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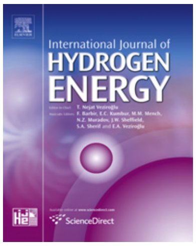

Effects of architectural changes and inoculum type on internal resistance of a microbial fuel cell designed for the treatment of leachates from the dark hydrogenogenic fermentation of organic solid wastes

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ABSTRACT

A new design of a single chamber MFC-A based on extended electrode surface (larger σ, specific surface or surface area of electrode to cell volume) and the assemblage or 'sandwich' arrangement of the anode-proton exchange membrane-cathode (AMC arrangement) and a standard single chamber MFC-B with separated electrodes were tested with several inocula (sulphate-reducing, SR-In; methanogenic, M-In, and aerobic, Ab-In) in order to determine the effects on the internal resistance R_{int} and other electrical characteristics of the cells. In general, the R_{int} of the new design cell MFC-A was consistently lower than that of the standard MFC-B, for all inocula used in this work. Resistances followed the order $R_{int,SR\text{-}In} < R_{int,M\text{-}In} \ll R_{int,Ab\text{-}In}$.

These results were consistent with reports on reduction of ohmic resistance of cells by decreasing inter-electrode distance. Also, the volumetric power P_V output was higher for the MFC-A than for MFC-B; this was congruent with doubling the σ in the MFC-A compared to MFC-B. Yet, power density P_{An} delivered was higher for MFC-A only when operated with SR-In and Ab-In, but not with M-In. The MFC-A loaded with SR-In showed a substantial improvement in P_V (ca. 13-fold, probably due to the combined effects of increased σ and decreased of R_{int}) and a 6.4-fold jump in P_{An} compared to MFC-B. The improvement was higher than the expected improvement factors (or algebraic factors; 6.5 improvement expected for P_V due to combined effects of increase of σ and lowering the R_{int}; 3.25 improvement expected for P_{An} due to lowering the R_{int}).

Our results point out to continuing work using the two-set, sandwich-electrode MFC and sulphate-reducing inoculum as a departing model for further studies on effects of inoculum enrichment and electrode material substitution on cell performance. Also, the MFC-A model seems to hold promise for future studies of bioelectricity generation and

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pollution abatement processing leachates produced during biohydrogen generation in dark fermentation processes of organic solid wastes.

1. Introduction

Our modern societies mainly rely on fossil fuels in order to satisfy their present energy needs. Unfortunately, renewable energy still plays only a marginal role in the menu of commercial energy technologies, in spite of its sustainability. Fossil fuels use and abuse present several disadvantages such as high and unstable costs, increasing scarcity in the near future, and negative impacts on the environment and human health due to harmful combustion products, spills and leaks during exploration, production and transportation [1,2]. On the other hand, oil experts have predicted a plateau of oil extraction and production and the start of declining by 2020–2030 [3,4], whereas other experts in energy and hydrogen have forecasted a near future technological transition where fossil fuels importance will progressively decrease and renewable energy contribution will become more substantial [5,6].

Renewable energies, such as wind, solar, hydraulic, and biological-based energy represent an interesting alternative because of their potential lower costs and minimum environment negative impact [7,8]. Among the biological-based energies, biohydrogen is an attractive alternative because wastes may be used as feedstocks and the double goal of waste treatment and management and bioenergy production may be attained [6,9,10]. Sometimes this is not possible, as in the biohydrogen production from fermentation of organic wastes. In this type of process, there is just a partial biodegradation of waste to hydrogen, with the consistent production of organic metabolites remaining in the spent solids [11,12]. These metabolites, usually low molecular weight organic acids and solvents, can be used to yield additional bioenergy by a methanogenic system [13,14], by phototrophic bacteria capable of producing hydrogen as a fuel [10], or by a microbial fuel cell [9,14,15].

Microbial fuel cells (MFC) constitute a promising technology for sustainable production of alternative energy and waste treatment. A microbial fuel cell is an electro-biochemical reactor capable of directly converting organic matter into electricity. In the anodic chamber the microorganisms anoxically oxidize the organic matter and release electrons and protons. Electrons are transported to the anode that acts as an intermediate, external electron acceptor. The electrons flow through an external circuit where there is a resistor or a device to be powered, producing electricity and finally react at the cathode with the protons and oxygen producing water [16]. The corresponding protons released during the oxidation of organic compounds migrate to the cathode through the electrolyte (liquor) contained in the cell and a proton exchange membrane; in this way charge neutrality is kept [17].

The reversible thermodynamic or ideal voltage delivered by a MFC at a given temperature of operation, that is, the maximum voltage attainable, can be estimated by the Nernst equation [18]. However, the actual voltage output of an MFC is lower than the predicted by the Nernst equation due to irreversible losses or overpotentials [17,19,20]. The most important losses associated to poor MFC performance are the activation losses, ohmic losses, and mass transport losses. These irreversibilities are usually defined as the voltage required to compensate for the current lost due to electrochemical reactions, charge transport (also known as ohmic loss), and mass transfer processes that take place in the cell; these voltages substract from the potential calculated by the Nernst equation [20,21]. So, much of the current research on MFC is devoted to overcome the limitations imposed by these irreversibilities.

Ohmic potential η_{ohmic} is the ohmic loss from ionic and electronic resistances; it collectively represents the voltage lost in order to accomplish electron and proton transport in the cell. The η_{ohmic} is usually described by the Ohm's law, that is

$$\eta_{\mathrm{ohmic}} = I_{\mathrm{MFC}} \times R_{\mathrm{ohmic}} \tag{1}$$

where I_{MFC} is the current intensity of the cell; R_{ohmic}, ohmic resistance.

The ohmic resistance reflects the combination of the resistances of electrodes, electrolyte(s), membrane (if any), junctions, and connections; that is, it combines the ionic and electronic resistances. In most cases R_{ohmic} is dominated by the ionic resistance (R_{ion}) associated to the electrolyte(s) resistance [17,21] since resistance associated to electrodes and connections is relatively low. The R_{ion} due to electrolyte is given by the following expression [22]

$$R_{\mathrm{ohmic}} \approx R_{\mathrm{ion}} = \rho \times L/A = (1/\kappa) \times L/A \tag{2}$$

where ρ is the specific resistance or resistivity of the electroyte; L, distance between electrodes; A, electrode surface area; κ, specfic conductance or conductivity of the electrolyte.

Eq. (2) shows the key ways to lower ohmic losses, i.e., by reducing the distance that separates the electrodes (decreasing L), increasing the electrode surface area (increasing A), and increasing the conductivity of the electrolyte and materials of the proton-exchange membrane (increasing κ). A plausible physical picture of the effect of inter-electrode separation would be that the protons have less distance to travel, and consequently the ohmic resistance is lowered. Thus, electrode separation has been investigated by several researchers as one way to improve MFC performance [17].

The influence of electrode spacing on performance of MFCs has been shown in several works [23–28]. For instance, Liu et al. [27] in experiments with a membrane-less MFC, observed that decreasing the distance between the electrodes from 4 to 2 cm significantly reduced the ohmic resistance and resulted in a 67% increase in the power output.

Relatively high power outputs have also been achieved in MFCs with a 'sandwich' membrane-electrodes arrangement