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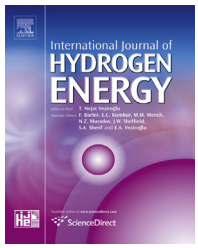

A novel small scale Microbial Fuel Cell design for increased electricity generation and waste water treatment

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ABSTRACT

Microbial Fuel Cells (MFCs) are a sustainable energy technology with minimal carbon footprint, which is promising for wastewater remediation and generation of useful amounts of electricity. This study focuses on the architecture and rapid prototyping materials used for building MFCs and their effect on overall performance. Three MFC variants of the same design were constructed using ABS, PC-ISO and RC25 materials and were compared with an established MFC design. MFCs were assessed in terms of power production and COD reduction both individually and when connected electrically in parallel. In all cases the new design showed a better power output and COD removal. The order of performance in terms of power production and COD reduction for individual MFCs was PC-ISO, RC25 and ABS. However when triplets of the same materials were joined electrically together, then the order was different with RC25 outperforming ABS and PC-ISO, which was dependent on the materials' properties. It is concluded that the best performing individual MFC may not necessarily result in the best performing stack.

Introduction

MFC technology

Microbial Fuel Cells (MFCs) are bio-electrochemical devices whose constituent electro-active bacteria harvest electrons and protons by oxidising organic matter. Electrons travel through the anode to the cathode electrode *via* an external load, and cations diffuse through a cation exchange membrane that separates the anode with the cathode. Atmospheric oxygen in the cathode reacts with the incoming electrons and protons to produce water [1]. Miniaturisation of MFCs has been reported in the literature as a more efficient way of generating electricity [2] and can be utilised for powering small devices [3]. To date, the highest volumetric power density of miniaturised MFCs reported, is 667 $\mu W/cm^3$ [4]. However this is still 1000-fold lower than that of lithium-ion batteries (7.2×10^7–2.16×10^8 W/m^3, with a theoretical density of 3000 kg/m^3) [5,6]. MFCs can nevertheless generate

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power from waste and can be maintained continuously. In addition, during the last decade, the MFC technology has improved in terms of current density by over a 1000-fold [6,7].

Physical and biochemical advantages of small-sized MFCs

Small scale MFCs benefit from lower activation losses, and higher substrate utilisation (mass transfer), due to a decreased diffusion resistance, which lowers the overall internal resistance [8,9]. In effect, there is improved percolation of feedstock in the anode, which provides the anodophilic biofilm with a higher supply rate of fuel. Furthermore, shorter molecular paths allow better diffusion of protons in the biofilm, which greatly enhances pH buffering [10]. These effects improve the reaction kinetics of the anodophiles, which lead to higher power densities. Decreased paths also affect the distance that electrons need to travel from the microbial source (planktonic and biofilm) to the external circuit, which also decreases the internal resistance [11]. Various types of MFC reactors have been developed from MFC research groups, including miniature, cylindrical, up flow, and stacked reactors [12]. For example, high power densities have been reported in small, single-chamber MFC reactors (6.25 mL) utilising catalyst-free carbon fibre veil electrodes, generating 0.44 W/m^3 [13].

Manufacturing materials of small MFCs

To date, many studies have focussed on the improvement of electrode materials or the reactor's architecture [2,13–16]. The majority of MFC publications, involves MFC casings made out of glass (borosilicate) or Plexiglas (polymethyl-methacrylate, PMMA or Perspex) [12,17–19]. However, little is known about the selection of manufacturing materials used to build MFC reactors and only a few studies report on MFC reactors made from various thermo-polymer plastics (polypropylene, polycarbonate, nanocure and acrylonitrile-butadiene-styrene) [20–23] where their effect on performance is examined. Thus, the main reason for experimenting with plastic polymers is the structural properties of thermoplastics, which combined with 3D printing, can produce intricate designs for a variety of shapes and sizes.

This study focuses on the structural materials as well as the reactor architecture of a novel MFC design (Twist n' Play) and emphasises the importance of criteria such as overall biocompatibility, selective electrical insulation and oxygen diffusion (low for anode; high for cathode) for high power output.

Materials and methods

Twist n' Play *MFC-chamber design and fabrication*

Improvements compared to the EcoBot-III MFC casing

In order to evaluate the performance standards of the new design and the materials involved, a direct comparison with an already proven small-sized MFC [23] of the same internal volume was performed. For this reason three RC25 Nanocure type EcoBot-III MFCs were used as controls so as to examine whether the architecture of the new design MFC or the materials involved in the making, can improve the performance. The new '*Twist n' Play*' MFC casing was designed using SolidWorks education Edition 2010 SP 5.0 software (Dassault Systemes, US) and maintained the same internal reactor volume (6.25 mL) as the fully tested model (EcoBot-III MFC) developed in 2008 and finalised in 2010 [13,23]. The improvements on the new MFC design comprised the following features:

I. Same internal volume with smaller external footprint (less building and support material).
II. Simple assembly without fixtures such as screws, clips or clamps.
III. Minimised exposure of the anode chamber to atmospheric O_2.

3D printing of the new design

In-house rapid prototyping facilities were employed to fabricate the new MFC in three different thermoplastics: PC-ISO (medical-grade biocompatible Polycarbonate; Laserlines, UK), ABS (Acrylonitrile Butadiene Styrene; Laserlines, UK) and RC25 Nanocure (ceramic-filled photo curable resin; envisionTEC GmbH, Germany). MFCs made out of RC25 Nanocure were fabricated with a Stereolithography 3D printer, whereas PC and ABS MFCs were produced using the method of Fused Deposition Modelling (FDM Titan/Dimension BST, Laserlines, UK). Due to the hygroscopic nature of ABS, parts were coated with a layer of methyl-ethyl-ketone (Sigma-Aldrich, UK) so as to render the units watertight.

The selection of the above materials was based on previous studies [2,3,13,20,22–26], in which they were considered to be the most common thermoplastics used for rapid prototyping and also they could be fabricated in-house.

MFC operation and monitoring

Inoculation and fuel supply

Triplicates of single-chamber air-breathing MFCs were assembled for each material; both the anode and the cathode electrodes employed catalyst-free carbon fibre veil sheets 30 g/m^2. Sheets of 11 × 14 cm (155 cm^2, total surface area) were folded down five times so as to form a 1.8 cm × 2.9 cm × 1.0 cm cuboid. Titanium wire was used as a current collector, pierced through the carbon veil cuboids. A cation exchange membrane (CMI-7000, Membranes International Inc., NJ, USA) with a surface area of 12 cm^2 was placed between two silicon rubber gaskets (Fig. 1), separating the anode from the cathode. The MFCs were initially inoculated in batch-mode with activated sewage sludge (Wessex Water, Saltford, UK). Anolyte pH was 7.3 and replenished every 24 h with 1 mL of TYE (1% Tryptone, 0.5% Yeast extract, Fisher Scientific, UK) for the first 14 days of the experiment. A 2.7 kOhm resistor was connected to each MFC during this period for selecting an anodophilic bacterial consortium; this value was selected in order to best match the Rint. Following 15 days from inoculation, the feedstock was replaced with fresh non-treated human urine and all MFCs were connected to a 24-channel peristaltic pump (Watson Marlow, UK) for continuous flow, at a rate of 1 mL/h corresponding to a hydraulic retention time of 6.8 h. Samples were received on a daily basis at fixed time of the day from a healthy individual. Measured pH on fresh urine samples

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