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Dedicated to Professor Emil Cordoș on the occasion of his 80th anniversary

CONSTRUCTION AND CHARACTERISATION OF A MICROBIAL FUEL CELL WITH SOIL MICROORGANISMS

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ABSTRACT. Microbial fuel cells are based on the ability of microorganisms to produce energy through biomass degradation. This study presents the construction, electrical characterization and possible applications of a type of MFC with microorganisms from soil. Although the obtained power density is low compared to other authors (1W/m^3, respectively 500mA/m^2), the proposed construction is very simple, without moving parts, chemical substances or external electrical energy consumption. Possible applications of this type of MFC are presented: sodium acetate aqueous solution sensor and electrical energy source in isolated areas.

Keywords: *microbial fuel cell, soil microorganisms, power density, miniaturised MFC*

INTRODUCTION

Microbial fuel cells (MFCs) represent a promising technology, based on the conversion of chemical energy into electrical energy *via* microbial catalysis [1-3]. This process results when bacteria switches from natural electron acceptor (oxygen or nitrate) to an insoluble acceptor (the MFC anode) [4]. Thus, an oxidation reaction occurs at the anode and electrons are released to respiratory enzymes [5-6]. The electrons are then conducted over a resistance towards the cathode, where a reduction reaction develops. In order for the electroneutrality to be preserved, an equal number of protons must be exchanged between the electrodes [6].

Due to the potential of microbial fuel cell systems, research has been made in every aspect regarding the power density – electrodes with

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different catalysts (platinum, Fe (III), Mn (IV)), electrogenic bacterial strains (*Brevibacillus* sp. PTH1 and *Pseudomonas* sp., *Saccharomyces cerevisiae* and *Hansenula anomala, Rhodoferax ferrireducens, Geobacter* species), various mixed cultures of bacteria (activated sludge, wastewater) and MFC configurations (two-chambered, membrane-less, stacked MFC, upflow MFC, etc.) [7-8].

Despite all of the efforts that have been made, the performance for large scale MFCs is limited by bottlenecks such as transfer resistances [9], concentration polarization [10], ohmic losses and the type of membrane that is being used [11][12]. As a solution to some of MFCs technical disadvantages, the current development implied miniaturised cells with faster mass transfer and reaction kinetics, better results for power density and internal resistance and a better start-up time [13].

The technologies developed for miniaturised microbial fuel cells vary from polydimethylsiloxane (PDMS) chambers [14] to microfluidic fuel cells, from a wide range of electrodes to different strains of algae [15] and bacteria [16-19].

Microbial fuel cells with soil microorganisms represent the latest topic in the research and development of MFCs. Easy to build and manage, these types of cells are based solely on the conversion of chemical energy from the soil into electricity.

Rich in complex sugars and nutrients, soils also contain electrogenic microbes [20] and aerobic bacteria that act as oxygen filters, the same as the most expensive proton exchange membrane materials used in laboratory MFC system, and that decrease the redox potential in soil according to depth [21].

Shewanella and *Geobacter* species, both present in soils and sediments have been the most successfully researched [22].

The power in the case of this type of MFCs is given by the difference in the potential of the two electrode areas. The metabolic compounds determine a decrease in the electric potential at the anode and the dissolved oxygen determines an increase of the potential at the cathode.

So far soil MFCs have been effectively used in pollution degradation and waste treatment. From marine sediment to garden compost, it is clear that organic matter and microorganisms from soil can be used as a resource for electrical energy [23].

The carbon, nitrogen and bacteria found in soils play an extremely important role in determining the operation of the microbial fuel cell with soil-based microorganisms. Agricultural soil is richer in carbon, nitrogen and different minerals, and thus it is used more often compared to forest soil or other types of soil, due to the higher rate of electricity production [24].

RESULTS AND DISCUSSION

Determining the electromotive force and the internal electrical resistance

The electromotive force (emf) and internal resistance of the batteries have been determined through the polarization curve method. Figure 1 shows a typical polarization curve for the μ103 battery at a 0.07 mol/L sodium acetate concentration.

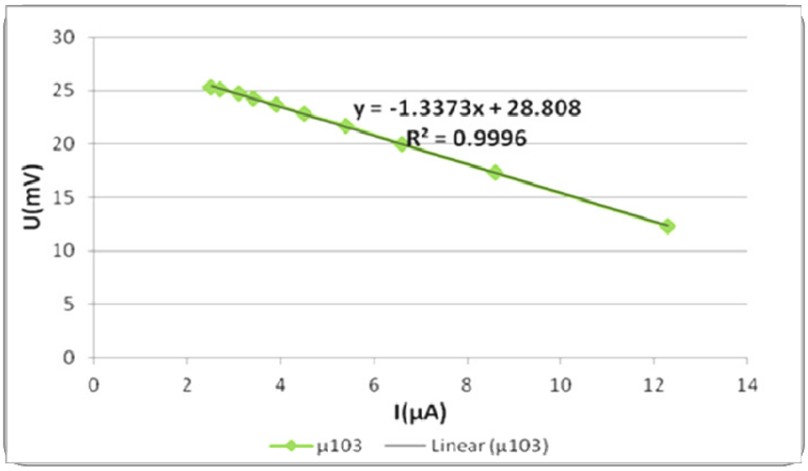

Figure 1. Polarization curve of μ103 battery for a 0.07 mol/L sodium acetate concentration

In this case the value of the emf is 29 mV and the internal resistance is 1.3 kΩ. The influence that the nutrient concentration has on the internal resistance has been studied. Figure 2 shows the influence of the concentration of the acetate on the internal resistance.

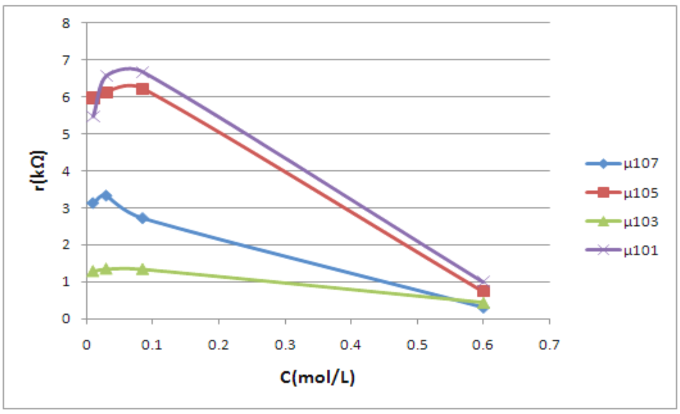

Figure 2. Internal resistance variation depending on sodium acetate concentration

A sharp increase in the internal resistance value is observed to be related to a slow increase of the sodium acetate concentration (0-0.03 mol/L).

When a maximum value is reached (at concentration between 0.03-0.085 mol/L), the internal resistance begins to drop. This decrease is supposed to appear due to the fact that the microorganism population reaches its maximum development, and the increase in sodium acetate concentration creates an excess of it in the cell material, reported to the population needs. This excess leads to an increase of the electrical conductivity in the liquid environment inside the cells, therefore reducing the internal resistance of the cells.

Power density dependence on acetate concentration

The power density generated by the microbial battery has been determined by the relation:

$$P_D = \frac{U \times I}{10 \times V}$$

where *U* is the voltage measured on the load resistance, *I* is the current through the circuit, *V* (cm^3) is the volume of one cell.

The current density has been determined by the relation:

$$I_D = \frac{I}{10 \times A}$$

where A (cm^2) is the projected area of the anode of one cell. Figure 3 shows the influence of the nutrient concentration on the power density.

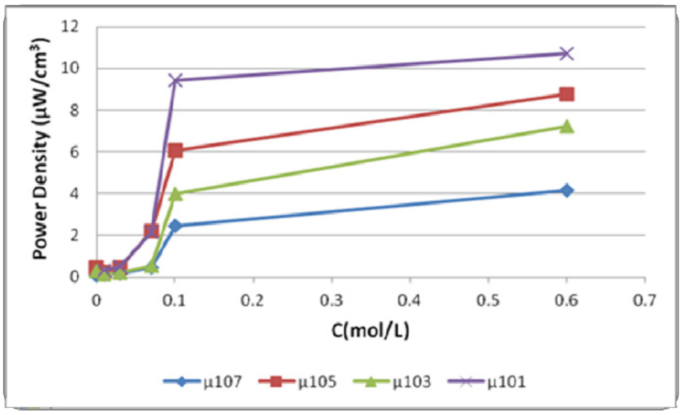

Figure 3. Power density variation depending on sodium acetate concentration

A significant power density increase in the 0.03-0.1 mol/L range has been found. It is followed by saturation at higher concentrations. This is believed to be due to the microorganism culture reaching a maximum development level, which is stationary as the nutrient concentration is increased, meaning that the generated power is limited at that level.

The majority of the miniaturised MFCs reported so far are mainly composed of two chambers, Nafion membrane, ferrycianide catholyte, pumps to circulate the electrolytes and pure bacterial strain [25][26].The model of miniature MFC proposed in this study has certain advantages: it has one chamber with no separation membrane, no artificial chemicals needed, no moving parts (and hence no electrical consumption) and contains a mix of natural microorganisms from soil.

Table 1 presents a comparison of this work with the best results from mL- scale MFCs papers.

Table 1. Comparison of the current paper with the best results from mL scale MFCs

	F.Qian et. all (2011)	**F.Qian et. all (2011)**	**Fan et. all (2007)**[27]	**Ringeisen et. all (2006)**	**Current paper**
Chamber volume (mL)	10	10	2.5	1.2	20
Projected anode area (cm^2)	5	2.25	7	2	1.5
Anode material	Carbon cloth	Gold	Carbon cloth	Graphite felt	Carbon cloth
Catholyte	Ferricyanide	Air	Air	Ferricyanide	N/A
Substrate	Trypticase soy brot	Lactate	Acetate	Lactate	Acetate
Max. current density (mA/m^2)	80	N/A	9000	11000	500
Max. power density (W/m^3)	0.2	N/A	1010	500	1
r_{int}(kΩ)	13	N/A	N/A	N/A	1

Power density dependence on time

Figure 4 and Figure 5 show the power density dependence on time.

As it has been expected, the power density decreases in time more sharply for lower concentrations of nutrient, and slower for higher concentrations. Furthermore, the generated levels of power are variable depending on the batteries.

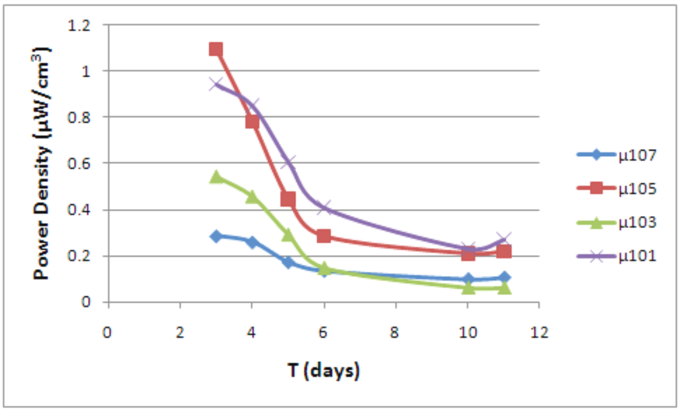

Figure 4. Power density variation depending on time in 0.03 mol/L acetate

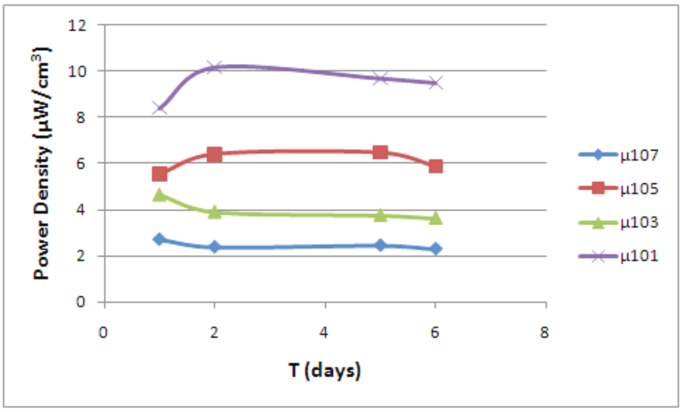

Figure 5. Power density variation depending on time in 0.1 mol/L acetate

Using the microbial fuel cell as a sodium acetate sensor

Figure 3 shows a univocal dependence of the power density regarding the sodium acetate concentration. As a consequence, the microbial battery containing microorganisms from soil can act as an acetate sensor. For the sake of simplicity, instead of the power density signal, the voltage signal has been used. The calibration curve U=f (conc) for battery μ103 has been built (Figure 6).

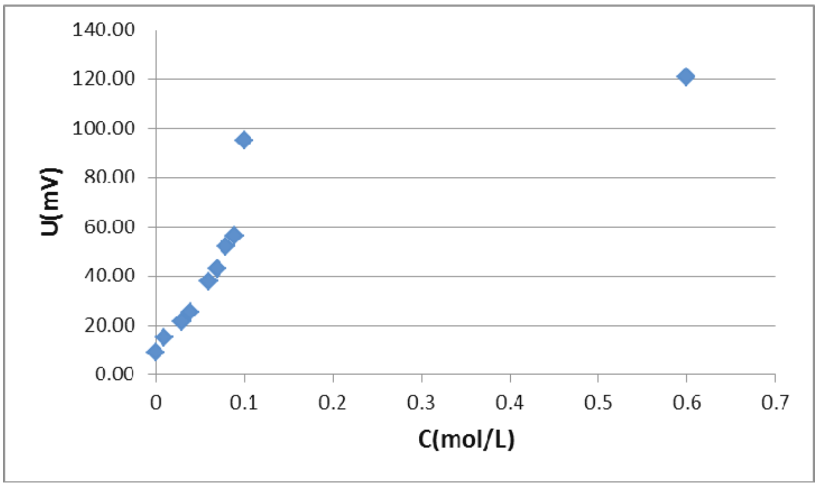

Figure 6. Voltage dependence of concentration for the μ103 battery

A steep slope of the curve is observed in the low concentration range (0-0.1 mol/L), and the saturation phenomenon at higher concentrations occurs. The MFC battery can be used as a sensor in the low concentration range, where it shows a higher sensibility. Figure 7 shows the calibration curve in the concentration domain 0-0.1 mol/L.

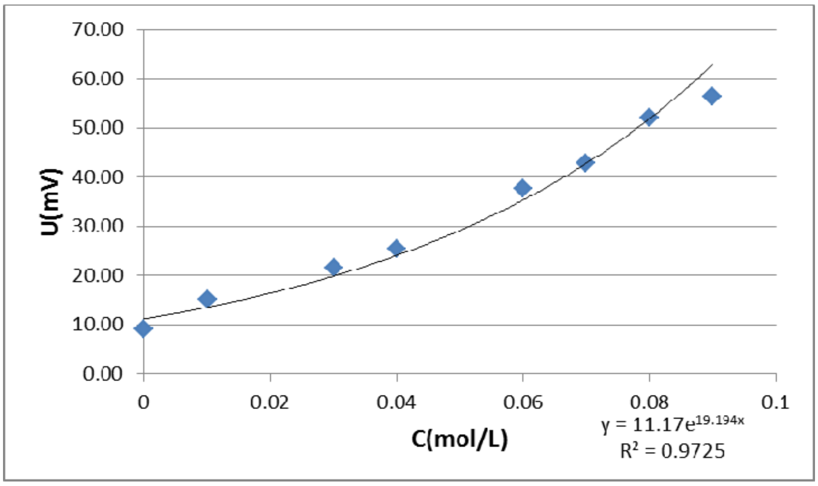

Figure 7. The calibration curve

The curve equation is $y = 11.17e^{19.194x}$, with a correlation coefficient R^2=0.9725.

For a standard concentration of 0.07 mol/L, by using the µ103 sensor, the concentration value c = 0.078± 0.013 mol/L has been obtained. The recovery values are presented in Table 2. Due to the fact that the obtained value is very close to the standard value, it can be assumed that microbial fuel cell batteries can be successfully used as sensors for different types of organic matter dissolved in water.

Table 2. The recovery values

Real concentration(mol/L)	Found concentration(mol/L)	Recovery values(%)
0.07	0.094	134
	0.081	116
	0.059	84

CONCLUSIONS

A miniaturised battery (made of 10 MFC cells connected in parallel) with microorganisms from soil has been built.

The maximum generated power density is 1 W/m^3 and the current density is 500 mA/m^2. Despite the fact that these values are far exceeded by other researchers' results, the current model has the following advantages: it has a simple construction, it has no membrane, no moving parts and no artificial chemical substances and nor does it consume electricity.

This type of battery could be used as a sensor for organic matter present in water.

Another application could be the production of electrical energy in crisis situations and/or isolated areas by using a plastic foil which has hundreds or thousands of cells with pre-printed electrodes. These could be filled with moist soil containing organic matter and the battery would be ready for operation.

EXPERIMENTAL SECTION

The construction of microbial fuel cells with soil microorganisms.

The 10-well array is made of plastic material characterized by a volume of approximately 2 mL/element. The electrodes have been painted on the inside of the wells using the graphite paste Electrodag 4023 ss (Acheson, Milano).

The MFC diagram is shown in Figure 8:

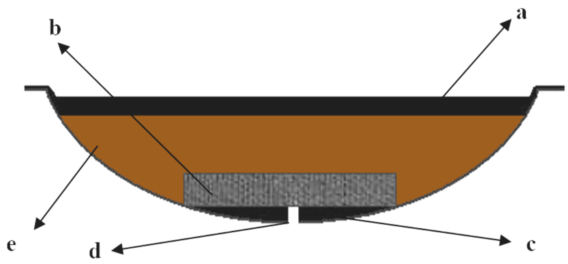

Figure 8. Scheme of MFC with microorganisms from soil
a) cathode, b) carbon cloth, c) anode, d) feed inlet, e) soil

Carbon cloth has been applied to the graphite paste to enhance the surface area of the anode, its dimensions being 1.5x1x10 mm. Ten individual cells have been connected in parallel using the graphite paste (Figure 9) and then filled with garden soil mixed saturated with water (Figure 10). The idea on which the soil MFCs were built was the presence of exoelectrogenic bacteria – most common being *Shewanella, Geobacter and Pseudomonas* [28]. It has been proven that a difference exists between forrest soil and agricultural soil, the latter containing species of *Clostridium* (important role in generating fermenting products), *Bacteroidetes*, *Geobacter* [29]. We can only speculate that the bacterial communities in the soil we used are similar with those that have been proven in previous research, bearing in mind that soil ecosystem is complex and variable.

To perform the experiments, four identical batteries denominated µ101, µ103, µ105 and µ107 have been used.

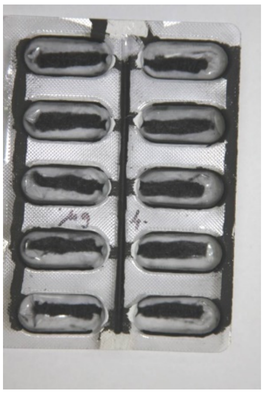

Figure 9. Blister of ten batteries ready for filling

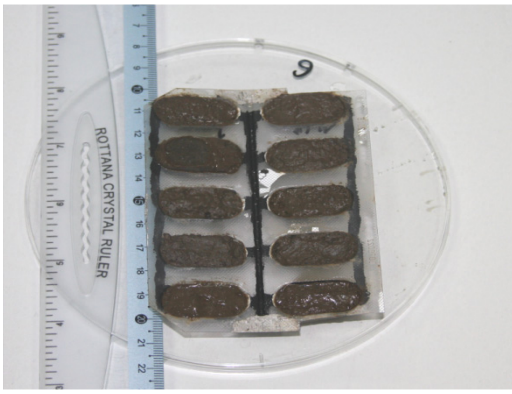

Figure 10. Battery ready for measurements

The batteries have been functioning continuously onto a 1 kΩ resistance load. They have been placed in Petri dishes containing sodium acetate solutions which have been used to feed the microorganisms. The solution enters the anodic part of the cells through an orifice drilled in the bottom. The experiment was conducted at ambient conditions.

The electrical measurements have been made using the MasTech MAS 830 (Taiwan) and PeakTech 3340 DMM (Germany) multimeters.

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