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Sediment microbial fuel cell utilizing river sediments and soil

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In this study, results obtained during eighteen months operation of column-type Sediment Microbial Fuel Cells (SMFCs) using river sediments and soil collected near Blagoevgrad, Bulgaria, are presented and discussed. The SMFCs were operated without any supplying of nutrients except periodic addition of water for compensation of the losses from evaporation. Polarization measurements under constant as well as variable load resistances were carried out during SMFCs operation. Higher electric characteristics and efficiency as well as more stable performance were obtained with the SMFC using river sediments. Power supply, constructed of two SMFCs connected in series, is able to supply low-power consumers, which demonstrate the perspectives for further development and application of the technology.

Key words: sediment microbial fuel cells, fresh water sediments, electrogenic bacteria, electricity generation, power supply.

INTRODUCTION

Sediment Microbial Fuel Cells (SMFCs), in which bacteria-assisted conversion of the organic matter in aquatic sediments into electricity takes place, are considered as one of the most perspective representatives of the innovative Microbial Fuel Cell (MFC) technology for power supplying electronics in remote areas or for monitoring of different aquatoria. SMFCs offer a unique opportunity to investigate the efficiency of harvesting electricity from natural systems and the potentials for their real application in power generation or bioremediation in natural environments.

SMFCs are adaptation of reactor-type microbial fuel cells (MFCs), where anode and cathode are contained in one or two closed compartments. The anode is embedded into the sediment placed at the bottom of the reactor and the cathode is immersed in the aerobic water column above the phase boundary with the sediment and the device operates on the potential gradient at a sediment-water interface (Fig. 1). Unlike other MFCs, where proton-exchange membrane (PEM) and mediators are used to create the needed conditions for the bacteria to generate current, SMFCs are very cost-effective since the expensive PEM is not necessary. Sediments themselves act as a nutrient-rich anodic media, inoculum and proton-exchange membrane. This fact allows cheap and easy to build SMFC, which can be used successfully on the field.

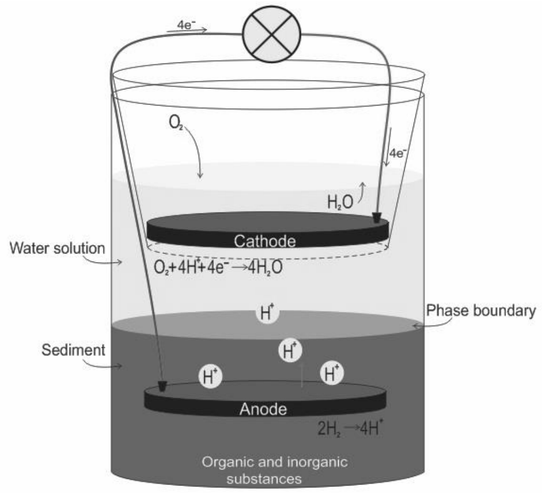

Fig.1. Scheme of SMFC.

The first practical devices to be powered by SMFC technology were reported in 2008 [1]. Meteorological buoys capable of measuring variety of parameters and transferring data via real-time line were powered by benthic SMFCs. Until now, most of the research in the field has been performed with marine sediments [1-3] and very few reports reveal the potential application of freshwater sediments [4, 5] or soil [6, 7] for electricity generation.

In this paper, we report the results from over eighteen months operation of SMFCs using river sediments and soil collected near the town of Blagoevgrad, Bulgaria. The collected data verify the possibility for electricity generation by utilization of these widely spread natural materials and the potential of SMFC technology for power supply application.

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EXPERIMENTAL

River sediments and water were collected from the basin of river Struma (GPS coordinates: 41.990354, 23.067501). Soil samples were taken near Blagoevgrad (GPS coordinates: 42.051209, 23.076744).

Cylindrical plastic vessels were used for construction of single-chamber fuel cells. Half of the vessel volume was fulfilled with the collected sediments/soil. Graphite disk (6 cm diameter, 1 cm thickness; GES Co., apparent density 1.68 g/cm^3, porosity 24%, electrical resistance 6.0 μΩ.m) served as anode was buried into the sediment 3 cm above the vessel bottom. Water from the place of the sample collection was poured above the sediment layer. Graphite cathode with the same dimensions as the anode was placed few millimeters beneath the water surface.

The constructed SMFCs were operated for over 18 months without any supplying of nutrients except periodic addition of water for compensation of the losses from evaporation. Polarization measurements under constant or variable load resistances were carried out periodically using resistor box. The cell voltage was measured with a digital voltmeter MAS- 345 and the current was estimated by using Ohm’s law.

RESULTS AND DISCUSSION

Few hours after the start up the open circuit voltage (OCV) of both types of MFCs stabilized and began to rise slowly. This increase continued till the 15th day for the river sediment MFC and the 20th day for the soil MFC, respectively, after which a slow drop began – Fig.2. When the drop of voltage was significant some measures, such as replacing the water layer, cleaning and shifting the cathode, were taken in order to restore it.

Two months after the start up, the SMFCs were polarized for 20 days using a 510 Ω load resistor. After switching the external resistance, the voltage dropped initially and stabilized at relativity constant values. The estimated mean current values were 0.30 mA for the sediment MFC and 0.15 mA for the soil MFC, respectively, which shows that the electrochemical processes in the sediment MFC take place twice faster.

Right after disconnecting the loads, the OCV of the both MFC rose sharply to 450 mV for the sediment MFC and 300 mV for the soil MFC. After the initial sharp increase, the voltage continued to rise slowly and in the following days, values up to 350 mV for the soil MFC and 770 mV for the sediment MFC were recorded. Such high values had not been achieved to that moment. This fact indicates that the operation of the SMFCs under an electric load stimulates the metabolism and growth of the electrogenic bacteria.

At the end of the fourth month of the MFCs operation an electrical air ozonator was placed near them. Its purpose was to enrich the air around the cells with the highly reactive ozone. This led to an increase in the voltage of both MFCs. The OCV of the Soil MFC reached a record value of 590 mV.

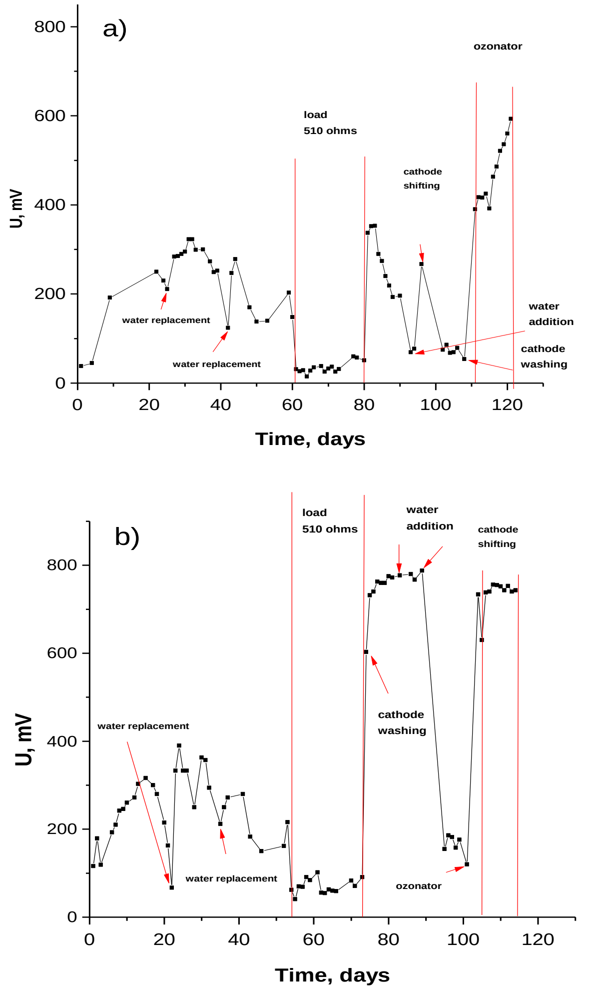
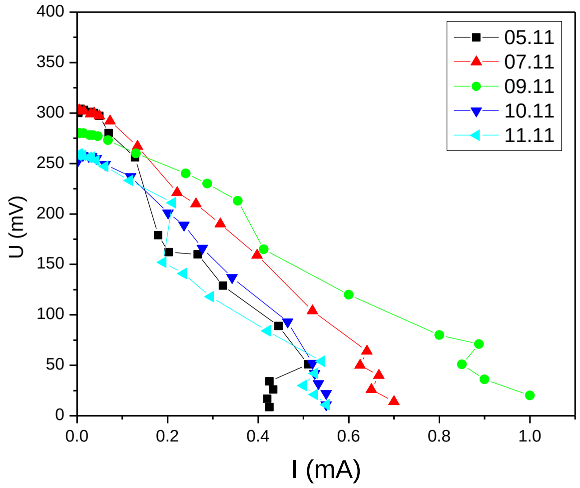


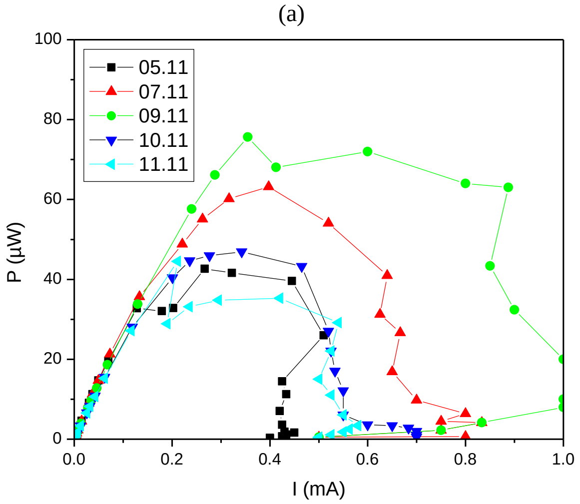
Fig.2. Variation of the measured voltage with time during operation of : a) Soil MFC; b) Sediment MFC.

Along with the voltage measurements at open and closed circuit conditions under constant load, polarization measurements of the studied SMFCs under variable resistances were also carried out. The obtained data were plotted as polarization (*U-I*) and power (*P-I*) curves – Figs. 3 and 4. As seen from the graphs, the sediment MFC generates higher current and power and at the same time the data fluctuations are smaller.

From the linear slopes of the polarization curves, the values of the MFCs internal resistance were calculated. Despite some fluctuations, the estimated values of the internal resistance maintain near constant throughout the whole long-term experiment and they are close to the resistance of the load, at which the maximum power is achieved. This is in accordance with the theory, which claims that the internal resistance of a galvanic element is equal to the external resistance at which the element generates maximum power.



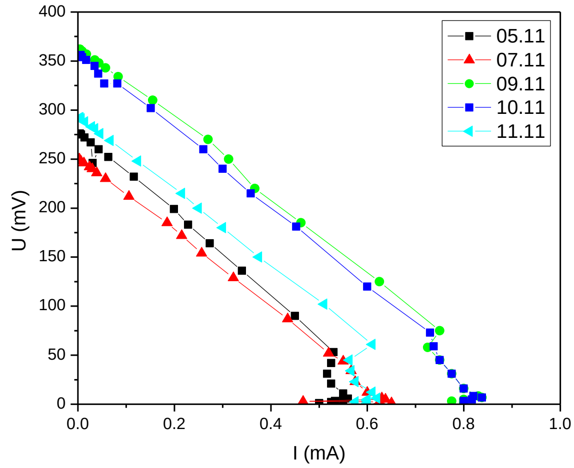
(a)



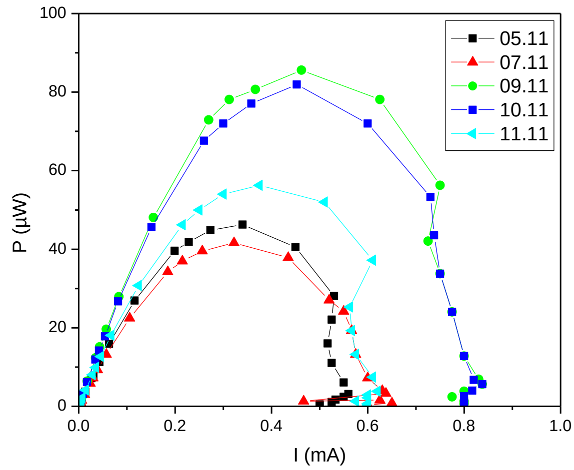
(b)

Fig. 3. a) Polarization curves; b) power curves obtained with Soil MFC at several subsequent days (shown as dates in the legend) starting from the 50th day after the beginning of experiment.

It is worth noticing that the polarization characteristics obtained with Sediment MFC few days after the continuous work under load were much higher than those achieved before. The maximum power reached 410 µW, which is over five times higher than the maximum power measured in the previous period. In contrary, the Soil MFC showed worse polarization characteristics, which indicated that the system was exhausted from the continuous work under a load.



(a)



(b)

Fig. 4. a) Polarization curves; b) power curves obtained with Sediment MFC at several subsequent days (shown as dates in the legend) starting from the 50th day after the beginning of experiment.

After 18 months operation, the SMFCs' outputs have continued to be stable and even grown up. The OCV values 900 mV and 650 mV have been achieved with the Sediment MFC and Soil MFC, respectively [9]. Connected in series, both SMFCs are able to supply low-power consumers – Fig. 5.

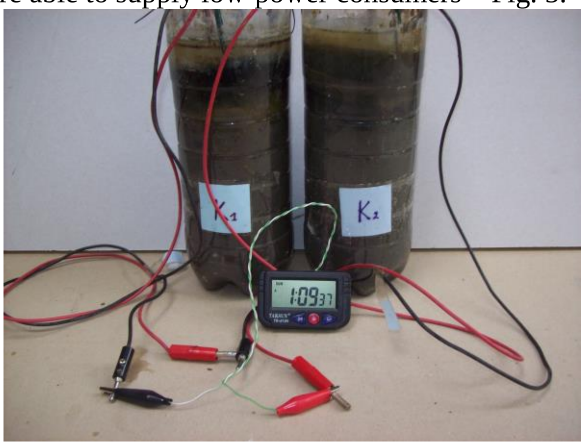


Fig. 5. Connected in series SMFCs supplying digital watch

CONCLUSION

Based on the results obtained in this study, it can be concluded that Sediment microbial fuel cells using river sediments and soil are able to generate current during long term operation. The better performance of the SMFC utilizing river sediments is probably due to the higher content of organic matter as well as to specific electrogenic properties of the bacteria in this type of sediments. The low cost and easy maintenance make sense the further research and development of this promising power supply devices.

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СЕДИМЕНТНИ МИКРОБИАЛНИ ГОРИВНИ ЕЛЕМЕНТИ ИЗПОЛЗВАЩИ РЕЧНИ СЕДИМЕНТИ И ПОЧВИ

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(Резюме)

В настоящата работа са представени и дискутирани резултати от 18-месечни изпитания на Седиментни Микробиални Горивни Елементи (СМГЕ) от колонен тип, използващи речни седименти и почви, събрани от покрайнините на Благоевград. През целия период на изследване горивните елементи работеха без подаване на хранителни вещества, освен периодично добавяне на вода за компенсация на загубите от изпарение. Работата на изследваните СМГЕ бе оценена чрез провеждане на поляризационни измервания както при постоянни, така и при променливи товарни съпротивления. По-добри електрически характеристики, по-висока ефективност, както и по-стабилен режим на работа бяха постигнати със СМГЕ с речни седименти. Захранващ блок, конструиран от два последователно свързани СМГЕ, бе успешно използван за захранване на електрически устройства с малка консумация, което демонстрира перспективите за понататъшно развитие и приложение на технологията.