Journal of Power Sources 325 (2016) 739–744

Contents lists available at ScienceDirect

Journal of Power Sources

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

The effect of number and configuration of sediment microbial fuel cells on their performance in an open channel architecture

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HIGHLIGHTS

- An open channel with flow of catholyte was used to simulate natural river flow.
- Performance of stacked SMFCs in the open channel was investigated.
- Power density of individual cells increased along the catholyte flow in the channel.
- Increase in the number of SMFCs affected cell performance at different configurations.
- Parallel mode performed better than series mode with increase in the number of cells.

ARTICLE INFO

Article history:
Received 6 March 2016
Received in revised form
31 May 2016
Accepted 16 June 2016

Keywords:
Sediment microbial fuel cells
Power density
Number of cells
Stacking
Electricity generation

ABSTRACT

The aim of this study is to investigate the effect of the number of sediment microbial fuel cells (SMFCs) with different configurations on the electricity generation in open channels. For this purpose, two open channels, one with three and another with four SMFCs, were operated over a long period of time and their performances were analyzed. Individual SMFCs followed an almost similar trend for electricity generation during the operation time. In addition, it was found that three-SMFC stacking in series mode produced a relatively higher maximum power density (18 mW m^{-2}) than four-SMFC stacking (16 mW m^{-2}). However, in parallel mode, four-SMFC stacking had a higher maximum power density of 90 mW m^{-2} compared to three-SMFC stacking with maximum power density of 78 mW m^{-2}. These findings indicate that different numbers of cells significantly affect electricity generation depending on the type of SMFC configuration in the channel. The results would be helpful for application of SMFCs in large-scale.

1. Introduction

Renewable resources of energy are compatible with the environment and are able to overcome the drawbacks involved with the production and consumption of the fossil fuels. Thus, researchers have recently focused on energy production using different types of inexhaustible resources [1–3]. Sediment microbial fuel cells (SMFCs) are promising technologies as they produce energy through the conversion of chemical energy present in sediments to electrical energy via microbial metabolism [3–6]. Compounds in the sediment at anode side of an SMFC are oxidized and the produced electrons are transferred through an external circuit to the cathode where oxygen is reduced by accepting the electrons from the anode. During the process, electricity is generated with concomitant treatment of sediment due to the degradation of compounds in it [7–9].

SMFCs may be used to power remote sensors and electrical instruments for environmental monitoring, due to their little maintenance requirement, long-term power generation as well as in situ wastewater treatment, while the batteries usually used for this reason are not applicable for a long period of time [8,10,11].

Despite their advantages, SMFCs suffer from some shortcomings such as low output current and power [8,11]. Many efforts have been done to tackle these limitations. Hong et al. [6] studied the limiting factors affecting the electrical current in SMFCs. They found that factors such as temperature, electrical conductivity, electrode spacing, external load, dissolved oxygen concentration, and electrode surface area ratio affect current production. An et al. [12] reported that the maximum power and current of the SMFC increased with the increase in depth of the embedded anode from 2

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http://dx.doi.org/10.1016/j.jpowsour.2016.06.080
0378-7753/

to 10 cm so that the SMFC with the anode being placed at a 10 cm depth had the best performance. Sajana et al. investigated the effect of operating parameters including external resistance, pH and distance between electrodes on the performance of SMFC (power generation, COD removal and total nitrogen removal) by applying a statistical model [13]. Other attempts include using rotating cathode [4] and algae assisted cathode [11] to increase the oxygen availability, applying pretreatment methods on sediments [9], using floating cathode to increase the electricity production [14], and introducing iron sheet into the sediment to increase the activity of microorganisms to generate electron [15].

In addition, the limitations mentioned in microbial fuel cells can be solved by stacking the cells in various configurations [16–19]. Although, connecting microbial fuel cells in series boosts the total voltage, it also leads to voltage reversal that negatively affects voltage production [16,17]. Attempts have been made to eliminate this phenomenon by using resistor [20], capacitor and running SMFC with high external resistance [17].

In this research, a novel partitioned open channel was designed and continuous flow of catholyte with river sediment at anode section was used to simulate the natural environment of rivers. In order to explore the behavior of different numbers of SMFCs in the open channel, SMFC performances in single mode were investigated. Furthermore, as individual SMFCs produce little electricity [21], their operation in stack with different configurations (series and parallel mode) was also examined. Some of the previous studies claimed that SMFCs cannot be stacked in series connection as the electrodes are located in the same electrolyte solution [17,22,23], thus other approaches were suggested including power management systems to increase power output of SMFCs [10,14,23,24]. However, our hypothesis was that increase in voltage in series configuration would be possible by designing an appropriate system. The SMFC performance was evaluated in terms of output voltage and power density.

2. Experimental

2.1. SMFC construction

Two identical open channels were made of Plexiglass each with the size of 100 cm × 5 cm × 12 cm with wall thickness of 3 mm being divided to nine compartments at the anode side by vertical plates of Plexiglass with 10 mm thickness and 6 cm height. Three similar SMFCs were located in one channel (named Channel-3) and four in another one (Channel-4). The first cell in each channel was placed in the second compartment beginning from the channel entrance (named SMFC3-1 in Channel-3 and SMFC4-1 in Channel-4) and each subsequent cell was located in the next second compartment (SMFC3-2 and SMFC3-3 in Channel-3, and SMFC4-2, SMFC4-3 and SMFC4-4 in Channel-4). The experimental setup is shown in Fig. 1.

In order to reduce the negative effect of the cells on each other, one empty compartment was considered between each two SMFCs (Fig. 2). Taking into account the size of channel and the number of its compartments, one channel with three cells and another with four cells were run.

Square anodes and cathodes (3 cm × 3 cm × 7 mm, PANEX35, ZOLTEK) were made of carbon felt. The anode and cathode electrodes were embedded 2 cm under and above the sediment level, respectively. They were hold tight in their position using Plexiglass holders. Electrodes were connected to an external resistance by means of a stainless steel wire. The external resistance of each SMFC in single mode operation was set to 1000 Ω. Anode sections were filled with sediment samples collected from Kashafrood river (36° 23′ 51″ N, 59° 34′ 51″ E) in Mashhad, Iran. The anode compartments of the control SMFCs were filled with autoclaved sediment (121 °C, 20 min); While other experimental conditions were exactly identical to the other experiments. Water (pH = 7.9, DO = 5.1 mg/L, Conductivity = 770 μs/cm, Temperature = 22.7 °C) was used as electrolyte in the cathode chamber. A closed loop system including containers, pump, and level sensor was used to circulate water through the system (Fig. 2). The water storage container A equipped with liquid level sensor and pump was located 80 cm lower than the SMFC channel. In order to have a constant hydrostatic head, container B was located 1.5 m above

Fig. 1. Experimental setup used in the laboratory.

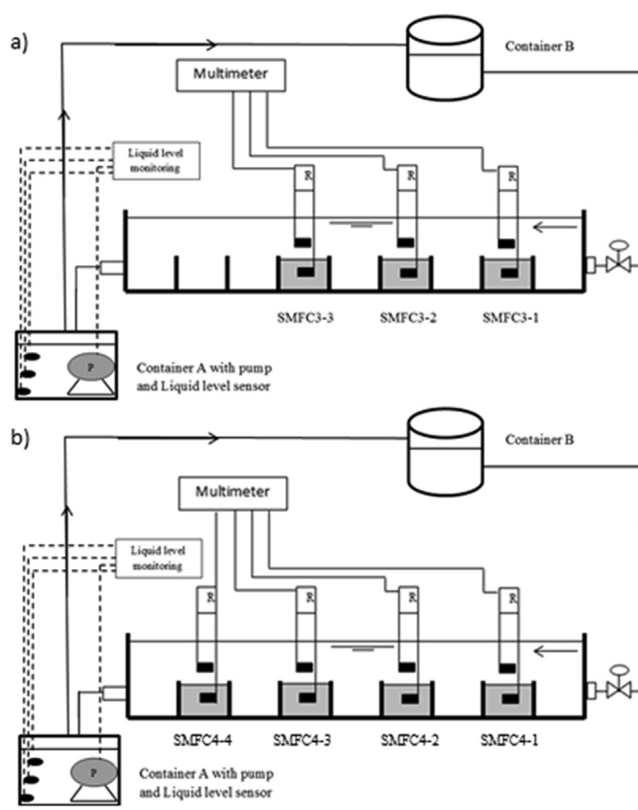

Fig. 2. Schematic of the setups used in the experiment. a) Channel-3, b) Channel-4. R represents the external resistance used in each SMFC.