Desalination 445 (2018) 204–212

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Simultaneous organics, sulphate and salt removal in a microbial desalination cell with an insight into microbial communities

Tahereh Jafary[a], Wan Ramli Wan Daud[a], Saad A. Aljlil[b], Ahmad Fauzi Ismail[c], Abdullah Al-Mamun[d], Mahad S. Baawain[d], Mostafa Ghasemi[e,*]

[a] Fuel Cell Institute, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia
[b] National Centre for Water Treatment and Desalination Technology, King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia
[c] Advanced Membrane Technology Research Centre (AMTEC), Faculty of Chemical and Energy Engineering (FCEE), Universiti Teknologi Malaysia (UTM), 81310, Johor, Malaysia
[d] Department of Civil and Architectural Engineering, Sultan Qaboos University, P.O. Box 33, Al-Khoud 123, Muscat, Oman
[e] Petroleum Engineering Department, Universiti Teknologi PETRONAS, Seri Iskandar 32610, Perak, Malaysia

ARTICLE INFO

Keywords:
Microbial desalination cell
Desalination
Sulphate removal
Organic matter removal
Microbial community

ABSTRACT

Microbial desalination cells (MDCs) are known among the bioelectrochemical systems for their green and cost-effective application in salt removal. However, the low efficiency of desalination compared to other chemical and membrane-based methods still holding this technology in laboratory and requiring further research and development (R&D) to establish actual plants. This study focused on integrating different applicable functions in one setup to promote applying MDCs in actual scale. In this research, the behavior of the MDC upon applying different salt concentrations in the desalination chamber was studied. Moreover, salt, sulphate and organic matter removal in acetate and sulphate-fed MDCs (A.MDC and S.MDC) were investigated. 10, 20 and 35 g/l of salt were successfully removed by using MDC technology. Sulphate removal of 72% was achieved within the S.MDC setup while similar current productions were observed in both A.MDC and S.MDC. Higher COD removal (88%) was recorded in S.MDC compared to 65% in A.MDC. Furthermore, the microbial communities were characterized and *Rubrivivax* was identified as the dominant genus in A.MDC while *Desulfobulbus*, *Geobacter* and *Desulfovibrio* were the most abundant genera in S.MDC setup.

1. Introduction

Water and wastewater are among the sought-after subjects in the current research world. The first is important mainly due to the depletion in the global water sources, while the latter gained attention for two concerns of energy and environment [1,2]. World Water Assessment Programme (WWAP) has reported 40% worldwide water shortage by 2030 as a result of world climate change [3]. Moreover, wastewater generation is an inevitable incident due to the rapid industrialization and population growth [4]. The generated wastewater needs to be treated and or regenerated in the most economical and environmental ways to save both energy and environment. The energy employed for wastewater treatment is important due to the fact of its high consumption of energy and the energy value at the first place and to save the environment which is polluted to produce this energy as well [5]. So, inventing and improving the strategies which could treat the waste while saving the energy and environment is one of the most interesting and promising focus of the recent researches [6,7].

Bioelectrochemical systems (BESs) have gained significant attention for their green, economical and environmentally friendly characteristic in recent years [8–10]. Microbial fuel cell and microbial desalination are among the known BESs [11]. Microbial fuel cell is a well-established process which uses the microorganism in one or both anode and cathode compartments to produce bioelectricity as a result of degrading the organics in wastewater and leaving the waste treated [12–14]. Saline water (e.g. seawater and brackish water) is considered as a potential source for drinking water while the current sources are significantly decreasing [11]. Current non-green desalination techniques have estimated to consume 3–10 kWh of energy per 1 m^3 of fresh water production which the energy is mostly provided by fossil fuel sources, addressing both high energy consumption and subsequent greenhouse gases emissions [15]. Microbial desalination cells (MDCs) have recently emerged, by modifying the known microbial fuel cells (MFCs), as a promising method for water desalination along with wastewater

* Corresponding author.
E-mail address: mostafa.baboli@utp.edu.my (M. Ghasemi).

https://doi.org/10.1016/j.desal.2018.08.010
Received 29 April 2018; Received in revised form 30 July 2018; Accepted 11 August 2018

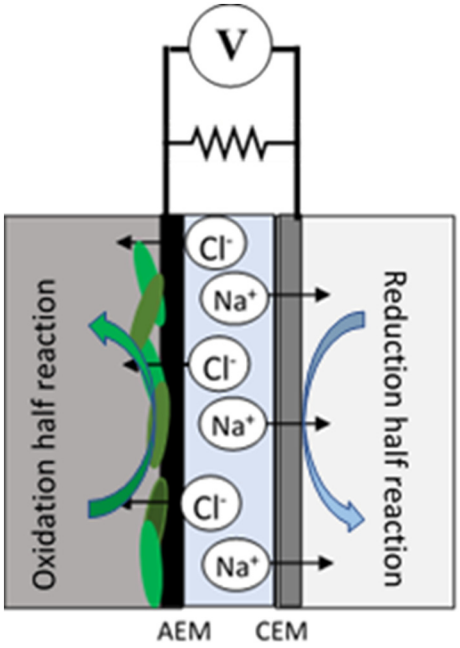

Fig. 1. Schematic diagram of a microbial desalination cell.

treatment [16]. MDC can represent an energy and cost-effective technique for saline water desalination while treating the waste despite the energy and cost-intensive current water desalination technologies; e.g. thermal and membrane-based desalination [17]. Moreover, this technology is totally environmentally friendly since the microorganisms serve as the biocatalysts [18]. An MFC is consisted of two anode and cathode compartments which are generally separated by placing a membrane between them. The degradation of the waste in anode chamber will result in proton and electrons production. Protons pass through the membrane and will reduce to water by using the electrons which flow through the external circuit to the cathode and the final electron acceptor (oxygen) [7,19]. An MFC can be modified simply to an MDC by inserting a middle chamber between the anode and cathode. The MDC configuration will be completed by placing an anion exchange membrane (AEM) between the anode and desalination chambers and a cation exchange membrane (CEM) between the cathode and desalination chambers (Fig. 1). Oxidation and reduction reactions will result in accumulation of positively and negatively charged species in the anode and cathode chambers respectively. The selection of anion and cation membranes will direct the spontaneous movement of the negatively and positively charged species (e.g. Cl^- and Na^+) present in the desalination chamber towards the anode and the cathode chambers respectively. The whole process will lead to spontaneous desalination in the middle chamber without extra applied energy in forms of voltage, pressure and/or heating. Rather than the biological electricity production in microbial fuel cell and salt desalination in microbial desalination cell, these BESs can be enriched for wastewater treatment in general by COD removal and or for selective toxic elements in wastewaters [20,21]. It should be noted that pH maintenance in anolyte and catholyte, high internal resistance, use of noble expensive catalyst, membrane durability and fouling are among the technical challenges towards practical application in MDCs [22]. Al-Mamun et al. [22] have thoroughly reviewed the latest findings and the current status on MDCs (e.g. configuration and optimization). They have implied the importance of MDC scale-up as the future status of the research path. Moreover, the need for engineering development of the MDCs to bring it to the actual plants for the purposes of energy recovery from wastewater and desalination was stated as the current research path.

Sulphate is one of the most abundant and common pollutant in wastewater streams. It can be generated and discharges from specific industries e.g. edible oil production, fermentation, pulp and paper processing and or be present commonly in wastewaters as bleaching or pH adjustment agents. Despite releasing a large quantity of sulphate content wastewater to the environment and its severe indirect health and environmental negative effect, little attention has been devoted to the subject. Excessive untreated sulphate content in the wastewater could adversely affect the water supplies, ecological stability, and lead in acid mine drainage and corrosion issues [23,24]. Lee et al. [25], Angelov et al. [26] and Zhao et el. [27] have reported that the combination of sulphate reducing bacteria, some exoelectrogens and anode surface could result in sulfate reduction along with electricity production in the anodic chamber.

Even though BESs have the promising potential in terms of energy consumption and environmental protection to be implemented in actual plants, however, their low efficiency slowed down their scale-up rates. Improving the application of these green technology by integrating different applications in one setup could facilitate their entrance to the actual plant for further research and development (R&D) purpose in a functional size and environment [28,29]. This study has focused on the integration of wastewater treatment and desalination process for the purpose of organic and sulphate removal while desalinating saline water in an environmentally friendly unique setup. Low to high concentrations of saline water have been tested in a recirculated MDC while treating the organic wastewater within the anode chamber. Moreover, desalination of high concentration of saline water (in range of seawater) and wastewater removal were studied in presence of acetate and sulphate-based wastewater. The microbial communities of the efficient systems were investigated afterwards.

2. Materials and methods

2.1. Experimental setup and operation

The anode, cathode and desalination chambers of the MDC were fabricated out of polycarbonate solid block. The volume of the anode and cathode chambers were each 48 ml (4 cm × 4 cm × 3 cm) and the desalination chamber was 24 ml (4 cm × 4 cm × 1.5 cm) resulting in the desalination chamber versus anode/cathode chamber (electrochemical cell) in volume (DV/EV) ratio of 0.5, during salt concentration study. The system configuration changed in terms of DV/EV for acetate and sulphate-fed MDC study to increase the volume of salt removal. The volume of the anode and cathode chambers were each 36 ml (3 cm × 6 cm × 2 cm) and the desalination chamber was 27 ml (3 cm × 6 cm × 1.5 cm) resulting in DV/EV of 0.75. The cation exchange membrane (CEM, CMI-7000 Membranes internationals Inc.) and the anion exchange membrane (AEM, AMI-7001 Membranes internationals Inc.) were prepared by immersing in 5% NaCl overnight for further hydration and expansion upon usage. The graphite felt was used as the anode and the cathode electrodes. The graphite felt was washed and prepared by soaking in absolute ethanol, 1 M HCl and 1 M NaOH for 30 min, 1 h and 1 h, respectively [30]. The cathode was coated with 0.5 mg Pt/cm^2 for catalyzing cathodic oxygen reduction reaction. The electrical circuit was closed by connecting the anode and the cathode by using 1 Ω external resistance. The anode composition during salt concentration (Section 3.1) and A.MDC (Section 3.2) studies was consisted of 50 mM phosphate buffer solution (Na_2HPO_4: 4.58 g/l, $NaH_2PO_4.H_2O$: 2.45 g/l), $MgSO_4.7H_2O$: 0.1 g/l, NH_4Cl: 0.5 g/l, KCl: 0.13 g/l, NaCl: 0.5 g/l, $CaCl_2.2H_2O$: 0.05 g/l, sodium acetate: 2 g/l and 10 ml/l of wolf's vitamin and mineral solutions. The sodium acetate was replaced by sodium lactate: 2 g/l and sodium sulphate: 2 g/l during S.MDC study (Section 3.2). A mixed culture source of palm oil mill effluent (POME) was used as the initial inoculum to enrich the anodic biofilm [31,32]. A 50 mM phosphate buffer solution in the cathode chamber (pH = 7) was continuously aerated and recirculated over a 1 l bottle to maintain the pH [28]. The recirculation bottle was equipped with a pH meter (BL 981411 pH controller, Hanna, USA). The catholyte