Electrochimica Acta 192 (2016) 89–98

Contents lists available at ScienceDirect

Electrochimica Acta

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

Towards effective small scale microbial fuel cells for energy generation from urine

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ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form 14 January 2016
Accepted 15 January 2016
Available online 18 January 2016

Keywords:
Microbial Fuel Cell
Urine
Biochar
Bioenergy

ABSTRACT

To resolve an increasing global demand in energy, a source of sustainable and environmentally friendly energy is needed. Microbial fuel cells (MFC) hold great potential as a sustainable and green bioenergy conversion technology that uses waste as the feedstock. This work pursues the development of an effective small-scale MFC for energy generation from urine. An innovative air-cathode miniature MFC was developed, and the effect of electrode length was investigated. Two different biomass derived catalysts were also studied. Doubling the electrode length resulted in the power density increasing by one order of magnitude (from 0.053 to 0.580 W m^{-3}). When three devices were electrically connected in parallel, the power output was over 10 times higher compared to individual units. The use of biomass-derived oxygen reduction reaction catalysts at the cathode increased the power density generated by the MFC up to 1.95 W m^{-3}, thus demonstrating the value of sustainable catalysts for cathodic reactions in MFCs.

1. Introduction

In the face of the growing problem of fossil fuel depletion, there is global interest in developing sustainable and environmentally friendly forms of energy. One form of alternative energy that may be viable in addressing this problem is bioenergy [1,2]. In this context, Microbial fuel cells (MFC) hold great potential as green and carbon-neutral technology that directly converts biomass into electricity [3].

MFCs are electrochemical devices that take advantage of the metabolic processes of microorganisms to directly convert organic matter into electricity with high efficiencies for long periods of time [4]. Compared to other bioenergy conversion processes (i.e. anaerobic digestion, gasification, fermentation), MFCs have the advantage of reduced amounts of sludge production [5], as well as cost-effective operation, since they operate under ambient environmental conditions (temperature, pressure) [6]. Moreover, MFCs require no energy input for aeration so long as the cathode is passively aerated, for example *via* the use of a single-chamber device [7]. Lastly, MFCs have the ability to generate energy remotely by using a range of feed stocks, and can thus be used in areas of poor energy infrastructure. Organic waste used as a feed stock in particular offers attractive prospects from its cost-effectiveness and abundance. Urine has been demonstrated to be an effective feed stock for MFC operation with the additional benefit of nitrogen, phosphate and potassium recovery from the fuel [8]. In particular, according to Ieropoulos et al [9]. urea is enzymatically hydrolysed to ammonia and carbon dioxide. Ammonia is then oxidised at the anode of the MFC to generate mainly nitrite and in smaller amounts nitrate [10].

Despite the breadth of applications and the growing interest in MFC technology over the past two decades, commercialisation of MFCs for energy generation has not yet been realised.

The major limiting factors that hinder the practical implementation of MFCs at large scale, are the cost of materials used and the difficulties in the scale-up process [11].

Typically the electrodes are made from highly cost-effective materials such as carbon cloth, carbon paper, and graphite based

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http://dx.doi.org/10.1016/j.electacta.2016.01.112

rods, plates and granules. Recently, even some metals, such as copper and silver, have been shown to be effective anode materials [12]. However, expensive metals, such as platinum, are usually used at the cathode to enhance the oxygen reduction reaction (ORR) [13–15]. Recently, the use of biomass-derived catalysts recovered from waste has been proposed as an effective alternative to expensive metal ORR catalysts. In particular, biomass-derived materials from wood [16], sewage sludge [17] and bananas [18] have been shown to function as ORR catalysts to boost MFC performance whilst reducing the device cost and its carbon footprint. Doping these materials with heteroatoms such as nitrogen and sulphur [19], also in combination with nanoparticles like iron [20], has been shown to enhance the catalytic activity towards the ORR even further.

Another limitation towards practical implementations of MFCs, is their poor performance due to high internal resistances and ohmic losses experienced upon scale-up [21]. Consequently, the power performance of MFCs is low compared to other renewable energy technologies [8,22]. Considering the thermodynamic limit of an MFC (1.14 V open circuit), the most feasible approach to scale-up the power generated by this technology is to create a collection of multiple MFCs connected together as a stack. By miniaturising individual MFC units, stacks of large numbers of constituent MFCs could be developed, within a compact footprint. This approach has been referred as the 'miniaturisation and multiplication' strategy [9].

MFC miniaturisation offers other advantages as well. The large surface area-to-volume ratio and short electrode distances - typical characteristics of miniature MFCs- provide a pathway to reducing ohmic losses, improving the mass transport processes between bulk liquid, biofilm and electrode and therefore enhancing power performance [23]. The consolidation of microfabrication techniques has led to the first prototypes of micro-sized MFCs, which have been discussed in a recent review [11]. Nonetheless, the process of miniaturisation of the MFC technology is still in its infancy. The two-chamber configuration is typically adopted for the miniature MFCs reported thus far, and, usually, a ferricyanide solution is used as the catholyte [24]. Given the greater operational simplicity and cost-effectiveness of oxygen diffusion systems, air-cathode MFC designs should be considered instead. Moreover, a more in-depth analysis on how to effectively miniaturise the system for better performance would be beneficial.

With the aim of guiding the development of efficient small-scale MFCs, this study reports the development of an innovative air-cathode small-scale MFC and analyses the effect that the chamber length (and therefore the electrodes length) have on its performance either when operated as a single unit or when assembled in a stack. No expensive metals have been employed at the cathode, and the use of two types of innovative and highly sustainable biomass-derived ORR catalysts are compared with a catalyst-free device.

2. Experimental

2.1. Materials

All reagents used were of analytical grade and purchased from Sigma-Aldrich and Alfa Aesar. Unless otherwise stated, all aqueous

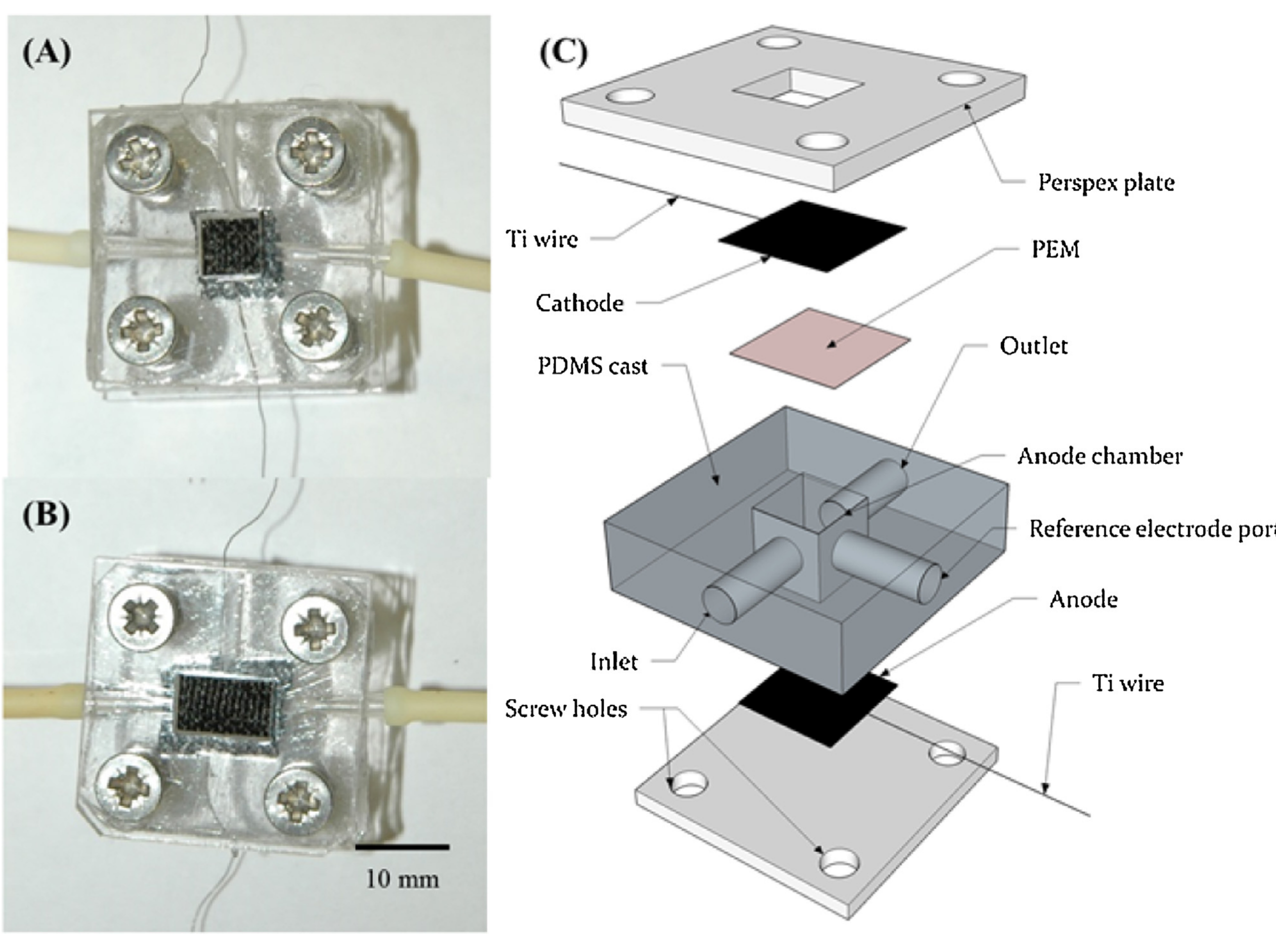

Fig. 1. MFCs used in this study; A: Photograph of MFC_S; B: Photograph of MFC_L; C: Schematic layout of the device.