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Microbial desalination cells as a versatile technology: Functions, optimization and prospective

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HIGHLIGHTS

- The functions of microbial desalination cells are analyzed and discussed.
- The role of process parameter in improving the MDC performance is reviewed.
- Main challenges for using MDC in seawater desalination are discussed.
- Current challenges in MDC scale-up are examined and presented.

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ABSTRACT

Saline water such as seawater or brackish water is a potential source for drinking water or for non-potable applications, but the existing desalination techniques are energy intensive. Therefore, there is an urgent need to develop sustainable desalination methods. Microbial desalination cells (MDCs) hold great promise for energy-efficient saline water desalination. In MDCs, electrical energy from wastewater is extracted by taking advantages of microbial extracellular respiration and used to drive desalination. Herein, we have comprehensively reviewed and discussed the potential functions of MDCs, including seawater desalination, brackish water desalination, water softening, hydrogen and chemical production, and groundwater remediation along with wastewater treatment. The role of process parameters in improving the MDC performance was also analyzed. We expect to provide insight into the advantages and limitations of this emerging technology from the aspect of its functions, thereby encouraging more research efforts towards further development and commercialization of MDCs.

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1. Introduction

Although water is an abundant natural resource on the earth, 97% of it is seawater that cannot be directly used for drinking. The demand for freshwater is further intensified due to the rapid industrialization and increase in human population. To meet the fresh water demand especially in the areas where freshwater resource is limited and seawater/brackish water is available, desalination processes are widely used. Table 1 summarizes all the major desalination technologies. A major limitation in the current desalination processes (membrane or thermal) is the high energy demand [1–3]. Therefore, an energy efficient desalination technology is desired. In the past decade microbial fuel cells (MFCs) have emerged as a promising technology for simultaneous wastewater treatment and bioelectricity generation. In the anodic chamber of MFCs, microbes work as biocatalysts to generate electrons through the oxidation of organic compounds (e.g. in wastewater) and transfer them to the anode electrode. These electrons flow through an external circuit to the cathode electrode where they are used to reduce terminal electron acceptors (e.g., oxygen) [4]. MFCs modified to desalinate salt water are known as microbial desalination cells (MDCs). MDCs are of great interest because this technology may address both wastewater treatment and water desalination in a single device through taking advantage of the energy content in wastewater [5–7]. To convert MFC to MDC, a middle chamber is inserted in between the anodic and cathodic chambers using a pair of anion exchange membrane (AEM) and cation exchange membrane (CEM). This middle chamber works as a desalination chamber in the MDC (Fig. 1). Cations and anions from the desalination chamber move to the cathodic and the anodic chambers, respectively, due to the cell potential difference between the electrodes. As a result, salts are removed from the saltwater [8].

The first proof-of-concept of MDCs was demonstrated by a three-chamber configuration [8]. The MDC using acetate as an electron donor and ferricyanide as an electron acceptor was able to remove up to 90% of salt and generated a maximum power density of 31 W/m^3. Further study of three-chamber MDCs using actual domestic wastewater as an anodic substrate also demonstrated effective desalination [9]. However, the use of ferricyanide as a cathode electron acceptor is neither sustainable nor cost effective. To overcome this problem, an MDC with air cathode was studied with different concentrations of acetate in the anode and achieved up to 63% reduction in salinity [10]. Moreover, aerobic microbes were used as biocatalysts in a biocathode MDC, which performed better than both air cathode (no catalysts) and a ferricyanide cathode [11]. This result suggests that the accumulation of cations exerts little effect on the microbes on the cathode electrode. The basic three-chamber MDCs, especially those with air cathode and biocathode, show the feasibility of this concept for practical applications and may act as a foundation for future MDC development. The successful operation of the MDCs with single desalination chamber encouraged the development of stacked MDCs [8,9,12,13]. It was found that increasing the number of desalination chambers increased the charge transfer efficiency of the MDC and improved the total desalination rate [13]. However, the cell number should be increased with caution because the resistance of membranes should be considered [14,15].

In the past few years, there has been an increasing number of publications on various aspects of MDC, indicating a strong interest and rapid development of this technology (Fig. 2). A recent review article gave a comprehensive overview of MDC configurations [5]. Table 1 summarizes the comparison of MDCs with all the major available desalination technologies. Herein, we focus on analyzing and discussing the potential functions of MDCs and provide perspectives on the optimization of process parameters for the enhancement of MDC performance.

2. MDC functions

2.1. Seawater desalination

Membrane based desalination processes have been prevailingly used for the production of pure water from seawater, but the present

Table 1
Summary of different water desalination technologies.

Desalination technology	Key features	Limitation/disadvantages
Thermal based desalination		
• Multi-stage flash distillation • Multiple effect distillation • Mechanical vapor compression	Most commonly used (commercially available) Economical for large volumes Suitable for removing high salt concentration Suitable where waste heat source is available or cost of energy is low	High energy demand Not suitable for low volumes High capital cost High maintenance cost
Membrane based desalination		
• Reverse osmosis	Suitable for treating brackish water Energy consumption is low compared to thermal process High recovery rate Start-up and shutdown of the process is quick Commercially available	Membrane fouling High maintenance cost
• Electrodialysis	Electrochemical separation of ions and salt Long membrane life time High water recovery & high efficiency Commercially available	High operational cost High capital cost
• Microbial desalination cell	Desalination is driven by energy from treating wastewater Wastewater treatment, desalination and power production in one system No external power supply needed	Commercially not available Longer start-up time Still at lab scale High capital cost