where the removal is nearly 99% of the salt and yield higher energy than the external energy needed for the functioning of the system [8].

The rate of desalination is the key factor in MDC function. It depends on the initial salt concentration of the sample to be desalinated. MDC is primarily appropriate for desalinating water with high salt content. This may lower the ohmic resistance and result in higher current production and a higher desalination rate (DR). Recently, a new approach to anode-cathode recirculation was seen to be effective in stabilizing pH both in anode and cathode which enhanced the desalination rate by a factor of 2.52 folds and electron yield by 98% [3]. The salt concentration gradient in all the three chambers largely influenced the desalination process. If the salt concentration is low it could lower the desalination rate when dialysis occurs between the electrolytes and the saltwater by reverse concentration gradient [9].

For the first time, a group of scientists studied the concept of MDC [1]. They worked on the shape and design of MFC. They made it three chambered instead of two. The chambers were separated by anion exchange membrane (AEM) and cation exchange membrane (CEM). The chamber volume was reduced with the carbon rods felt in cathode and anode which was later studied with the graphite rods.

El-Mekawy et al. [1] attempts to discuss if desalination has the capability to stand alone as an efficient replacement for RO, or

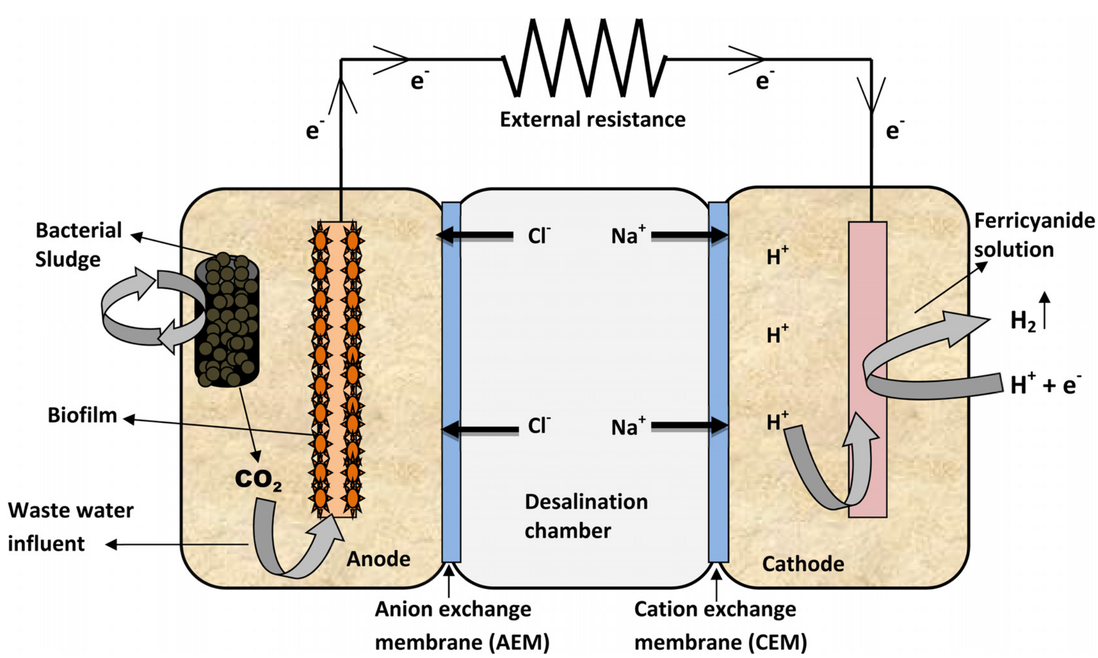

Fig. 1. Schematic representation of ionic flow in microbial desalination cell (MDC).