International Biodeterioration & Biodegradation 106 (2016) 75–79

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

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

Short communication

Sustainable electricity generation by biodegradation of low-cost lemon peel biomass in a dual chamber microbial fuel cell

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ARTICLE INFO

Article history:
Received 16 September 2015
Received in revised form
11 October 2015
Accepted 12 October 2015
Available online 23 October 2015

Keywords:
Bioelectricity generation
Lemon peel waste
Microbial fuel cell
Renewable energy

ABSTRACT

Microbial fuel cells (MFCs) are envisaged as an emerging cost effective technology for organic waste treatment and simultaneous bioelectricity generation. In this work, the potential use of lemon peel waste for bioenergy generation was investigated in a dual chamber MFC. A stable voltage generation of 0.58 ± 0.02 V (500 Ω external resistor) at peel waste concentrations of 0.5–1.5 g l^{-1} was achieved. A maximum power density of 371 ± 30 mW m^{-2}, corresponding to a current density of 994 ± 41 mA m^{-2}, was obtained at an initial peel waste concentration of 1.0 g l^{-1}. Performance characteristics in terms of coulombic efficiency and internal resistance obtained by the MFC at this initial concentration were 32.3% and 143 Ω, respectively. The effect of sonication time, temperature, and external resistance were also studied to determine the maximum level of cumulative power generation. These preliminary results clearly indicate that the carbon source present in lemon peel waste can be utilized by exoelectrogens present in the anodic chamber, and that it ultimately releases electrons, which results in the generation of cell voltage.

1. Introduction

The depletion of the world's limited reserve of fossil fuels and their substantial use, which results in severe pollutant emissions, poses serious threats to human societies and ecosystems. These issues require the use of effective, benign, renewable, and sustainable technologies for energy conversion and power generation (Ghimire et al., 2015). In recent years, advancements in environmentally friendly technologies have expanded the variety of organic wastes and renewable biomass types that could act as potential substrates for the production of electrical energy or other high-value added products (Cristiani et al., 2013). Microbial fuel cells (MFCs) are among the most efficient and environmentally-friendly devices for energy conversion and power generation, due to their minimization of emissions through the use of microbes as biocatalysts (Rahimnejad et al., 2011; Rikame et al., 2012). MFC technology is gradually progressing in the fields of design, material selection, and most importantly, the exploitation of renewable sources, allowing MFCs to reach their full potential (Pant et al., 2011).

A plentiful and renewable carbon source that has been considered for MFC applications (mainly for electricity generation) is biomass (Moqsud et al., 2013). In particular, (plant) lignocellulosic biomass corresponds to a direct carbon neutral substrate, formed by the reduction of atmospheric CO_2 through the use of solar energy (via the autotrophic process of photosynthesis) (ElMekawy et al., 2014). Citrus (containing lignocellulosic biomass) is a major global crop type, with a yearly production of approximately 135.8 million metric tons in 2013 according to the Food and Agriculture Organization of the United Nations (http://faostat3.fao.org/home/E). Together, lemons and limes are the third most important cultivated citrus species after oranges and mandarins, with a global annual production of 15,191,482 metric tons in 2013. Lemon peel waste (LPW) comprises 50–65% of the total fruit weight, and is the primary by-product and a major source of environmental pollution (González-Molina et al., 2010). The effective use of peel waste can lead to the manufacture of valuable products and reductions in environmental burdens caused by its inefficient handling. One possibility for LPW use can be as cattle feed either fresh or after ensilage or dehydration (Talebnia et al., 2008). Like other citrus peel wastes, LPW can also be used for the manufacturing of useful products like multienzymes or many other natural compounds such as single-cell protein, citric acid, flavonoids, minerals, dietary fiber, and citrus essential oils (CEOs) (Boluda-Aguilar and López-

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http://dx.doi.org/10.1016/j.ibiod.2015.10.009
0964-8305/

Gómez, 2013). However, in recent years, LPW, as it contains various soluble and insoluble sugars is seen as a potential feedstock for bioenergy (bioethanol) production (Choi et al., 2015). This low cost and abundant by-product can alternatively be tested in MFCs for efficient and economical conversion to bioenergy. MFC has the major advantage over contemporary technologies (anaerobic digestion for methane production, bioethanol and hydrogen production etc.) for transforming biomass to energy, obtainable from a bio-convertible substrate, directly into electricity (Rabaey and Verstraete, 2005).

The aim of this study was to explore the lemon peel biomass as a low cost potential substrate for bioelectricity generation using MFCs. The performance of the cell was evaluated for voltage generation at different initial lemon peel concentrations. Performance parameters such as maximum power density, current density, coulombic efficiency, internal resistance (R_{int}), organic matter removal, etc., were tested. The effects of external resistance (R_{ext}), operating temperatures, and sonication times were also studied to determine the maximum level of cumulative power generation using LPW.

2. Materials and methods

2.1. Culture, nutrient medium and lemon peel

Sludge was collected from the anaerobic section of a local wastewater treatment plant in Daegu, Korea, for use in a MFC as an inoculum medium. The sludge was screened prior to introduction into the MFC to remove any metal or large foreign particles. The nutrient medium used to support the growth of exoelectrogens in MFC was primarily composed of (in units of mg l^{-1}): 560 $(NH_4)_2SO_4$, 420 $NaHCO_3$, 200 $MgSO_4 \cdot 7H_2O$, 20 $MnSO_4 \cdot H_2O$, and 15 $CaCl_2$, along with other trace minerals and the buffer solution to ensure neutral pH conditions. The lemons were purchased from a local market in Daegu, and then peeled and dried in an oven at 50 °C for 24 h. The dried peel was reduced to a size of <2 mm and stored at 4 °C for further use in the MFC for different experiments. Dried lemon peel powder (with 21.46% pectin, 10.60% hemicellulose, and 21.16% cellulose) at concentrations of 0.5, 1.0, and 1.5 g l^{-1} was used as a substrate for bioelectricity generation in the MFC. The physicochemical composition of the lemon peel used for the study is listed in Table 1.

2.2. MFC construction and operation

A rectangular dual chamber MFC was used for this study, with each chamber having dimensions of 8 cm × 5 cm × 5 cm (H × L × W) and separated by a Nafion 117 membrane for proton transfer (Fig. 1). The membrane was treated with 0.5 M H_2SO_4, 3% H_2O_2, and deionized water, with 1 h of each treatment under boiling conditions. The utilized anodes and cathodes were carbon felt (having a thickness of 3.18 mm) and carbon cloth (with 20 wt. % Pt.), respectively. Each electrode had a projected surface area of 25 cm^2, and was connected with copper wire through a resistor of 500 Ω or unless stated otherwise after the optimal resistance determination by polarization curve. Anolyte was continuously stirred using a magnetic bar, whereas catholyte (0.1 M phosphate buffer) mixing was achieved by sparging air (oxygen), which also acted as an oxidant in the cathode for the reduction reaction. All experiments were performed in a control temperature environment of 30 ± 2 °C, except for when the effect of temperature on power generation was studied. The anolyte was purged with pure nitrogen prior to introduction into the anode chamber to ensure anaerobic conditions in this section. Experiments were performed in batch modes to study voltage generation by changing the initial concentrations of lemon peel dry powder, and the effects of temperature, sonication times, and Rext on cumulative power production in different cases were investigated.

Table 1
Physico-chemical characteristics of lemon peel waste.

Composition (%)	Values
Moisture	12.4 ± 3.0
Ash	4.0 ± 1.2
C	41.3 ± 0.2
H	5.8 ± 0.04
N	1.2 ± 0.04
S	0.1 ± 0.01
Protein	7.5 ± 0.22

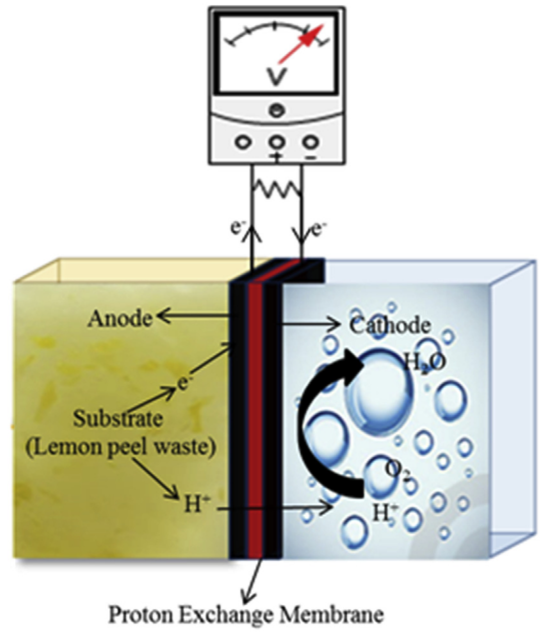

Fig. 1. A schematic diagram of a dual chamber MFC for voltage generation using lemon peel biomass waste.

2.3. Electrochemical calculations and chemical analysis

Electric current (*I*) was estimated by measuring the voltage (*V*) across the resistance (*R*) with the help of a data acquisition and data logging multimeter system (2700, Keithley, USA) which was connected to a personal computer for data storage. Polarization curves were obtained by changing the R_{ext} from 10 Ω to 0.1 MΩ during steady state, whereas the slope of this ohmic region in the *V–I* curve was considered to be R_{int} (Samsudeen et al., 2014). The maximum power density (mW m^{-2}) and corresponding current density (mA m^{-2}) was attained by using the power density curve method. The power density and current density were calculated as:

$$\text{Power density} = I{*}V/A$$

$$\text{Current density} = \frac{V}{R}{*}1/A$$

where *I* (mA) is the current, *V* (mV) is the voltage, *R* (Ω) is the resistance, and *A* (m^2) is the projected surface area of the anode (25 cm^2). The coulombic efficiency (CE) was determined on the basis of the ratio of total coulombs transferred in actual to the