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Microbial fuel cell with an algae-assisted cathode: A preliminary assessment

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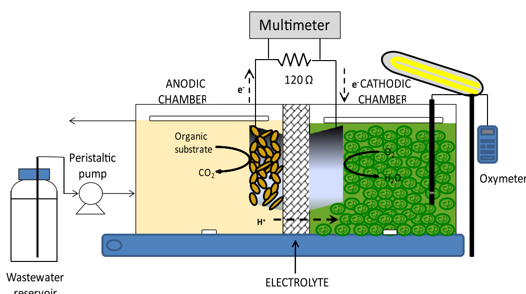
HIGHLIGHTS

- An MFC with not precious metal but using algae in the cathode has been implemented.
- At night the MFC still produces high amount of energy.
- The cathode has the biggest polarization resistance.
- Energy recovery from fruit juice industry wastewater has been produced.

GRAPHICAL ABSTRACT



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ABSTRACT

A microbial fuel cell (MFC) with an algae-assisted cathode, i.e., a system where the oxygen required by the cathode is not provided by aeration but by the photosynthetic process of the algae (*Chlorella vulgaris*), has been studied. The cathode was illuminated for 12 h each day (from 8:00 h to 20:00 h). 25 days was necessary to achieve steady state conditions. The time evolution of dissolved oxygen and cell voltage were assessed over the course of each day. As expected, the dissolved oxygen values were not constant throughout the day, reaching maximum values between 14:00 h and 20:00 h when dark phase reactions began and the algae started to consume oxygen. Cell voltage (R_{ext} 120 Ω) followed the same trend as the oxygen profile. The supply of CO_2 in the cathode was also studied, and half an hour was enough time to get the system working properly. During the acclimation stage, power density increased up to 13.5 mW m^{-2} at steady state conditions. However, impedance analysis showed that polarization resistance was higher at the cathode than at the anode. Nevertheless, it can be concluded that the studied system is a feasible method to treat wastewater in a self-sustainable way.

1. Introduction

The food products industry is very important in Spain, particularly in the region of Castilla-La Mancha. This industry comprises 16.38% of Gross National Product and has become one of the more healthy sectors of the Spanish economy.

Wastewater effluents from the fruit juice industry primarily contain high concentrations of organic materials (2300–11,000 mg dm^{-3}) [1], which are occasionally discharged into the municipal wastewater system and processed at wastewater treatment plants (WWTPs) with domestic wastewater. However, these effluents are usually pretreated in the factory prior to discharge in

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order to reduce their pollutant load. Due to the high solubility of pollutants and their high biodegradability, aerobic biological treatment is the preferred technology. Major problems associated to the treatment of raw effluent from the fruit juice industry include low pH values, unbalanced nutrient/COD ratios, and significant fluctuations in the daily profiles of flow and organic load [2,3]. In addition, aerobic biological treatment has some disadvantages, such as high sludge generation and high energy consumption. Thus, the aeration process is a predominantly energy-consuming process, comprising 30–55% of the total treatment energy demand [4] in aerobic biological treatment. Moreover, the costs of energy are rising as carbon-based resources become depleted and renewables struggle to make up the difference. Thus, a radical shift away from aerobic wastewater treatment technologies and toward an alternative that not only requires less energy but also produces energy is necessary to make the overall operation of wastewater treatment plants self-sustainable. Because the organic load of these effluents is not high enough for effective anaerobic treatment, alternative treatments have a great chance for development.

The microbial fuel cell (MFC) is a device that converts the chemical energy of a fuel (organic substrate) into electrical energy with the aid of biocatalytic reactions carried out by microorganisms [5]. Thus, MFCs provide new opportunities for the sustainable production of energy, in the form of electricity produced directly from biodegradable compounds. MFCs typically comprise an anode compartment and a cathode compartment separated by an ion-conducting membrane. In the anode compartment, microorganisms oxidize organic matter to carbon dioxide in anaerobic conditions and produce protons and electrons. Electrons pass through an external circuit, generating an electrical current. Protons cross the membrane to the cathode. In the cathode compartment, protons and electrons are combined with an electron acceptor, usually oxygen, to produce water.

Wastewater containing a high percentage of biodegradable organic compounds can be used as fuel in MFCs, achieving simultaneous wastewater treatment and energy production. Moreover, excess sludge production in an MFC is very low compared to conventional aerobic processes [6], which will help to minimize the overall operating cost of a treatment plant by decreasing the cost of sludge management.

Although MFCs are promising for wastewater treatment processes, there are still many technical and economic obstacles to overcome before practical applications will be feasible [7]. Currently, platinum is often used to catalyze oxygen reduction, which requires a significant investment cost. For this reason, some researchers have recently started working on the concept of biocathodes. There are three different concepts:

i) Aerobic biocathodes that use oxygen as the oxidant and microorganisms to assist the oxidation of transition metal compounds, such as Mn(II) or Fe(II), for electron delivery to oxygen [8].
ii) Anaerobic biocathodes that use compounds such as nitrate, sulfate, iron, manganese, selenate, arsenate, urinate fumarate and carbon dioxide as terminal electron acceptors [9].
iii) Algal biocathodes in which the cost of aeration is reduced by changing the mechanical aeration device to an algal oxygen supply, which can also reduce CO_2 emissions from the factory [10,11]. Hence, a photosynthetic culture of algae at the cathode, with light radiation, utilizes CO_2 as the carbon source for photosynthesis and produces oxygen, which acts as an electron acceptor for electricity generation. Algae can also act as a biological electron acceptor while simultaneously reducing carbon dioxide to biomass [12].

These systems represent the first approach to designing a lagooning wastewater treatment process with microbial fuel cells [13] for the treatment of wastewater from the fruit juice industry.

The aim of this work was to assess the start-up of a microbial fuel cell fed with synthetic fruit juice waste, where the cell was equipped with an algae-assisted cathode with the aim of producing oxygen at a low cost. The use of algae at the cathode has advantages that include eliminating the need for a mechanical air supply at the cathode (with corresponding cost savings) and reducing the CO_2 emitted from bacterial respiration and metabolism. Furthermore, in our system, no external mediators or precious catalysts were necessary.

2. Materials and methods

2.1. Experimental set-up

The set-up used in this study, Fig. 1, consisted of a two-chambered (800 cm^3 each) MFC, using a proton exchange membrane (PEM, by Sterion®) with high ion exchange capacity (0.9–0.02 meq g^{-1}), high ionic conductivity ($8 \cdot 10^{-2}$ S cm^{-1}) and low electronic conductivity ($<10^{-10}$ S cm^{-1}) to separate the electrodes. Both electrodes were built of Toray carbon cloths with 10% Teflon to improve the mechanical properties of the carbon support over the course of the study and because Teflon only caused a small drop in performance [14]. The active area of each electrode was 8 cm^2. Both electrodes were connected by an external resistance (R_{ext}) of 120 Ω; this low value was chosen to prevent activation losses and facilitate electron transfer during the acclimation period [15].

2.2. Inoculum

Activated sludge from a wastewater treatment plant (Ciudad Real, Spain) was used as the inoculum for the anodic compartment; it was fed in batch mode with a synthetic fruit processing industry effluent containing 322 mg dm^{-3} of sugar (fructose and glucose) and nutrients as shown in Table 1. This composition is very similar to the composition of wastewater from the fruit juice industry, taking into account the organic composition of fruit juice [16]. First, activated sludge was introduced into the anodic compartment with synthetic wastewater in a 3:1 ratio. The anode chamber was covered from light to prevent the growth of algae [15].

The cathode compartment contained a culture of *Chlorella vulgaris*. This compartment was illuminated for 12 h a day (from 8:00 h to 20:00 h) with an 11 W fluorescent lamp (Philips) located 10 cm above the reactor, and it was controlled by means of a programmable timer (Noru). Hence, the MFC was operated under a 12 h light and 12 h dark regime. Every day, water evaporated from the

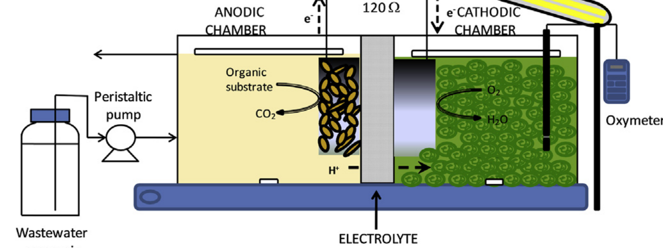

Fig. 1. Schematic view of the set-up.