Journal of Power Sources 241 (2013) 703–708

Contents lists available at SciVerse ScienceDirect

Journal of Power Sources

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

A single sediment-microbial fuel cell powering a wireless telecommunication system

Yohann R.J. Thomas [a], Matthieu Picot [a], Arnaud Carer [b], Olivier Berder [b], Olivier Sentieys [b], Frédéric Barrière [a,*]

[a] Equipe MaCSE, Institut des Sciences Chimiques de Rennes, Université de Rennes 1, CNRS UMR no 6226, Rennes 35042, France
[b] IRISA, INRIA, Université de Rennes 1, Equipe Cairn, France

HIGHLIGHTS

- A single sediment-microbial fuel cell (MFC) powers a wireless sensor network.
- The energy harvesting device adapts to the intermittent power supplied by the MFC.
- The radio-transmitter is able to switch from a continuous to degraded mode.

ARTICLE INFO

Article history:
Received 4 March 2013
Received in revised form
5 May 2013
Accepted 9 May 2013
Available online 17 May 2013

Keywords:
Sediment-microbial fuel cell
Sensor networks
Wireless communication
Energy harvesting

ABSTRACT

We report the ability of a single sediment-microbial fuel cell (MFC) to power wireless sensor network (WSN) nodes. Such a system is able to collect information from sensors and to transmit it to sinks. In particular, the PowWow platform presented here is combining an open and modular hardware design with an open-source software with a very light memory footprint and relying on event-driven programming. It includes energy harvesting capabilities and is able to adapt its radio data transmission behavior to the available energy supplied by the sediment-MFC. The MFC developed in this study successfully powered the WSN and results showed very stable performances over a long time frame with a high rate of signals sent from a source to a receptor connected to a computer. This sediment-MFC is moreover simple to produce and handle, with no membrane or artificial catalysts.

1. Introduction

Microbial fuel cells (MFC) have attracted a lot of interest in the last decade [1], as they produce electricity from a wide range of organic substrates including biomass and wastewater, using living bacteria as the electrode catalyst [2]. Several MFC architectures have appeared in the literature of which the simplest design is the sediment-MFC. In such a configuration, there is a single chamber containing the electrolyte with usually no physical separation between the anode and the cathode [3]. The cathode is commonly exposed to ambient oxygen at the air/water interface while the anode is close to anaerobic conditions as found in the sediment at the bottom of the cell. Indeed there is a decreasing oxygen gradient from the electrolyte surface and cathodic zone (top) to the anodic zone (bottom) [4].

Although MFCs produce only moderate amounts of energy (below ca. 1 mW cm^{-2} (10 W m^{-2}) of projected electrode area), these devices could be useful power sources for systems that demand only low power. For example chemical and wireless sensors, or miniaturized telecommunication systems, could be powered by MFCs provided that these electronic devices integrate an appropriate energy management program. To the best of our knowledge, only a few studies have shown the viability of MFC-powered electronic systems. Tender et al. [5] have shown the first demonstration of an MFC as a viable power supply for a meteorological buoy in an estuary. Other applications have been proposed such as the powering of robots [6], wireless temperature sensor using sediment-MFCs with vertical arrangement of electrodes [7] and other wireless sensors [8,9]. Moreover, MFCs as power sources have the advantage to be easily placed where the energy is needed, like in remote locations [10].

For most applications, the voltage output of a single MFC is usually too low (<1 V) to run electronic systems. It is then advantageous to control the electronic system by a DC/DC inductive

* Corresponding author. Tel.: +33 223235943; fax: +33 223236797.
E-mail address: frederic.barriere@univ-rennes1.fr (F. Barrière).

0378-7753/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.jpowsour.2013.05.016

converter or use stacks of multiple small-scale MFCs, in series, parallel and series–parallel configurations [6]. Those configurations increase the total power output compared to a single cell [11]. However, a connection in series of the fuel cells leads to operating problems such as voltage reversal in one of the cell when the anode potential shifts to positive values. This happens when a cell with limited performances is operated at high currents [11] or when a single MFC is connected to an external load that is too demanding [12].

Some authors have reported the powering of wireless sensors thanks to a capacitor that stores the energy produced by an MFC and hence permits its intermittent use [13]. A recent study [14] has demonstrated that duty cycling experiments performed with periodic resistance connection and disconnection allows the MFC to be operated at electrical loads below the MFC internal resistance. The authors concluded that shorter cycles lead to an increase in power generation. An alternative solution is to implement a control which allows the cell to work at its maximum power conditions [15–18].

In this study, the aim is to develop a power management system based on a single, cost effective and efficient sediment-microbial fuel cell and to adapt this power source to the Wireless Sensor Network (WSN) context.

A WSN is a collection of autonomous nodes with the abilities to collect information from sensors and to transmit this information to one or several sinks. WSN nodes are usually powered with batteries or self-powered with energy harvesting solutions [19,20]. The PowWow platform (Power Optimized hardware/software frameWOrk for Wireless sensor nodes) [21,22] has been developed at the University of Rennes 1 by the Cairn research team of Irisa/Inria. This platform has the specificity to include energy harvesting capabilities and to adapt the behavior of radio data transmission to the available energy. The PowWow platform has been adapted to the sediment-MFC context and therefore, the sensor node (or mote) is able to operate in degraded (intermittent) mode when the energy supplied by the sediment-MFC is decreasing.

The advantages of our setup are the use of a simple configuration based on a single sediment-MFC with no added catalysts other than naturally occurring bacteria and no pre-treatment of any of the materials (carbon electrodes), that are utilized as received from the manufacturers.

The paper is organized as follows. After a brief description of the building of the MFC, its stable performances are characterized by electrochemical measurements. The PowWow platform power consumption is analyzed before realizing the powering experiment by the MFC. Finally, data transmission analyses show that the system is a suitable adequate energy harvesting solution for this kind of application.

2. Materials and methods

2.1. Microbial fuel cell setup

The sediment-MFC (Fig. 1) was constructed using a 10 cm diameter cylindrical tube of polyvinyl chloride for a total volume around 0.8 L. The anode was made of graphite granules forming a bottom layer of about 4 cm thickness (Le Carbone, Belgium) and a graphite rod (5 mm diameter from Morganite Luxembourg SA) as the current collector.

The cathode was made of a carbon felt disc (10 cm diameter and 2 mm thickness as received from MAST Carbon Ltd., Guildford, UK). This non-woven activated carbon is highly microporous with a specific surface area of 1650 $m^2\ g^{-1}$ determined by N_2 adsorption isotherm with the B.E.T. method [23] on an Autosorb-1 from Quantachrome Instruments. The distance between the floating cathode and the anodic graphite granules bed was ca. 4 cm.

The electrolyte was prepared as described in Picot et al. [24] by mixing garden compost with sodium acetate (20 mM) in 20 mM phosphate buffer solution (pH 7) with 10 mL L^{-1} of a macronutrient solution (28 g L^{-1} NH_4Cl, 10 g L^{-1} $MgSO_4 \cdot 7H_2O$ and 0.57 g L^{-1} $CaCl_2 \cdot 2H_2O$); 1 mL L^{-1} of a trace element solution (2 g L^{-1} $FeCl_2 \cdot 4H_2O$, 1 g L^{-1} $CoCl_2 \cdot 6H_2O$, 0.5 g L^{-1} $MnCl_2 \cdot 4H_2O$, 0.05 g L^{-1} $ZnCl_2$, 0.05 g L^{-1} H_3BO_3, 0.04 g L^{-1} $CuCl_2 \cdot 2H_2O$, 0.07 g L^{-1} $(NH_4)_6Mo_7O_2 \cdot 5H_2O$, 1 g L^{-1} $NiCl_2 \cdot 6H_2O$, 0.16 g L^{-1} $Na_2SeO_3 \cdot 5H_2O$ and 2 mL L^{-1} of HCl 37%).

2.2. Electrochemical measurements

Reactors were operated in a batch mode at room temperature (20 ± 5 °C) and under a 1 kΩ external resistor. Cell voltage and electrode potentials were measured using a digital multimeter (Agilent U1253B). When the biofilm had developed, polarization and power curves were recorded under steady-state conditions using a potentiostat (Autolab PGSTAT302N) and a two-electrodes cell configuration (using the anode and cathode of the microbial fuel cell). A scan rate of 10^{-3} mA s^{-1} was applied from zero current to the current found at cell potential equal to 0.05 V (before short circuit). Chronoamperometry curves were obtained with the same

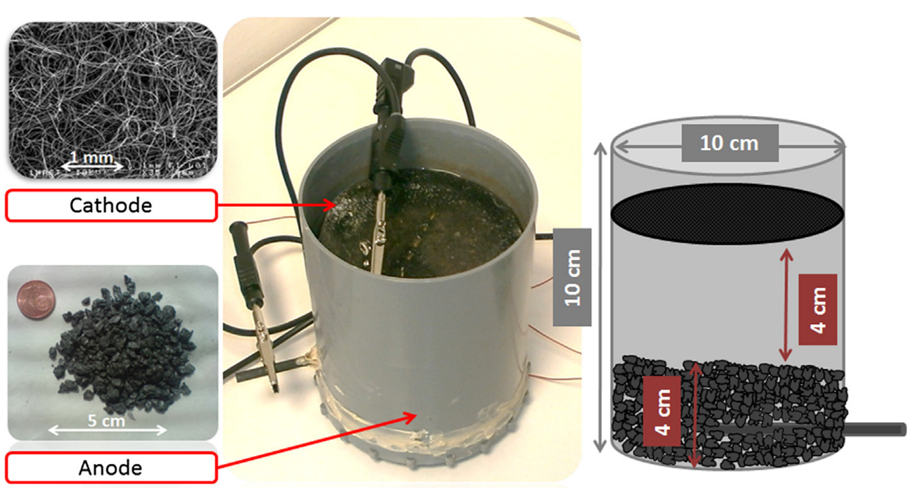

Fig. 1. Sediment-MFC with graphite granules as anode and carbon felt from MAST Carbon Ltd (image obtained with a JEOL JSM-6301F Scanning Electron Microscope) as cathode.