Seasonal dynamics of plant sediment microbial fuel cell efficiency in a moderate continental climate zone

Rosen Ivanov
Faculty of Geology and Exploration – University of Mining and Geology, Bulgaria
rosen_iv@abv.bg

Abstract: *Plant sediment microbial fuel cells (PSMFC) transform solar energy in an environmentally friendly and efficient way. Their integration in constructed wetlands allows the generation of electricity in parallel wastewater treatment. The work of plant sediment microbial fuel cells is influenced by a number of factors, such as environmental conditions, vegetation type, hydraulic retention time, water flow, the presence of heavy metals and other contaminants in the treated water and others. The purpose of this study is to establish the seasonal dynamics of the effectiveness of PSMFC in Moderate continental climate zone. Seasonal changes in environmental conditions have a significant impact on the generation of energy from the PSMFC in regions with moderate continental climate. With the best electrical parameters the cell is characterized in spring and summer. They are significantly lower in autumn and winter. The effectiveness of PSMFC, both as a treatment facility and as electricity generation is directly related to the vegetation period of the planted vegetation and the effectiveness of the photosynthesis, which are a function of the intensity of the light, the duration of the sunshine and the average daily temperatures.*

Keywords*: PLANT SEDIMENT MICROBIAL FUEL CELLS, SEASONAL EFFICIENCY*

1. Introduction

Electricity production capturing solar energy by living higher plants and in combination with microbial fuel cell is attractive because these systems promise to generate useful renewable energy in sustained manner. [11] These systems are based on natural potential gradient between bottom sediment and upper oxygenic water. Electrons are released by microbial oxidation of organic matter and anaerobic environment of sediment and flow from anode to the cathode through an external circuit. [8] Plants are known to release organics in to soil or aquatic sediments as rhizodeposits, which comprises of carbohydrate, fatty acids, aminoacids, hormones, and organic compounds. This material, rhizodeposits, were then in situ oxidized in the bio anode of the PSMFC and transformed into electrical power. Rhizodeposits account up to 40 % of plants photosynthetic productivity. [7]

Light intensity, quality and photoperiodism are the input signal that can affect the growth of plant and system performace of PMFCs. [2] Effect of an illumination as a light cycle and a power has been studied in the photosynthehtic microbial fuel cell since it is directly linked to the metabolic activity of the microbes. [6] There is an optimal light intensity requirememt for the microbial species and the operational conditions of a system. In addition to this, in PMFCs, light plays an important role for photosynthesis resulting in the concurrent biomass and bioelectricity production. [14] Besides the optimal conditions for the heterogenous microbial community in the rhizosphere, the role of light in maximization of the root exudates with high photosynthehtic activity is an important aspect of research in a PMFC. [13] Therefore, light is not only the limiting factor for power generation while plant physiology also affects the overall performances. Thus, plants having the physiology that can convert the photosynthetic matters in root exudates with the simultaneous absorption by the microbes are well suited to PMFCs since enhanced bioenergy harvest can be achieved. [1] Nevertheless, identification of the optimum light intensity for an efficient photosynthesis, optimum microbial activity, and higher rhizodeposition are the factors that need to be researched intensively within PMFCs. [10]

The species composition of plants depends on climatic conditions and should therefore be carefully selected. The most common aquatic plants are ferns (*Typha latifolia* and *Typha angustifolia)*, reeds (Phragmites), sedges (Carex), peat moss (Sphagnum) and others. In the wetlands there are some algae - *Microspora*, *Oscillatoria*, *Zygnemophyta*. The presence of plants increases bacterial activity as it supplies microorganisms with a source of carbon and energy. [4]

The best prospects for successful energy generation should be in the tropical or subtropical regions of the world, and application of plant sediment microbial fuel cells in frigid climate presents special challenges. Nevertheless, over the past decades, studies in North America and Europe showed that energy generation from PSMFCs may be feasible also in cold climate. [9]

However, there still exists uncertainty about how temperature can affect energy generation processes. In general, plant sediment microbial fuel cells relies largely on biological and biochemical processes, and reliable energy generation is often a function of climate conditions. [5] Nutrient uptake by plants and microbial activity of electroactive bacteria in PSMFC are both directly and indirectly affected by climatic conditions. Direct influence means that the temporal variations in PSMFC performance depend often on the plant physiology, which is governed by solar radiation and temperature. Indirect influence refers to the dependence of biological and biochemical processes on physical conditions; for instance, the low temperature restrains microbial activities and reduces bacterial growth, resulting in low efficiency of PSMFC. [12] These factors make plant sediment microbial fuel cells application more dependent on climatic conditions than standard microbial fuel cells. [3]

As compared to the PSMFC studies in tropical and subtropical regions, there are relatively few published reports in moderate and cold climate. Therefore, this study seeks to highlight the practice, applications, design and operation of PSMFC system in moderate climate. A comprehensive review of the seasonal dynamics of plant sediment microbial fuel cells efficiency in a moderate continental climate zone is presented. The strategies of optimal design and operation of PSMFC for performance intensification in moderate climate are also discussed.

2. Materials and Methods

In order to determine the seasonal dynamics of plant sediment microbial fuel cells efficiency in a moderate continental climate zone, three variants of cells with different vegetation were constructed. The PSMFC consisted of a cylindrical base with a volume of 3650 cm^3.The bottom of the vessel was covered with a layer of gravel with a thickness of 7 cm (≈ 3 kg). The particle fraction was in the range 10-20 mm. In the center of the container was placed a perforated in the base PVC tube with a diameter of 110 mm and a height of 440 mm. At the base of the tube was placed an electrode of stainless steel formed as a spiral whose surface is 400 cm^2 and was covered with a 7 cm layer of gravel. The top the tube was filled with a mixture of sediment and peat in a ratio of 3:1. The device was filled with water and in the surface layer of water was placed a second electrode - the cathode. The cathode was also a spiral and had a surface of 400 cm^2. The first PSMFC was planted with *Carex acuta*, the second with *Carex disticha* and the third with *Typha angustipholia.*

On Figure 1 is shown a scheme of the laboratory model of the PSMFC.

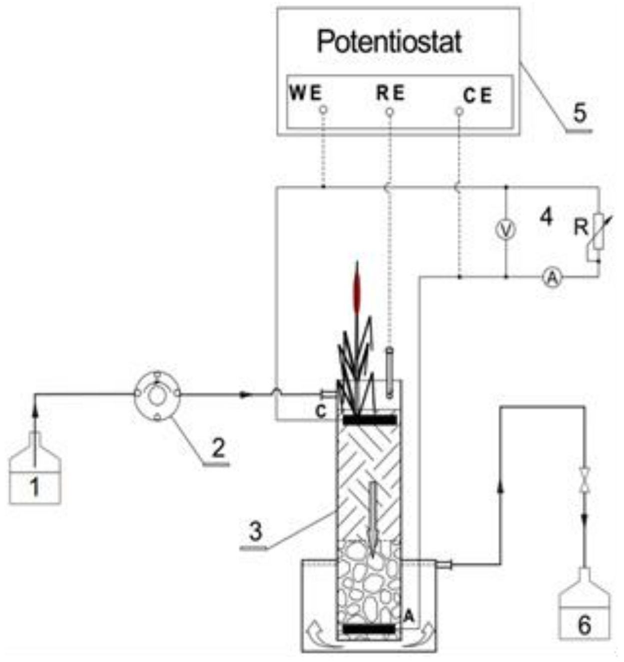

Fig. 1 *Design of Plant sediment microbial fuel cell*
1 – Inflow, 2 – Peristaltic pump, 3 – Plant sediment microbial fuel cell, 4 – Digital multimeter, 5 – Potentiostat, 6 – Outflow, A – Anode C – Cathode

The electrical parameters of PSMFC was measured using portable digital multimeter UNI-T UT33C. A precise potentiometer with maximum value of 13,5 kΩ used for measuring of external resistance.

After stabilization of the electrochemical parameters, the polarization curves of the three variants of PSMFC-s were measured. The best electrical parameters were measured in PSMFC 2 planted with *Carex disticha*, therefore it was selected for further studies. In order to determine the efficiency of the plant sediment microbial fuel cell in a moderate continental climate zone, the electrical parameters of the cell were monitored for one year.

3. Results and Discussion

After a two-month vegetation period, basic electrical parameters were measured in the plant sediment microbial fuel cells. Data for measured electrical parameters of presented on figures 2 and 3. Maximum values of voltage and power density are set in PSMFC 2 - *Carex disticha*. The open circuit voltage in this variant is 791 mV. Maximum power density – 9,2 mW/m^2 is set at an applied voltage of 200 Ω.

Lower values of the above parameters are found in PSMFC 1 planted with *Carex acuta*. In this cell, a maximum open-circuit voltage of 645 mV was measured. The calculated power density reaches 7,27 mW/m^2 at a current density of 23,72 mA/m^2 and an applied resistance of 100 Ω.

PSMFC 3 - *Typha angustipholia* is characterized by the lowest values of the electrical parameters. The open circuit voltage in this variant is 435 mV. The maximum power density of 2,79 mW/m^2 is set at a current density of 10,45 mA/m^2 and an applied resistance of 200 Ω.

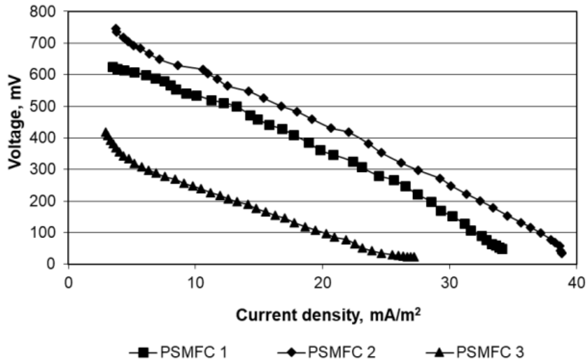

Fig. 2 *Polarization curves of PSMFC-s planted with different vegetation*

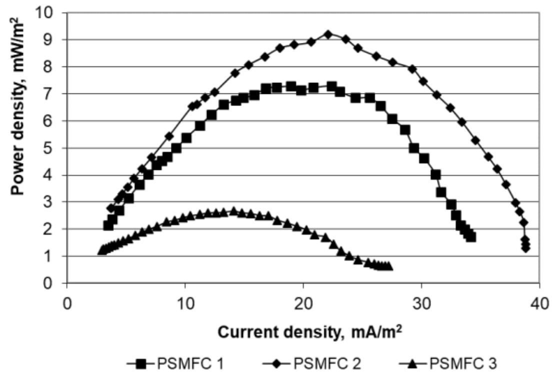

Fig. 3 *Power density of PSMFC-s planted with different vegetations*

Because PSMFC 2, planted with *Carex disticha*. showed the best electrical performance, it was selected for experiments related to the study of the seasonal dynamics of the effectiveness of PSMFC in a moderate continental climate zone. It should also be noted that the vegetation period of *Carex disticha* is about a month longer than *Carex acuta* and *Typha angustipholia*. This would have an additional effect on the seasonal efficiency of the plant sediment microbial fuel cell.

Figure 4 shows the data of the measured open circuit voltage in the cell for one year.

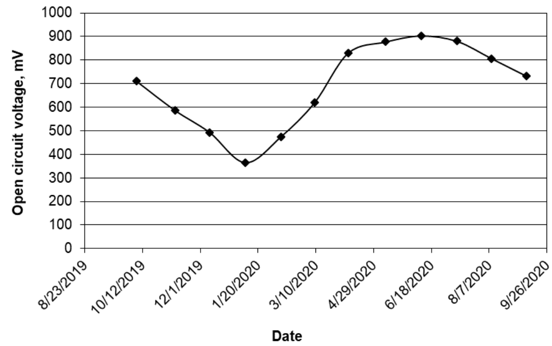

Fig. 4 *Open circuit voltage of PSMFC in different seasons*

The presented data show significantly higher values of voltage in spring and summer, in contrast to autumn and winter. The highest values were measured in the spring, with voltages ranging between 820 mV and 900 mV. Values between 730 mV and 890 mV were measured during the summer. Slightly lower voltage was measured in the autumn. It is in the range of 510 mV - 720 mV. The cell was characterized by significantly lower voltage in winter, with measured values between 380 mV and 580 mV.

Figure 5 presents data on the relationship between open circuit voltage and average daily temperatures for one year.

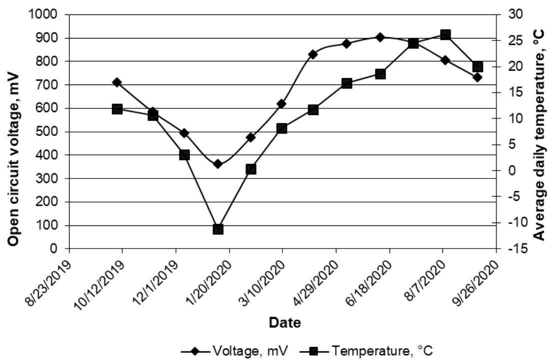

Fig. 5 *Relation between average daily temperatures and open circuit voltage of PSMFC*

The graphs show a clear relationship between average daily temperatures and open circuit voltage. With increasing temperatures in spring and summer, there is an increase in voltage, reaching 890 mV - 900 mV. As the temperatures decrease in autumn and winter, a decrease in the voltage generated by the cell is observed. This dependence is determined by the reduced microbial activity in the anode zone of the plant sediment microbial fuel cell during the cold months. As the temperature increases, the activity of the microorganisms increases, which leads to the generation of a higher voltage in the cell.

As an additional factor should be noted the vegetative period of plants, which through their photosynthesis further increase the voltage of the plant sediment microbial fuel cell.

Figure 6 shows the relationship between the length of the day and the voltage generated by the plant sediment microbial fuel cell.

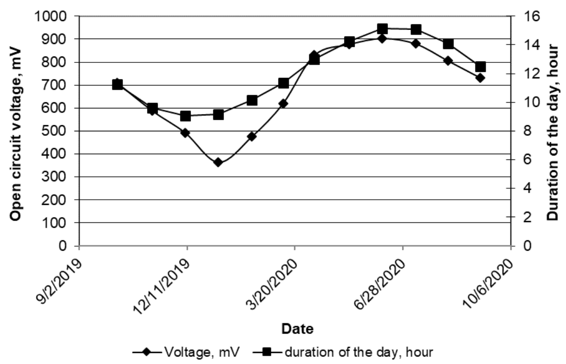

Fig. 6 *Relation between duration of the sunshine and open circuit voltage of the PSMFC*

From the presented data it can be seen that the highest values of open circuit voltage were measured at a day length of more than 12 hours. The generated voltage is in the range 730 mV - 900 mV. In autumn and winter, when the length of the day is less than 12 hours, the values of open circuit voltage range between 380 mV and 700 mV.

The data obtained show a clear relationship between day length and voltage. This indicates that the duration of photosynthesis helps to generate a higher voltage from the plant sediment microbial fuel cell.

Figures 7 and 8 show the measured electrical parameters of the plant sediment microbial fuel cell during the seasons.

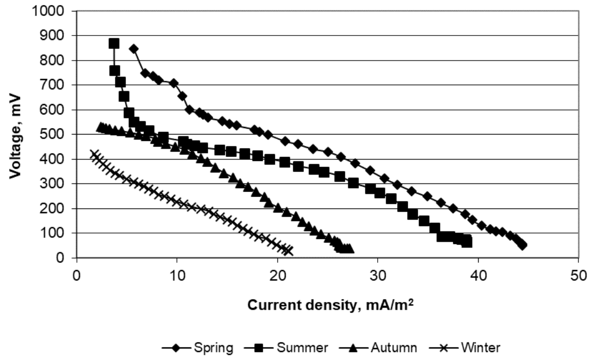

Fig. 7 *Polarization curves of PSMFC in the four seasons*

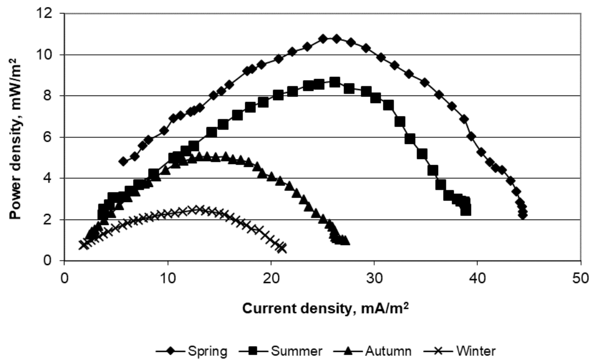

Fig. 8 *Polarization curves of PSMFC-s in the four seasons*

The figures above show that the plant sediment microbial cell showed the highest efficiency in the spring. The voltage in the spring reaches 850 mV. Maximum power density - 10.93 mW m^2 is reached at an applied resistance of 200Ω. The maximum current density reached is 44.5 mA m^2. Slightly lower values of electrical parameters were found in the summer. The maximum power density in summer reaches 8.31 mW/m^2 with a current density of 38.87 mA/m^2 and an applied resistance of 100Ω. The voltage reaches 890 mV.

The plant sediment microbial fuel cell shows significantly lower efficiency in autumn and winter. This shows the significant role of temperature on the activity of microorganisms in the cell, as well as photosynthesis, as factors for higher efficiency of the plant cell.

4. Conclusion

In order to determine the influence of vegetation type on the efficiency of plant sediment microbial fuel cell, three variants with different vegetation were constructed. PSMFC 2, planted with *Carex disticha*, is characterized by the best electrical performance. In this variant, the open circuit voltage of 791 mV was measured, and the maximum power density - 9.2 mW/m^2 was calculated at a load resistance of 200 Ω. Therefore, PSMFC 2 was selected for the next experiments related to the study of the seasonal dynamics of the efficiency of PSMFC-s in a zone with moderate continental climate. Seasonal changes in environmental conditions have a significant impact on the generation of energy from the PSMFC. With the best electrical parameters the cell is characterized in spring and summer, and the maximum power density was reached, respectively 10,71 mW/m^2 and 8,48 mW/m^2. They are significantly lower in autumn and winter. Studies have shown that the effectiveness of PSMFC in a zone with a moderate continental climate is directly related to the vegetation period of the planted vegetation and the effectiveness of the photosynthesis, which are a function of the intensity of the light, the duration of the sunshine and the average daily temperatures.

Acknowledgements

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5. References

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