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Characteristics of a single chamber microbial fuel cell equipped with a low cost membrane

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ABSTRACT

The aims of this research were: *(i)* to develop and test a new, low cost, organic membrane (*LCM*) in an air-cathode, single chamber microbial fuel cell (*MFC*), and *(ii)* to compare its characteristics with those of an *MFC* equipped with a Nafion® 117 membrane (*NF*). The internal resistances (R_{int}) were 112 and 110 Ω using *LCM* and *NF*, respectively, whereas the maximum volumetric powers ($P_{V,max}$) were 2146 and 14,246 mW/m^3 for *LCM* and *NF*, respectively. The relatively low value of R_{int} of the *MFC* equipped with *LCM* was encouraging. Furthermore, the R_{int} of the *NF*-equipped *MFC* was of the same order.

$P_{V,max}$ delivered with *LCM* was 15% of that with *NF*. However, the cost ratio *LCM/NF* was very low, ($14/m^2)/($1733/m^2) ~ 0.8%. These results point out to a trade-off between sacrificing some power output of the cell (85%) but achieving outstanding savings on membrane costs (99.2%).

Introduction

Microbial fuel cells (*MFCs*) constitute a promising technology for simultaneous wastewater treatment and energy recovery [1–4]. A *MFC* is a bioelectrochemical system that can generate electricity utilizing anaerobic microorganisms as the biocatalysts and effluents as substrate (or "fuel"); it converts chemical energy stored in organic and inorganic matter into electricity [5–7].

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In an *MFC*, the electrons produced in the anodic chamber are transferred to the anode and subsequently conducted through an external circuit to the cathode. On the other hand, internally, protons migrate from the anodic chamber to the cathode region through a membrane also called separator or proton exchange membrane (*PEM*) [7–9].

The *PEM* is an important material in the configuration and operation of the *MFCs*. The main features and purposes of membranes in *MFCs* are the following [8,10,11]:

(i) to separate the anodic chamber from the cathodic one (Fig. 1)
(ii) to minimize back-diffusion of oxygen to the anodic chamber and reduce the substrate flux from the anode to cathode
(iii) to increase the Coulombic efficiency (*CE*) reducing the flux of the oxygen from the cathode chamber to the solution in the anode chamber
(iv) to ensure an efficient and sustainable operation over time.

However, *PEMs* have some disadvantages. The main one is the high cost of standard, polymeric membranes [8,10,11]. Nafion® 117 (*NF*), a perfluorinated membrane, is the most commonly used as *PEM* in *MFCs* due to their good properties. However, it is very expensive and its cost has a significant impact on the overall production cost of a *MFC* [7,11–14]

Logan [11] reported that Nafion® can cost up to $1400/m^2 (the updated price is about $1733/m^2) [15,16]. It is recognized that membrane costs is one of the factors that has deterred the scale up of *MFCs* [8,9,17].

Active research on replacing Nafion separators by other membranes has been carried out in recent years, *i.e.*, experiments with ultrafiltration and microfiltration membranes, sulphonated polyether ether ketone membrane, anion and cation exchange membranes, bipolar membrane, forward osmosis membrane have been reported in the open literature [1,5,7,8,11,14,17,18]. Sivasankaran & Sangeetha [14] developed a sulphonated polyether ether ketone (SPEEK) to use in a *MFC* instead of *NF*. The maximum volumetric powers ($P_{V,max}$) produced by their system, using dairy wastewater and domestic wastewater as influent were 5.7 ± 0.2 and 3.2 ± 0.2 W/m^3, respectively. The SPEEK was compared with *NF* and they reported that the SPEEK membrane produced *ca*. 55% higher power density than *NF*. Yet, the cost of SPEEK membrane is still high (J. Benavides, personal communication, September 2015, CIQA, Coah., México).

Generally, polymer-based membranes costs are generally high, either by price of the raw material involved or the manufacture method (electrospinning, for instance).

In order to reduce the impact of membrane high costs some other options have been explored, such as membrane-less *MFCs* and new alternative materials. Membrane-less *MFCs* have been studied because the membrane is not strictly necessary in an *MFC*. In spite that water is a good conductor of protons, most of works with membrane-less *MFC* have reported low *CE* [5,7,8,10,11]. Liu and Logan [10] determined the bioelectricity generation in a membrane-less *MFC*, in order to increase the energy output and reduce the cost. They reported a power density of 146 ± 8 mW/m^2 and 20% of *CE* for their membrane-less *MFC* using wastewater as substrate. In contrast, their *MFC* equipped with *NF* membrane achieved 28% of *CE*. Incidentally, after 180 h of cell operation, the voltage was drastically reduced to 0 mV with the consequent reduction of power output and *CE*.

Regarding new materials for *PEMs*, a few studies with glass fibers or glass wool, salt bridge, as well as other materials and configurations such as assemblages have been reported [8,11,19,20]. Yet, the findings on a low cost and effective separator or membrane to replace *NF* are still scarce. Thus, the aims of this research were *(i)* to test a new, low cost organic membrane (*LCM*) in an air-cathode, single chamber *MFC*, and *(ii)* to compare its characteristics with those of an *MFC* equipped with a Nafion® 117 membrane.

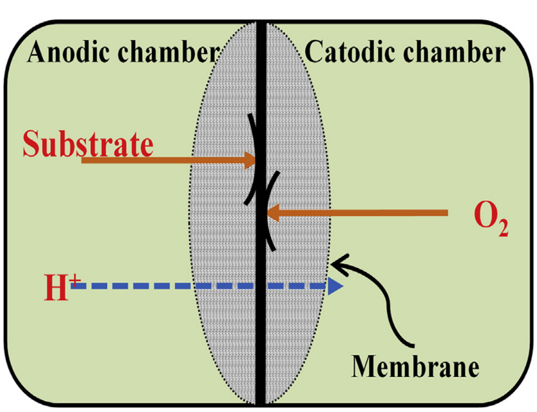

Fig. 1 – Scheme of a microbial fuel cell equipped with membrane (separator).

Materials and methods

Experimental design

The experiment consisted of the characterization of the *MFCs* packed with graphite flakes (*GF*) as anode and loaded with a sulphate-reducing inoculum (*SR-In*). The *PEMs* tested were a *LCM* and *NF* as reference. The experiment was carried out in two replicates.

Here-in after, the *MFC* equipped with *LCM* will be denoted as *LCM–MFC*, whereas the *MFC* equipped with the Nafion membrane, will be represented by *NF–MFC*.

The main response variables were $P_{V,max}$ and the internal resistance (R_{int}) of the *MFCs*.

Microbial fuel cells

The *MFCs* were single compartment, air-cathode devices. They were operated at ambient temperature, with no mechanical mixing nor heating. Each *MFC* consisted of a horizontal cylinder built in Plexiglas 80 mm long and 57 mm internal diameter. The anodic chambers were packed with *GF* as anodic material with surface area of 0.28 m^2. The *GFs* were supplied by QR Minerales S.A. de C.V., Guadalajara, Jal., México. Table 1 exhibits some properties of the anodic