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Microbial fuel cells as power supply of a low-power temperature sensor

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HIGHLIGHTS

- We used microbial fuel cells (MFCs) to continuously power an autonomous sensor.
- A power management system is developed to control and supply the sensor.
- In a wastewater treatment plant (WWTP), MFCs can supply electronic systems.
- The concept of powering applications in WWTP by the harvested energy from MFCs.

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ABSTRACT

Microbial fuel cells (MFCs) show great promise as a concomitant process for water treatment and as renewable energy sources for environmental sensors. The small energy produced by MFCs and the low output voltage limit the applications of MFCs. Specific converter topologies are required to step-up the output voltage of a MFC. A Power Management Unit (PMU) is proposed for operation at low input voltage and at very low power in a completely autonomous way to capture energy from MFCs with the highest possible efficiency. The application of sensors for monitoring systems in remote locations is an important approach. MFCs could be an alternative energy source in this case. Powering a sensor with MFCs may prove the fact that wastewater may be partly turned into renewable energy for realistic applications. The Power Management Unit is demonstrated for 3.6 V output voltage at 1 mW continuous power, based on a low-cost 0.7-L MFC. A temperature sensor may operate continuously on 2-MFCs in continuous flow mode. A flyback converter under discontinuous conduction mode is also tested to power the sensor. One continuously fed MFC was able to efficiently and continuously power the sensor.

1. Introduction

Microbial fuel cells can be considered as a future option for the treatment of organic wastes and the recovery of bioenergy from wastes. Microbial fuel cell (MFC) is a device that converts electrochemically the chemical energy of organic matter into electricity by means of metabolisms of bacteria [1].

A typical MFC for production of electricity consists of an anode and a cathode partitioned by a proton exchange membrane (PEM). Bacteria or enzymes in the anodic chamber of an MFC oxidize the substrate and generate electrons and protons. These bacteria utilize electrodes for conserving the electrochemical energy required for their life. The bacterial activity was described by Kim et al. [2]. The electrons are absorbed by the anode and are transported through an external circuit to the cathode for corresponding reduction, whilst the protons migrate to the cathode and combine with the electrons and the catholyte (oxygen) that are reduced at the cathode surface. Simple design of MFC can be is the single-chamber air-cathode MFC [1]. This reactor possess only an anodic chamber without the requirement for aeration in a cathodic chamber such as the MFC detailed in Ref. [3].

The theoretical output potential of a MFC that uses acetate as fuel and the oxygen as electron acceptor is ≈1.1 V [4]. Practically various types of losses take place in the MFC including ohmic, activation, and mass transport losses [5]. The output voltage therefore does not reach its ideal theoretical value. Many efforts are devoted to improve the output voltage and the output power

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produced by MFCs [6,7].

MFCs have been used in many applications. They have been considered as sensors for pollutant analysis and in situ process monitoring and control [8,9]. They have also been studied in the field of electrical power production and their applications [10–12]. Tender was first to study the demonstration of a benthic microbial fuel cell as a viable power source [13]. Two benthic microbial fuel cells with 24 mW and 36 mW supply respectively a meteorological buoy with an average power consumption of 18 mW. In Ref. [14] an intermittent supply of a wireless sensor of 2.5 W has been realized by a complex power management system supplied by a single sediment MFC (S-MFC) producing 3.4 mW average continuous power. In [15], the electric energy has been extracted from the S-MFC, stored in a supercapacitor and used to power a wireless sensor [15]. A power management system was studied in Ref. [16] with two DC/DC converters to continuously power an underwater hydrophone from a sediment microbial fuel cell. Powering a wireless sensor for several hours from a sediment-MFC and without any external control on the system was also reported in Ref. [17]. The first example of a robot that was solely powered by MFCs was EcoBot-I in 2003 [18]. Energy harvested from 8 MFCs was accumulated in a bank of six capacitors and investigated to power the robot in a highly intermittent manner. The robot was then developed in many versions (EcoBot II, EcoBot III, EcoBot IV) with increasing power densities, more autonomous behavior, and variability in tasks that could be achieved by the system [19–21]. Scaling up MFCs by serial or parallel associations is possible to boost the available energy level. However this is facing many issues. Parallel association of MFCs step-up the output current but all connected MFCs operate under a common voltage that is still lower than the threshold voltage in CMOS technologies. Therefore energy harvesting from one MFC as a stack of parallel-connected MFCs requires a specific technology PMU.

In series-connected MFCs, the individual voltages of each cell add-up at the output while a common current flows through the fuel cells. This association can overcome the limitation with respect to the threshold voltage of transistors in CMOS process. However, in the serial connection, fuel starvation, the absence of bacterial activity in cells and dispersions between the associated MFCs are reasons that cause the voltage reversal phenomenon, what limits the net efficiency of the stack [22]. The series connection of MFCs offers advantages if the reversal phenomenon is corrected.

The paper is organized as follows. After a brief description of the lab-scale MFC, the performances of the MFC are characterized. The sensor power consumption is analyzed before designing the experiment. In this study, a simple power management system was used to supply continuously a temperature sensor in a first part. It is composed of two capacitors and a single DC/DC converter. In a second part, a flyback under discontinuous conduction mode with a MPPT is tested to supply the sensor from one MFC. This efficient system permits uninterrupted operation of the sensor.

2. Material and methods

2.1. Construction of MFCs

A single-chamber air cathode lab-scale reactor was built using a stainless steel mesh anode with a projected area of 100 cm^2. The reactor is made of a low-cost PVC draining tube with a volume of 0.7 L. The 120 cm^2 cathode of carbon cloth (30% Teflon treated, Fuel Cell Earth LLC, USA) is manufacturing manually, using a paintbrush as described in Ref. [23] and 1.56 mg cm^{-2} of black carbon and 0.5 mg cm^{-2} of platinum. The cathode is connected to the electric cable with a titanium wire. The MFC has been inoculated with wastewater from an industrial wastewater. MFC has been used in other experiments and the biofilm was already developed. MFC is then fed with 0.7 g of sodium acetate (1 g of acetate per liter, Sodium acetate, Sigma–Aldrich Chimie S.a.r.l, $C_2H_3NaO_2$, 82 g mol^{-1}, PN 71183) [24]. MFC is then connected to a load of 1 MΩ. After about one day, the output voltage reaches its maximum and stable value.

2.2. Electrical characteristics of MFCs

Characteristics of a MFC can be presented as both I–V polarization and power curves. There are several methods for tracing the polarization curve: (a) linear sweep voltammetry (LSV) [25]; (b) galvano-static discharge where the current is controlled and the resulting voltage measured [26]; (c) potentio-static discharge where the voltage is controlled and the resulting current is measured [25]; (d) resistorstat: connecting different resistors (from open circuit to short circuit) to the MFC and measuring the resulting current and voltage. A computer-controlled resistorstat, as previously described in Ref. [27], was used to control and obtain the data by varying the resistance load in the range of 4.7 Ω to 1 MΩ with time steps of 3 min. The output power can easily be calculated using the polarization curve.

Fig. 1 shows polarization and power curves for 2 MFCs. MFC$_1$ and MFC$_2$ have 0.934 V and 0.785 V open circuit voltage respectively and 1152 μW and 1108 μW output power at MPP respectively. In batch-mode operation, the MFC features a significant decrease in output power after 20–28 days but releasing about 2 kJ g^{-1} of acetate. The electrical characteristics of MFCs show that the output voltage at the maximum power point is about 50% of the open circuit voltage. The dispersion between the two MFCs could be explained by the non-uniform manufacturing process or microbial heterogeneities during inoculation and finally difference in microbial activities.

2.3. Sensor

Monitoring natural parameters (measuring PH, temperature… etc.) in remote locations (desert, under sea) where there is no suitable continuous power source is a challenge. A sensor network consists of spatially distributed sensors to monitor physical or environmental conditions and to cooperatively pass their data through a server to a main location. Data can be used in a number of applications such as environmental monitoring (e.g. fire detection, air pollution monitoring, temperature monitoring), industrial monitoring (e.g. health monitoring system) or agricultural monitoring (e.g. sun exposition, humidity monitoring) [28]. Each system

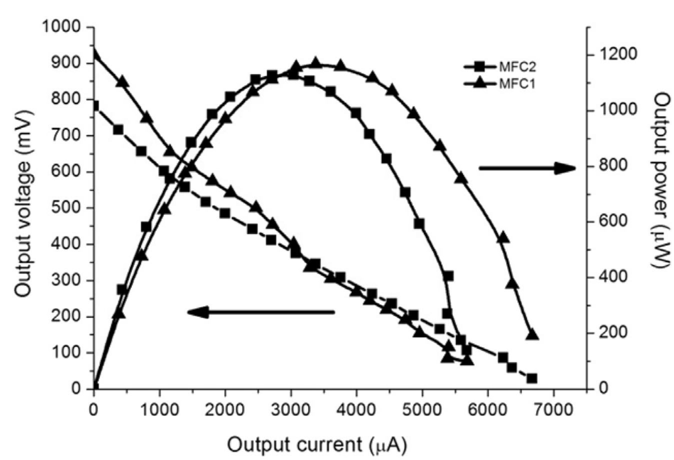

Fig. 1. Polarization and power curves for 2 lab-scales MFCs.