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Short communication

Influence of the thickness of the capacitive layer on the performance of bioanodes in Microbial Fuel Cells

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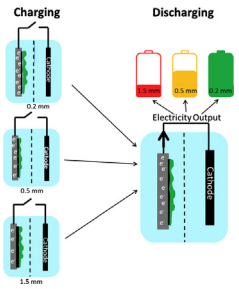
HIGHLIGHTS

- Storage of electricity produced by MFC possible with integrated capacitive bioanode.
- Thickness of the capacitive layer is influencing the performance of the MFC.
- Capacitive layer with a thickness of 0.2 mm was found to be the most efficient.
- Increase of 40% during intermittent operation compared to continuous operation of a noncapacitive electrode.

GRAPHICAL ABSTRACT



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ABSTRACT

Earlier it was shown, that it is possible to operate a Microbial Fuel Cell with an integrated capacitive bioanode with a thickness of 0.5 mm and thereby to increase the power output. The integrated capacitive bioanode enabled storage of electricity produced by microorganisms directly inside an MFC. To increase the performance of this integrated storage system even more; the thickness of the capacitive electrode was varied: 0.2 mm, 0.5 mm and 1.5 mm. Each of these capacitive electrodes was tested in the MFC setup during polarization curves and charge–discharge experiments for the steady-state current density and the maximum charge recovery.

The capacitive electrode with a thickness of 0.2 mm outperformed the other electrodes in all experiments: it reached a maximum current density of 2.53 Am^{-2} during polarization curves, and was able to store a cumulative total charge of 96013 cm^{-2} during charge–discharge experiments. The highest relative charge recovery for this electrode was 1.4, which means that 40% more current can be gained from this capacitive electrode during intermittent operation compared to continuous operation of a noncapacitive electrode. Surprisingly it was possible to increase the performance of the MFC through decrease of the thickness of the capacitive electrode.

1. Introduction

Energy production from renewable sources receives more and more attention due to the depletion of fossil fuels and the increasing pollution of the atmosphere. Most of this attention is focused on solar and wind energy [1]. But there are also an

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increasing number of researchers looking at possibilities to use biomass as a renewable energy source [2]. One type of biomass, which is not yet used in the most efficient way, is wastewater. So far, most wastewater treatment plants spend energy to remove the organic compounds contained in wastewater. But recently there has been developed a more efficient technology: the Microbial Fuel Cell (MFC). In MFCs the organic compounds of the wastewater are directly converted into electricity [3]. An MFC consists of an anode compartment and a cathode compartment, which are usually separated by a membrane [4]. Both compartments contain an electrode; the anode and cathode. On the anode grow electrochemically active microorganisms which convert the organic matter from wastewater into protons, electrons and carbon dioxide. Positively charged ions migrate through the membrane (in case of a cation exchange membrane) to the cathodic compartment and the electrons are transported through an external circuit to the cathode. At this cathode the protons and electrons react with oxygen to form water [5].

The MFC is thereby presenting a way of simultaneously treating wastewater and producing electricity. However, the wastewater needs to be treated continuously and the energy which is produced by the MFC might not be consumed continuously. To match the production and demand of this electricity, storage of the electricity would be necessary [6]. Two different techniques have been investigated for the storage of electricity from MFCs: external and internal capacitors [7–12]. Dewan et al. [7] and Kim et al. [8], Grondin et al. [9], Liang et al. [10] and Hatzell et al. [11] showed that using a Bio Electrochemical System (BES) with an external capacitor can improve the power output compared to continuous operation of the BES without capacitor. Another way of increasing the power output of MFCs was shown by Deeke et al. [12]. They operated the MFC with a capacitor integrated in the anode compartment, and also found an increase in power output. Until now, however, it is not known which parameters determine the performance of the MFC with a capacitor.

Several studies in the field of electricity storage in capacitors have shown that the specific capacitance is, amongst others, depending on the thickness of the active material of the electrodes [13,14]. Emmenegger et al. [13] compared the specific capacitance of electrodes used in electrochemical double-layer capacitors, which were made of Activated Carbon Powder (ACP) in 6 different thicknesses varying from 0.1 mm to 0.8 mm. They found an increase in the specific capacitance, when increasing the thickness of the active material. Tsay et al. [14] tested four different thicknesses for their supercapacitor electrodes: 0.05 mm, 0.1 mm, 0.2 mm and 0.3 mm. They found an optimum in the specific capacitance for their electrodes at a thickness of 0.1 mm.

To further improve the performance of MFCs with an internal capacitive bio-anode, we compared three different thicknesses for the capacitive layers: 0.2 mm, 0.5 mm and 1.5 mm. The performance of the layers with different thickness was analyzed using polarization curves and charge–discharge experiments to see the steady-state current density and the maximum charge recovery in a two chamber MFC.

2. Materials and methods

2.1. Electrochemical cell setup

In this study, six identical cells were used to characterize the performance of the different capacitive layers. The six cells were similar to the ones used in the proof of concept study of the internal capacitive bioanode [12]. The cells consisted of two flow channels of each 33 mL for the anodic and cathodic compartment. The flow channels were separated by a Cation Exchange Membrane (Ralex, Mega, Straz pod Ralskem, Czech Republic) and on both sides of the membrane the electrodes (Müller & Rössner GmbH, Troisdorf, Germany) were placed. The cathode electrode was a noncapacitive (plain graphite plate) electrode and the anode was a current collector (plain graphite plate) covered with the capacitive layer. Anode, cathode and membrane had a projected surface area of 22 cm^2 each.

2.2. Electrode preparation

The capacitive layers were prepared by mixing a pre-mixed PVDF-solution; 200 mL NMP (N-methyl-2-pyrrolidone, Boom, Meppel, The Netherlands) and 44.1 g PVDF (Polyvinylideenfluoride 2, Kynar, Arkema, Amersfoort, The Netherlands) with 25.2 g of Activated Carbon Powder (ACP, DLC Super 30, Norit, Amersfoort, The Netherlands). A scheme of the preparation of the capacitive electrodes is in Fig. 1.

This solution was placed in a ball-mill grinder (PM 100, Retsch, Haan, Germany) and mixed at 450 rpm for 30 min. Afterward the capacitive paint was kept in an oven for 24 h at 50 °C for deaeration. The capacitive paint was casted in three different thicknesses on the current collector using a casting knife. The thicknesses of the tested electrodes were, 0.2 mm, 0.5 mm and 1.5 mm. Each electrode was casted in triplicate.

Each capacitive electrode was analyzed using several techniques: BET-Analysis, AFM and SEM pictures The specific surface area of the capacitive electrodes was determined using the BET-Analysis [15]. The roughness of each capacitive electrode was determined using atomic force microscope (AFM, Nanoscope Illa, Veeco, Santa Barbara, CA, USA). The AFM-scan was performed on 1 mm^2 of the surface area. The roughness of the scanned surface area was determined using the AFM [16] as the arithmetic average R_a of the absolute roughness values of the surface of each capacitive

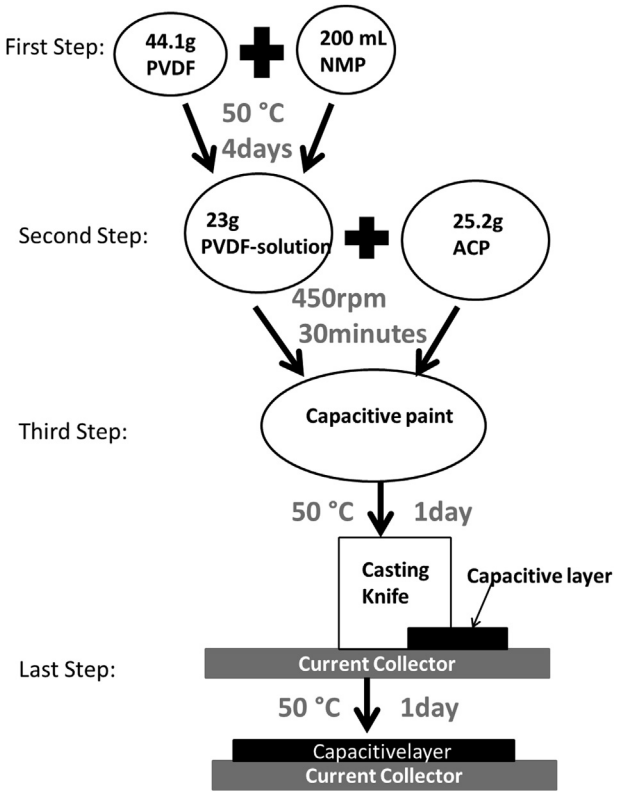

Fig. 1. Preparation of the capacitive layers from the beginning till the end.