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Batch operation of a microbial fuel cell equipped with alternative proton exchange membrane

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ABSTRACT

We compared the effect of membrane type on the performance of microbial fuel cells (*MFC*) fed with an actual leachate and operated in batch for 15 days. The tested proton exchange membranes (*PEMs*) were Nafion 117 (*NF*) and a low cost membrane (*LCM*). The cell equipped with *LCM* outperformed the one equipped with *NF*. In the first period of the batch, 0–8 d, average volumetric powers (P_V) were 9000 and 4000 mW/m^3 for the *MFC* equipped with *LCM* and *NF*, respectively. In the second period (8–15 d) when the external resistances were adjusted, the average P_Vs were 20 000 and 6800 mW/m^3 for *LCM* and *NF*, respectively. At the end of the batch, deposits of dry salts appeared on the external side of the cathode carbon cloth of the cell equipped with *NF*. Likely, this could be related to the decrease of power output in the last days of the batch (11–15 d) in the cell equipped with *NF*.

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Introduction

Nowadays the human-kind depend heavily on the use of petroleum oil as well as other fossil energy sources, and consequently faces at least two great risks: the inevitable depletion and the environmental pollution caused during exploration, transport, combustion of fossil-based fuels. Thus, the investigation to develop novel, renewable energy sources, particularly bioenergies, has notably increased in the last years [1–3].

Microbial fuel cells (*MFCs*) constitute a promising technology that generates electrical power from a wide range of soluble substrates (organic or inorganic), wastes included. The *MFCs* has become an interesting alternative to produce electrical energy and provide wastewater treatment simultaneously [4–8].

In order to increase the *MFC* efficiency, several conditions of *MFC* operation and components have been the subject of intensive research such as the type of biocatalysts, membrane (electrolyte) or separators, temperature, pH, substrates, the type and materials of electrodes, electrode catalysts, cell configuration and architecture, among others [2,8a–12].

The proton exchange membrane (*PEM*) is an important part of *MFCs*. The main features and purposes of the membranes in *MFCs* are listed below [13–15]:

- to separate the anodic from the cathodic chamber in order to reduce the substrate flux from the anode to cathode, to avoid the back-diffusion of the electron acceptor, and to isolate the catalyst from the cathode in single-chamber *MFCs*
- to perform as a barrier to the transfer of other ions between the chambers
- to increase the Coulombic efficiency (*CE*) reducing the flux of the oxygen from the cathode chamber to the solution in the anode chamber
- to ensure an efficient and sustainable operation along time

Yet, there are disadvantages related to the *PEM* use, such as the high cost of standard membranes such as those made of the polymer Nafion [13–15]. For instance, Nafion cost has increased up to \$1733/m^2 [16]. Furthermore, its use might affect negatively the power generated by the *MFC* due to the increase of the internal resistance (R_{int}) [14,15,17].

Presently, one of the challenges of the *MFCs* is their scaling up; this mainly depends on the performance of *MFC* and cost of materials [15,18]. So, in order to replace the Nafion 117 (*NF*), several polymeric membranes have been studied, such as ultrafiltration and microfiltration membranes, sulphonated polyether ether ketone membrane, anion and cation exchange membranes, bipolar membrane, forward osmosis membrane [2,9,14,15,18–21]. However, these polymeric membranes can also be expensive.

Membrane-less *MFCs* have also been tested, where the water conducts the protons by itself. However, in most of the works operated without a membrane, the *CE* is low or falls down to unfeasible values [9,13–15,19]. Liu & Logan explored the bioelectricity generation in a membrane-less *MFC*, in order to increase the energy output and reduce the cost [13]. They reported a power density of 146 mW/m^2 and 20% of *CE* for their membrane-less *MFC*. In contrast, their *MFC* equipped with *NF* membrane displayed a lower power density of 28 mW/m^2 but a higher *CE* of 28%.

Regarding the use of new materials for *PEMs* that could reduce costs there are few studies that have focused on glass fibers or glass wool, salt bridge, as well as assemblies membrane-cathode [14,15,22,23]. Yet, results so far indicate that either high R_{int} were found or low power was delivered by the cells or both. For instance, Li et al. indicated that some course-pore filters (*i.e.*, glass fiber, nylon mesh, and porous fabrics) can be more economic than ionic exchange membranes used in *MFCs* [15]. Yet, the first ones show the disadvantage of large pores that, in turn, would detract from the effectiveness of the separator for decreasing the flux of oxygen to the anodic chamber [24]. Glass fiber mats show better performance: they are resistant to biodegradation and biofouling, they exhibit a low O_2 permeability, and relatively high *CEs* can be achieved (81%) [15,24]. Indeed, it has been reported that glass wool can also serve as a low cost separator in *MFCs* [25,26]. Yet, the power was low, with a maximum of 10.1 mW/m^2. Besides the open circuit potential (*OCP*) was only 0.36 V with a resistance as high as 4000 Ω.

In another work, Min et al. [22] determined the power output in a *MFC* equipped with a salt bridge that replaced the Nafion membrane; the inoculum was a pure culture of *Geobacter metallireducens*. The power density was very low, 2.2 mW/m^2, whereas the R_{int} was nearly 20 kΩ. The authors ascribed the low power output to the higher R_{int} of the salt bridge system. In contrast, the R_{int} of a similar device equipped with Nafion membrane was 1286 Ω. Kargi & Eker worked with a two-chamber *MFC* separated by a salt-agar slab. A low power density *ca.* 3 mW/m^2 and current intensity of 0.24 mA were obtained [23]. The authors claimed that these values were comparable with those reported in the literature for *MFC* utilizing salt bridge, *i.e.*, a work by Min et al. [22].

Therefore, the purpose of this work was to compare the effect of membrane type on the performance of *MFC* operated in long batch process, using actual leachates from Mexico City sanitary landfill and inoculum previously enriched (*E-In*) in electrochemically-active bacteria (*EAB*). The tested separators were a low cost membrane (*LCM*) and *NF* as reference.

Materials and methods

Experimental design

The experiment consisted of the operation in a long batch process of the *MFCs* equipped either with a *LCM* or *NF* (as control). The *MFCs* were packed with graphite flakes (*GF*) as anodic material and loaded with a mixture of inoculum previously enriched in *EAB* and a very recalcitrant, actual leachate from Mexico City sanitary landfill. The mix was in a proportion 80% inoculum and 20% actual leachate. The *MFCs* were operated for 15 d.

The long batch process was divided in two periods, a first one from 0 to 8 d, and a second one from 8 to 15 d. In the first period the cells were fitted with external resistances (R_{ext}) defined by the first electrochemical characterization of the R_{int} at time 0 d. After a second electrochemical characterization