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Microbial desalination cell technology: A review and a case study

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HIGHLIGHTS

- The MDC process is discussed.
- Biofilms and biofilm formation as applied to MDCs are introduced.
- Different MDC modifications are compared to conventional MDCs for water treatment.
- The issues of scale-up and practical limitations of MDCs are also addressed.
- Three alternate designs for wastewater treatment plants with MDCs are evaluated.

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ABSTRACT

The microbial desalination cell (MDC) is a newly-developed technology which integrates the microbial fuel cell (MFC) process and electrodialysis for wastewater treatment, water desalination and production of renewable energy. Due to free energy requirements and environmentally friendly technologies, MDC recently received considerable attention for desalination and wastewater treatment. The technology can either be used as a stand-alone process, or can be combined with other desalination processes, such as reverse osmosis (RO) or electrodialysis. Recently, several different modifications of MDCs have been developed including stacked MDCs, biocathode MDCs and recirculation MDCs.

This paper provides a general review of the MDC technology. The working principle of the conventional MDC system is discussed, followed by a brief introduction to biofilms and biofilm formation. The different modifications of MDCs and the various advantages and disadvantages associated with each, including the desalination performance and electricity generation are also considered. The issues of scale-up and practical availability of the MDC technology are discussed, followed by a detailed discussion and evaluation of a proposed design for a wastewater treatment plant integrating the MDC technology. A case study of a wastewater treatment plant integrated with MDC technology to simultaneously treat wastewater and desalinate seawater is also considered.

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1. Microbial desalination cells

Microbial desalination cell (MDC) has demonstrated the ability to treat wastewater with simultaneous production of electricity. The MDC technology is an extension of the microbial fuel cell (MFC) technology. As shown in Fig. 1, the MFC unit is composed of an anode, cathode, cation-selective membrane and an external wire. Anaerobic and aerobic conditions are maintained at the anode and cathode, respectively. Microbial fuel cells can operate with or without a mediator; mediated fuel cells involve the addition of external bacteria to oxidize the substrate. However, MDCs without mediator do not require addition of bacteria but utilize an external source, where the bacteria present within the sludge are electrochemically active. In the case of electricity production from wastewater, wastewater containing the organic matter enters the anodic side where the available bacteria are proliferated and form a thick cell aggregate known as biofilm [1]. This biofilm clings to the anode and the process of biocatalysis initiates where bacteria oxidize organic matter releasing protons and electrons.

The electrons travel from the anode to the cathode through an external wire that links the two electrodes. The cathode is either exposed to air or is surrounded by aerobic water. Thus, bioelectricity is produced due to the potential difference across the cathode and anode chambers. The protons pass through the cation-selective membrane to the cathode and combine with oxygen and the electrons from the external circuit to form pure water. The cation-selective membrane is used to prevent the passage of oxygen to the anode, and thus could cause the reduction in columbic efficiency [3]. The following equations show the reactions at the anode and cathode:

At the anode:

$$(CH_2O)_n + nH_2O \rightarrow nCO_2 + 4ne^- + 4nH^+.$$

At the cathode:

$$O_2 + 4ne^- + 4nH^+ \rightarrow 2H_2O.$$

In the same line of MFCs, MDCs make use of microorganisms present in wastewater to convert the biochemical energy stored in organic matter into electricity. As a result, a potential gradient across the anode and cathode is created which drives desalination to take place. In contrast to other water desalination techniques that require about 6 to 68 kWh to desalinate 1 m^3 of seawater, MDCs can rather produce 180 to 231% more energy, in the form of H_2 as reported by Wang and Ren [4] for the desalination of sodium chloride solutions from 30 g/L to 5 g/L.

A typical MDC unit, as shown in Fig. 2, consists of anode and cathode chambers and an additional desalination chamber in the middle constructed by inserting an anion-exchange membrane (AEM) and a cation-exchange membrane (CEM) on either side. As mentioned, the anode chamber is responsible for organic degradation and electricity production; the middle chamber is responsible for salt removal from seawater; while the cathode chamber completes the electrical loop [5]. At the anode, bacteria oxidize the organic matter into CO_2 and H^+ released into the anolyte. The electrons flow to the cathode through an external electric circuit, and a current across the cell is established. The external electron acceptors in the cathode chamber, usually O_2, use these electrons to undergo reduction and produce water. This causes a potential gradient across the anode and cathode chambers and in order to maintain electro-neutrality, the anions (such as Cl^- and SO_4^{2-}) migrate from the saltwater in the middle chamber across the AEM into the

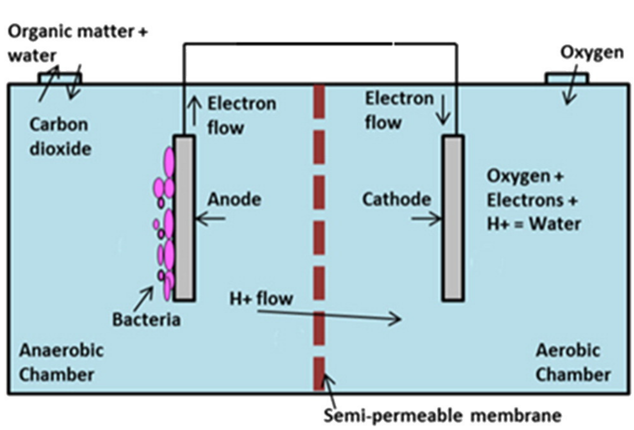

Fig. 1. General scheme of microbial fuel cell [2].

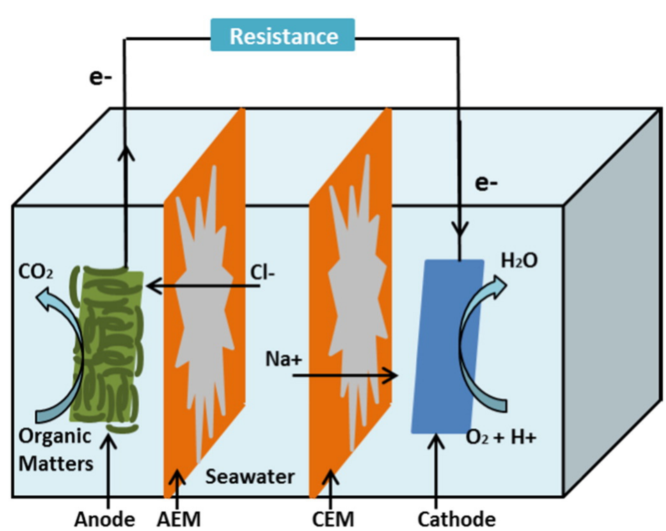

Fig. 2. Typical scheme of microbial desalination cell [7].