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Development and Performance analysis of Biowaste based Microbial Fuel Cells fabricated employing Additive Manufacturing technologies.

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Abstract

In this work two different configurations of MFCs are tested, evaluating the importance of the operative conditions on power production. All the MFCs were fabricated employing 3D printing technologies and, by using biocompatible materials as for the body as for the electrodes, are analyzed the point of strength and development needed at the state of the art for this particular application. Power productions and stability in terms of energy production are deepen investigated for both the systems in order to quantify how much power can be extracted from the bacteria when a load is fixed for long time.

Keywords: Microbial Fuel Cells, 3D printed Electrodes, Sustainable Materials, Operative Conditions.

1. Introduction

Nowadays researchers are finding out innovative solutions that will enable in the future to product clean energy and solve problems like climate changes and increasing pollution. In this context, we can consider microbial fuel

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cells (MFCs) as one of the most attractive technologies. In particular, these bio-electrochemical devices have the unique feature of directly produce power by converting the energy stored into a substrate, thanks to the activity of some electrogenic bacteria able to produce and transfer electrons to an electrode to which they are in contact [1-4].

Transfer mechanisms are not well understood yet, and further researches are needed in order to better comprehend how it really works. Several types of transferring processes have been presented, and the three main mechanisms are conductive nanowires, electrons shuttles and redox reaction between bacteria and the electrode. Without considering the biological processes, researchers have been shown that others are the main features that affect most MFCs, in particular, the specific design of the cell and operative conditions [5]. Researches showed how the power density can increase by limiting the chemical oxygen demand (COD) and how precious materials as platinum used as catalyst can improve the coulombic efficiency of the reactor and the power generation. Working in this way, energy production increased from less than 1 mW/m^2 to 1200-1500 mW/m^2 [1-9]. On the contrary, results obtained affected the economy of the reactors, in fact, scale-up for real application of MFCs presents high costs due to materials used (such as platinum and Nafion^R) for the purpose previously described. The steps that need to be overcome, to see real applications of this technology, are to get a more stable production of energy (it is yet relatively low) and to reduce their costs. In this contest, the using of additive manufacturing technologies can help to reach these goals. These technologies, in fact, use additive process that consists in a successive deposition of material layers to build prototypes or the final piece, contrary to traditional subtractive methods where blocks are cutted from the originally one. Due to that a more sustainable and less wasteful production can be applied to MFCs bioreactors. In addition, materials suitable for 3D printing are moving to bio-based solutions completely recyclable that would strength the sustainability by closing the loop also for the materials [10].

Nomenclature

MFC	Microbial Fuel Cell
FDM	Fused Deposition Modelling
PLA	Poly-Lactic Acid
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
AC	Activated Carbon
PTFE	Polytetrafluoroethylene

2. Materials and Methods

Several types of reactors have been proposed in the literature, showing how much of the potential of MFCs is affected to shape and operating conditions. From MFC configuration point of view, two reactors are mainly studied: single chamber reactors and double chamber reactors. The main difference is due to the using or not of a chamber in which to locate the cathode electrode.

In this study, these two configurations for the reactor are tested. In the reactors design the distances between cathodes and anodes in both layouts is fixed to 2 cm.

In the single chamber configuration, activated carbon coated with PTFE and a nickel mesh as current collector are used as cathode (7 cm^2 as active surface area) and a PLA based material is used for realizing the anode (9.7 cm^2 active surface area).

In the double chamber reactor, both electrodes (cathode and anode) are realized by using the PLA based material like that used for the anode of the single chamber reactor. These electrodes have also the same shape (9.7 cm^2 active surface area). Moreover, a cation exchange membrane (CEM) is used as medium between the two chambers.

2.1 Design and Fabrication

To design the shape of the reactors the open source code “Free CAD” has been used. It is a parametric computer aided design (CAD) software able to design 3D objects. Reactors were cubic shaped (500 x 500 x 465 mm) and an internal circular hole (30 mm in diameter) is added to get a 28 ml useful volume. For the single chamber MFC, a second plate is needed in order to close the cell. In the double chamber configuration, the chambers have the same shape and volume and on the top side of the reactors two circular hole of 7.5 mm each are realized (for inoculation purpose and for locating the electrodes in the chambers). The CAD outputs are presented in Figure 1. The electrodes for the MFCs are designed by considering two cylinders connected in series; they are 1 cm suspended upon the bottom surface of the chamber. The active area is calculated considering 15 mm of diameter and 17 mm of height.

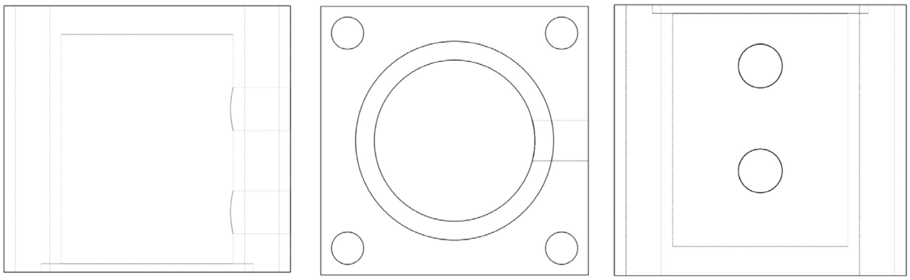


Figure 1: Reactor Design.

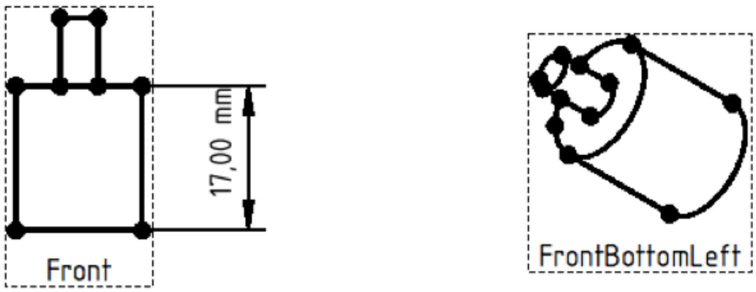


Figure 2: Conductive PLA Electrode Design.

Fused Deposition Modelling (FDM) printer (Delta Wasp 2040, Italy) has been implemented in order to fabricate the reactors. The process used by these printers is simple; in fact, a moving hot end nozzle melt material and deposit it on a flat plate, so that the building process is obtained by adding thin layers one by one. Thanks to the additive process, no wastes are produced and complex forms can be obtained in a short time while and a high level of accuracy (5 μm) is reached. The GCODE needed as input for the 3D printer has been generated by using the open-source software CURA (Ultimaker, USA) that can be considered as a computer aided manufacturing (CAM) software. It has the ability to cut the imported geometry into slices and to generate commands for most of the commercially available 3D printer. Materials used for the reactors is non-toxic with respect to bacterial communities present inside the anodic chamber (PLA, FormFutura, Netherlands). The electrodes are made of conductive PLA (ProtoPasta, USA) with a resistance of 30 ohm-cm. All the requirements are perfectly match by the final prototypes and the exploded and assembled pictures of the single and double chamber MFCs are in figure 3.

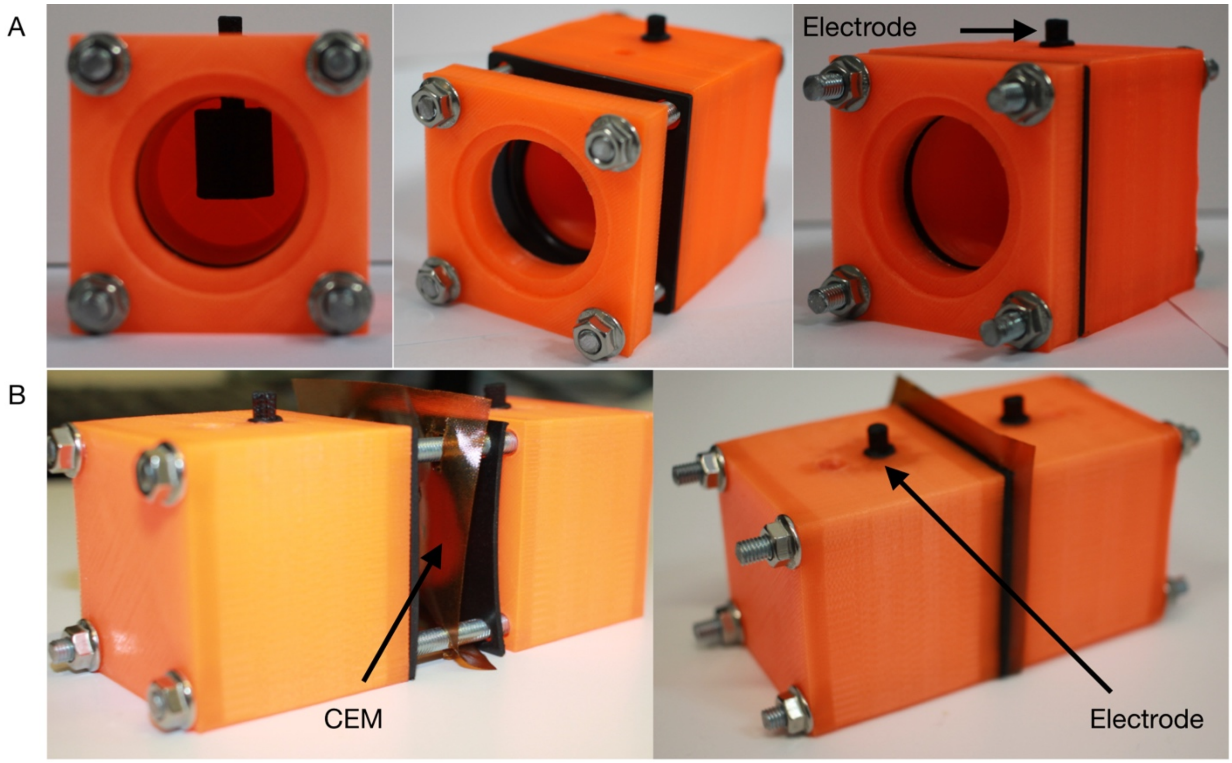


Figure 3:Exploded and Compact view of (A) Single Chamber MFC, (B) Double Chamber MFC.

2.3 Methods

Bacterial community, used for the experimental activities, is composed by bacteria present into a mixture of COMPOST taken from a waste treatment facility located in Caivano (ITALY) and FORSU composed by household vegetable waste for a total mixture volume of 100g (1/2 ratio). That ratio did not change in the two configurations.

Acclimation procedure is conducted in order to reduce the time needed to stabilize the power production [11]. This procedure consists of a filtering step of the bio-waste matter (0.22 μm filter) in order to remove bacteria that could occupies space on the electrodes surface; moreover, the microbial suspension is grown in a mineral medium prepared according the Cheng's method [12]. The nutritive solution is prepared starting from mix between compost and saline solution at 0.9% with a final volume ratio of ¼ (P/V). Electrodes are autoclaved before inserted them into the cells for ensuring that all the surface is clean. In the two chamber configuration, potassium permanganate is used in the cathode chamber as oxidant. Finally, the experiments are conducted considering 24 hours fed batch cycles in which the substrate is replaced with a new fresh medium of the same composition when needed.

3. Results and Discussions

3.1 Testing Procedure

Reactors are left 48 hours in a temperature controlled environment (20 ºC) before starting the acquisitions. An experimental data acquisition system, is used to record the performances of the MFCs, consisting of an embedded system controlled by an Arduino board connected to sensors that recorded voltage and current at each operative condition set. The DAQ, with a sample frequency of 0.1 Hz (10 s), is able to switch automatically the resistance applied at the ends of the electrodes in order to easily obtain polarization curves. In particular, polarization procedure consists in the application of four different resistance (36000-27000-12000-8000 Ω) for 5 minutes each.

The procedure is continuous, so the total time needed is 20 minutes. Finally, the value of resistance that gives the maximum power is applied for four hours in order to test how the response of the same to an extended load.

3.1 Performances

Before obtaining the polarization curves, both the MFCs are left in open circuit mode to be sure that the potential is stable and tests represent the real conditions. Open Circuit Voltage (OCV) is recorded continuously, showing a higher starting potential for the double chamber system (0.95 V) compared to single chamber (0.59 V). Both voltages slightly increased with time, reaching the maximum value at the end of the first day, 1.01 V and 0.61 V respectively. Second day results show that the voltages are stable, because no significant variations are recorded (Figure 4).

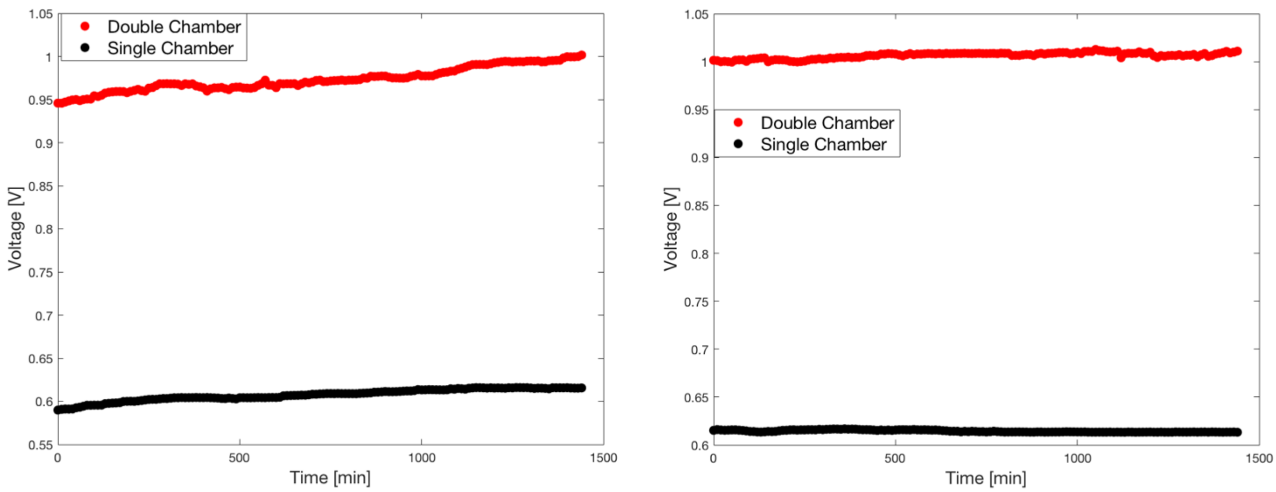
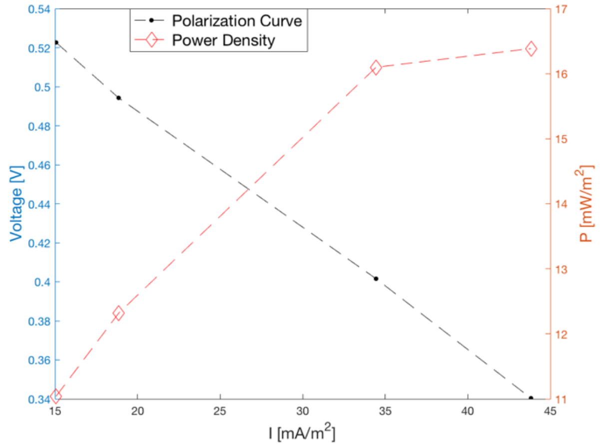
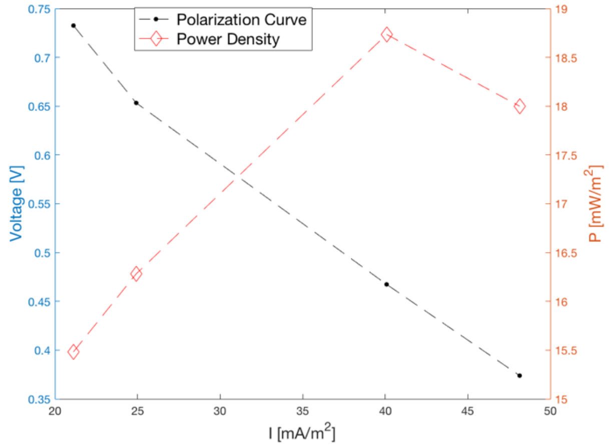


Figure 4: Comparison of the potential (OCV) recorded during Day 1 and Day 2, from left to right respectively.

All the results are normalized by using the active surface area of the anode electrode. The maximum power production is obtained at 8 kΩ for single chamber configuration, reaching the value of 16.4 mW/m^2, while 18.6 mW/m^2 is obtained at 12 kΩ resistance for the double chamber configuration. Moreover, by comparing the power production during the polarization procedure, it has been noted that for low values of resistances the power seems to be the same (Figure 5).





A

B

C

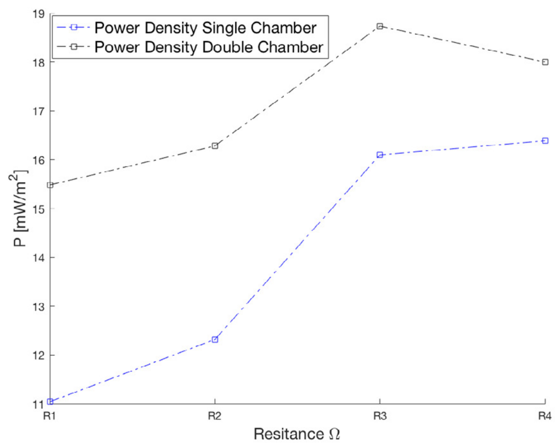


Figure 5:Power density and Polarization Curve for (A) Single Chamber MFC (B) Double Chamber MFC. (C) Comparison between Power

Results are obtained recording the voltage along time when a constant load is applied for many hours. As previously stated, once power and polarization curves are recorded, the load that gives the maximum power is applied for four consecutive hours. Also in this case, the voltage is very stable for both configurations all the time long. Data are illustrated in Figure 6.

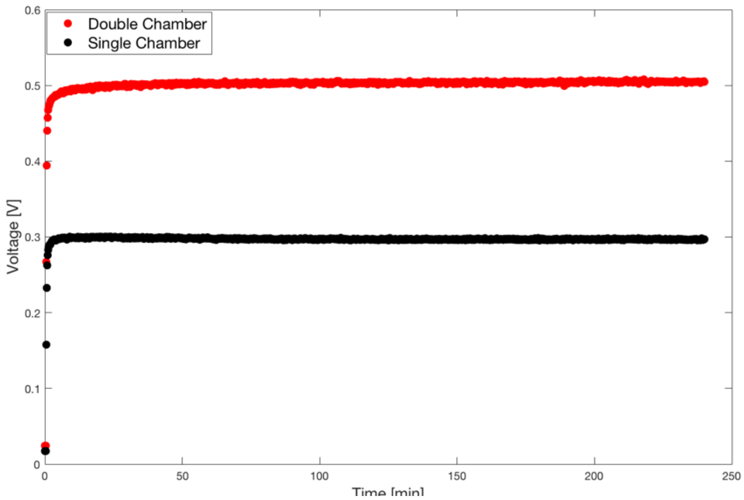


Figure 6: Voltage Recorded by applying a constant resistance (of 12 kΩ for Double Chamber and 8 kΩ for Single Chamber MFCs) for four hours.

4. Conclusions

In this work two different configurations of MFCs reactor have been tested in order to understand the influence of the operative conditions on the power production. Both the reactors have been made by using a 3D printer and a bio-compatible material: PLA. Thus, three electrodes (cathode and anode for the double chamber configuration and anode for single chamber) have been printed by using a conductive PLA (ProtoPasta). This material is suitable for the application in MFC, but improvements are needed in order to obtain better power production.

Results of the experiment show that both configurations are affected by a high internal resistance and, as a consequence, a limited power production has been achieved. As expected, better results are registered for the double chamber, mainly due to the use of CEM and the presence of potassium permanganate at the cathode that, probably, better balanced the redox reactions that occurred. However, this difference is very low (+11%) and the reason can be found in the materials used for the electrodes. AC coated with PTFE electrode (1 Ω resistance), used as cathode in the first configuration, allows better performance than the conductive PLA (400 Ω resistance approximately).

Finally, during the experimental tests, a great stability has been noted.

In this study, the additive manufacturing technologies has been applied as a suitable technology for the fabrication of the MFC in terms of precision and costs. Fast production and optimization have been possible during the designing procedure and a relatively low cost of used material, show the advantages in the application of 3D printing also in this field of sustainable energy conversion systems research.

Acknowledgement

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