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Electrical valorisation of Microbial fuel cell

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RESUME - This paper focuses on applications and electrical valorisation of microbial fuel cells (MFCs), a promising energy harvesting technique, suitable as clean power source to supply low power devices in wireless sensor networks (WSN) for environmental and agricultural monitoring. Additionally, MFC may be used directly as a biosensor to analyse parameters like pH and temperature or arranged in the form of a cluster of devices to be use as a small power plant. We perform a series of test for the electrical valorisation of reactors as well as biosensor issues.

Mots-clés— Microbial fuel cell, energy harvesting, low power electonics, wireless sensor network, bioreactor

1. INTRODUCTION

Microbial Fuel cell is an energy harvesting now well introduced in literature [1, 2, 3, 4, 5]. An MFC is a bioreactor that converts energy stored in chemical bonds of organic matter into electrical energy, through a series of reactions catalyzed by microorganisms. The principle is detailed below. We performed a series of test for the electrical valorization of MFC and to exploit the aspect as biosensors. The influence of temperature and pH on MFC are described as these are main parameters for application in agriculture. The electrical behavior of MFC is evaluated in different operating conditions because the major issues are related to the measurement setup that acts on the MFC kinetics, and the wide spectrum of MFC performance

2. MICROBIAL FUEL CELL

A MFC is a promising energy harvesting technology with zero carbon emission, which can produce suitable energy for low power electronic devices. An MFC is a bioreactor that turns energy stored in chemical bonds of organic compounds into electrical energy. The reactor considered here is composed of two chambers, one anode and one cathode, each of which includes an electrode. In the anode chamber, under anaerobic conditions and in a nutrient-enriched environment, the organic matter oxidized into carbon dioxide by microorganisms, produces surplus electrons by means of an equivalent reduction operation. These charges are transferred to the cathode through an external circuit connecting the electrodes and a simultaneous generation of protons, which are then passively transferred to the cathode electrode. The protons, a by-product of electrogenic metabolism, transferred to the cathode chamber in aerobic condition, react together with oxygen to form water molecules. A semipermeable proton exchange membrane (PEM) can divide the two chambers to insure the transfer of protons. A possible solution is to use the soil as membrane, in this case we are referring to terrestrial microbial fuel cell (TMFC), where the ground itself plays the roles of both PEM and source of biodegradable organic matter for the purposes of power generation. Instead, the waste-water acts as flow of nutrient and bacteria source in waste-water microbial fuel cell (WWMFC). Moreover, there is other configurations of MFC as marine MFC or sediment MFC. Also, exist reactors typologies that exploit the work of other kind of microorganism as mitochondrial or enzymes [6,7], in place of bacteria. We have built lab-scale prototypes of TMFC and WWMFC for experimentations. MFC has been widely used for application like empower a WSN [8, 9, 10, 11, 12]. There are different possibilities. One is arranging MFCs in form of clusters to use as a small power plant. In wastewater treatment plant (WWTP), MFC offers the possibility to convert organic materials present inside wastewater into electricity by the metabolism of bacteria. The efficiency of a WWMFC can be improved in WWTPs using wastewater rich in organic matters such as sanitary wastes, food processing and domestic wastewaters, swine and agricultural wastewaters. MFC can also be used to produce bio-hydrogen instead of electricity. Furthermore, it is possible to use MFC as a biosensor [13, 14], for example to measure pH, temperature, biological oxygen demand or water quality monitoring.

2.1. Lab scale MFC

We set up a lab-scale TMFC (Fig. 1) built in PVC with a height of 10 cm and cylindrical shape. Reactor diameter measures 10 cm. The anode is placed at a working depth of about 6-8 cm into the ground, while the cathode is on top of the soil. Both electrodes were made with graphite fibers with a diameter of about 9.2 cm and thickness of about 0.65 cm.

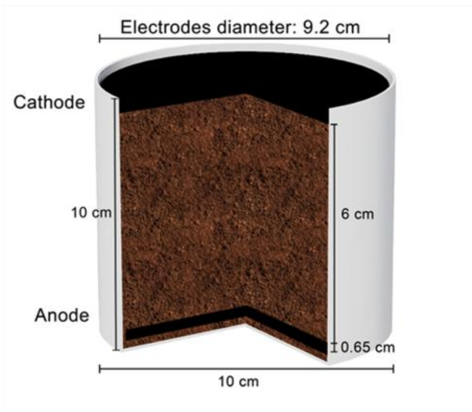

Fig. 1. Section of lab-scale TMFC

WWMFCs lab-scale prototypes of cylindrical shape were made of PVC draining tube of 0.7 liters. The distance between the electrodes is about 4 cm with an anode made by carbon fiber brush. An air cathode of 120 cm^2 of carbon cloth is realized manually, using a paintbrush with 1.56 mg of black carbon and 0.5 mg of platinum for every cm^2 of the cathode surface area. The reactors were fed with 0.7 g of sodium acetate and the wastewater was taken from an urban wastewater treatment implant or synthetized in laboratory. The figure 2 shows a 3D graphical section of WWMFC lab-scale reactor.

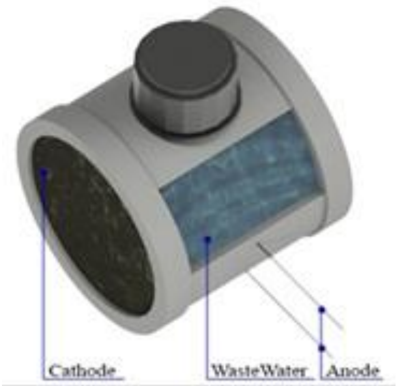

Fig. 2. Section of lab-scale WWMFC

3. ELECTRICAL VALORIZATION OF MFC

A series of tests was set up to evaluate the best energy performance and to study the effect of temperature on WWMFC. The best value of power generation was reached at ambient temperature (20°C), 490 µW for 0.7l of waste water taken from an urban waste water treatment implant. Moreover, we investigated the effect of temperature variation on reactor electrical performance. We conducted the experimentation in a controlled temperature chamber in a range from 15°C to 40°C. Fig. 3 shows experimental results where the power generated by a WWMFC was significantly affected by increase in temperature. Considering that we can assume that temperature plays a crucial factor on the biological activity and electricity production of MFCs, a WWMFC reactor have the potential to be used directly as temperature sensor for specific substrate. The maximum value of power generated was 812 µW at a temperature value of 40°C.

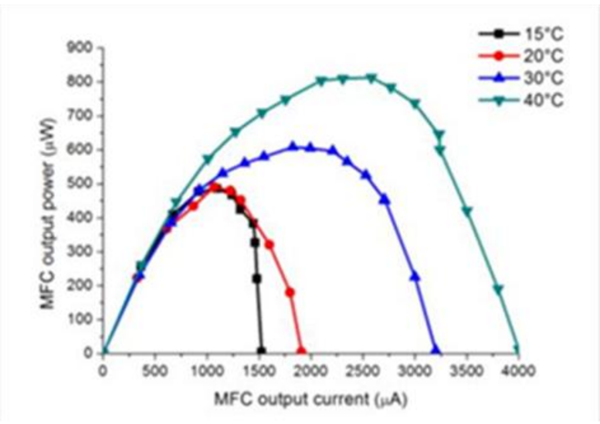

Fig. 3. Results of temperature influence on power performance of WWMFC

MFC performance depends on pH value because it causes alterations in concentration of ions, biofilm formation, membrane potential and proton-motive force. It is recognized that an environment with neutral pH is in the optimal conditions for the proliferation of microorganisms. We prepared three TMFC reactors under different conditions to study the effect of pH variations on TMFC performance. In the first batch, two reactors (Test A and B) were filled with the same earth sample, used for agricultural purposes. The pH of this soil, analysed by means of pH meter [15], has a value of 6. In the second batch (Test B) we added 5 mL of a phosphate buffer solution pH=7.5 (10mM), which brought the pH value to increase to 6.63. So, we monitored the influence on the output voltage, in the case of reactors with same soil but changing pH value. Furthermore, a third batch (Test C) was prepared using a different soil taken from bean plant with a pH value of 6.3. The experimental results show the pH influences on open circuit voltage. In fact, a higher pH value corresponds to an increase in the voltage, both in the case of the same type of soil at different pH value and both in the case of different soils at different pH value. The capacitive behaviour of a WWMFC was analysed to improve the electrical model of lab-scale reactor. Tests were done with a Keithley device able to impose zero current or zero voltage to the cell. It was used to get data of a complete discharge. Fig. 4 shows a behaviour similar to that produced by a capacitor. It required a minimum of 36 hours for a complete discharge (Fig. 4). The cell reaches a minimum value of 0.4µA and it started with a peak of 4 mA.

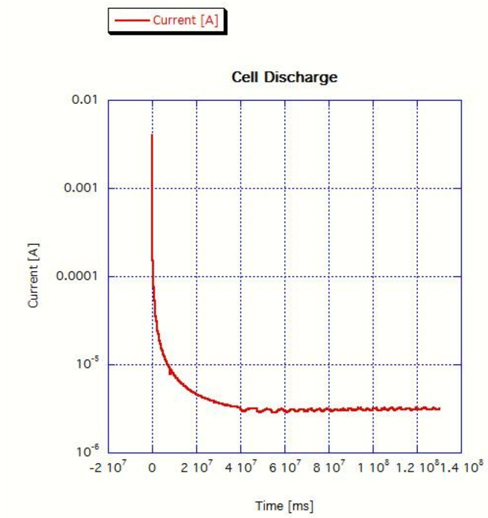

Fig. 4. Thirty six hour test of complete discharge of an operating WWMFC

A WSN node for monitoring can operate in sleep mode for most of the time and be activated only to transmit data. Considering that this requires a minimum transmission time, an MFC can be properly used to supply a WSN system. A low power device as a monolithic RF transceiver Atmel ATA8510, requires less than 90 µA in sleep mode. Also, it requires as supply voltage 1.9V, less than the 3.3V that usually was minimum threshold needed in the last years to supply a low power device. Considering a time needed for transmission and data collection of 3s, an electrical characterization of the performance of a WWMFC was done for this time horizon. A custom measurer instrument dedicated to MFC was utilized to self-collect the data. It was implemented to perform long time analysis of charge, discharge and power performance specifically for MFC. The measurement setup for the power performance tests was done with a measurement time of 3s for each load, assuming the time value useful for WSN node operation.

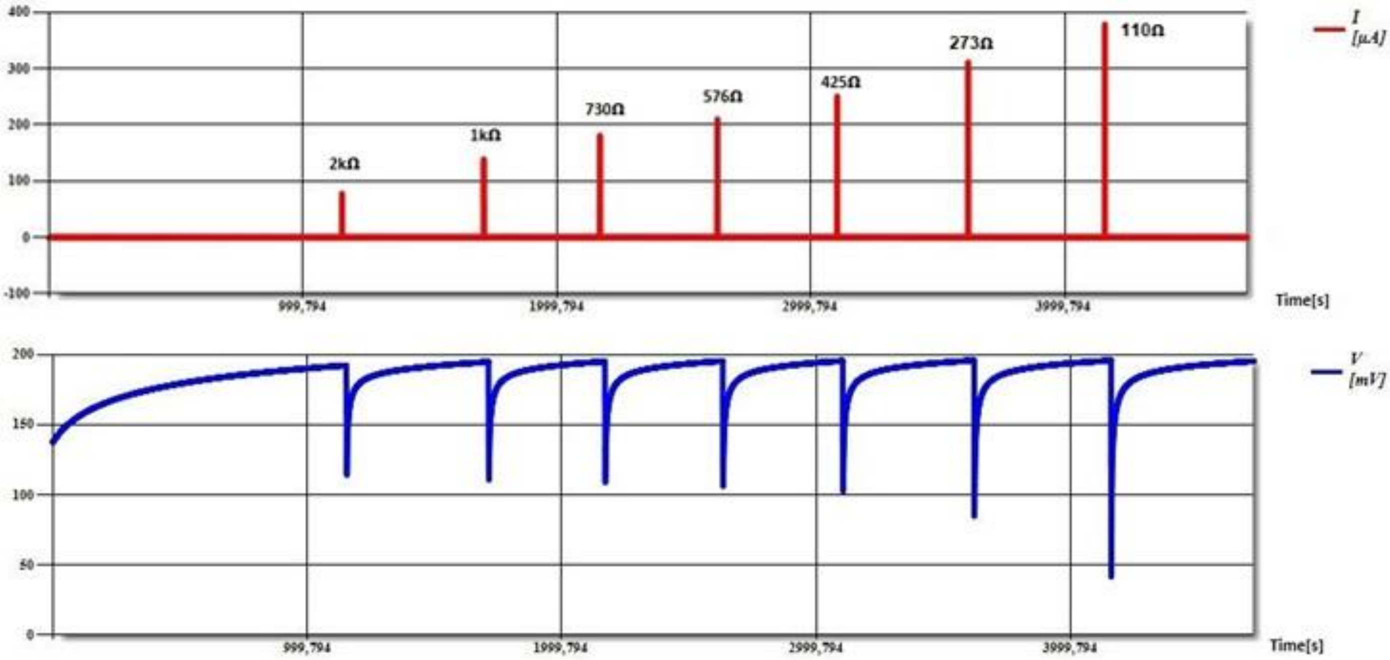

Fig. 5a. Results of I(mA) and V(mV) over time (s) of a WWMFC

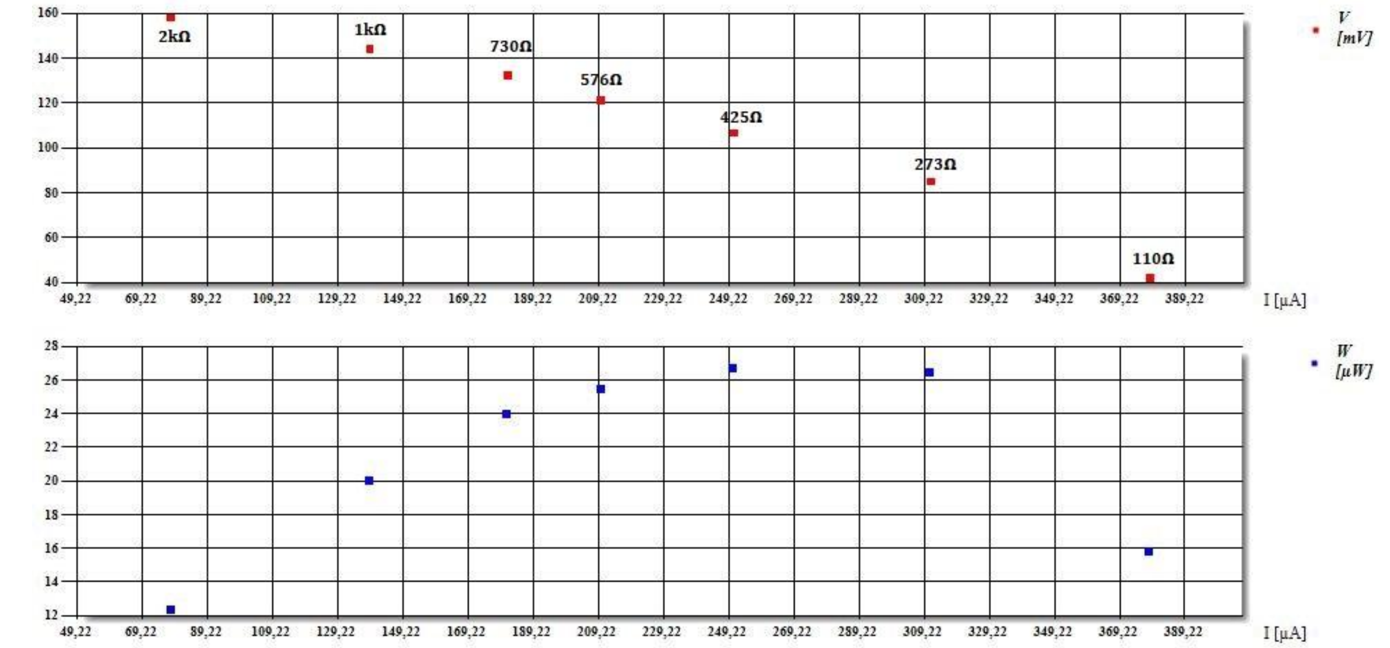

Fig 5b. Steady State Results for 3s measurement time with seven loads applied

After every power measurement with a certain load, the system allows the cell to reach again the open circuit voltage (OCV) before switch the desired load value. The results of power measurements in Fig.5a and Fig.5b are referred to the following loads values: 110Ω, 273Ω, 425Ω, 576Ω, 730Ω, 1kΩ, 2kΩ. The reactor was fed with a synthetize solution done from potable water adding a fixed concentration of 1g/l of acetate and imposing a pH solution value of 7.2, in this way the conditions are like the one of a waste water taken from an urban waste water treatment implant. So, the composition of the synthetize waste water is known, instead a waste water taken from a waste water treatment plant must be analyzed to understand its composition.

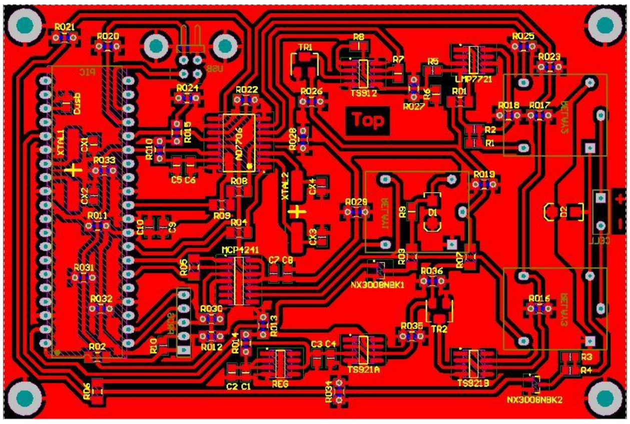

Fig. 6: PCB layout of the custom measurer instrument

On the other hand, the power performance is less due to a minor concentration or shortage of various organic matters and salt in the synthetized solution, differently from a real waste-water taken from an urban treatment implant. The capacitive behavior is described in figure 5a in respect of the different load values applied. Moreover, is shown in the figure the time required to be fully charge once a load has been removed. It requires a minimum of 8 minutes to fully charge after a discharge with loads applied for a measurement time of 3 second. A cell need a certain time to reach again the OCV after a load is applied. This time increase when the value of the resistance applied is smaller than the precedent due to a greater voltage drop. A dedicated algorithm manages this time and permit to wait until the measurement is stable. It can be set from the feature of the GUI. So, the sampling time between measurements is variable. The Fig. 6 represent the PCB layout of the custom measurer instrument used for the WWMFC electrical analysis. In Fig. 7 is shown the measurement system for the reactor. It is connected to a multimeter and to the custom measurer board which is connected to a computer where the graphical unit interface (GUI) dedicated to the board is running and collecting data.

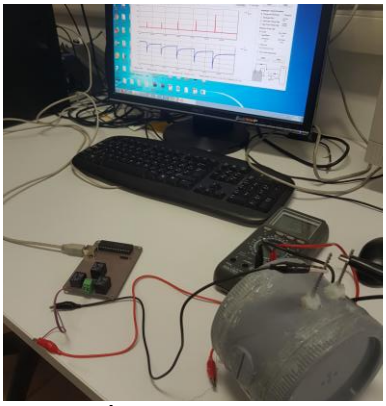

Fig. 6. Measurement test configuration

4. Conclusion

Microbial fuel cell is a rising energy harvesting technology that can be used to supply low power devices for many purposes and applications or directly as a biosensor. Efforts are needed to improve MFC with various set up, operations, electrode and membrane materials, substrates and microorganisms. As a matter of facts, main issues are related to the fact that MFCs produce a wide spectrum of performances in different configurations and measurements setup, a large database of MFC behaviour is needed, especially about the MFC kinetics and sampling time. As future development, the results about electrical behaviour of MFC will be compared with tests of electrical characterization in different conditions or reactors configurations.

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