Effect of light spectrum on the performance of SMFC with microalgae improved cathode

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Abstract- Sediment microbial fuel cells as a renewable energy production system can directly convert chemical energy into electricity. In these cells, the microorganisms present in the anode oxidize organic materials in anaerobic conditions and produce electrons. The generated electrons move to the cathode electrode via an external circuit and reduce the electron acceptor present in the cathode section. In this study, the microalgae *Chlorella* sp. has been used in cathode to produce oxygen, as terminal electron acceptor, during the photosynthesis process. In this study, the effect of three light colors (white, blue or red) at constant intensity (47.33±2.39 µmolphoton $m^{-2}s^{-1}$) was studied. The results showed that the photosynthetic sediment microbial fuel cells (PSMFCs) under red, white, and blue colors produced a maximum pseudo-steady voltage of 99.31±1.48 mV,110.17±1.33 mV, and 95.2±2.85 mV, respectively. Also, maximum power densities of 4.39 mW/m^2, 3.57 mW/m^2, and 1.5 mW/m^2 were obtained. The findings showed that the PSMFC under red color had better performance in terms of electricity generation.

Keywords: Biocathode, Light wavelength, Microalgae, Sediment microbial fuel cell

Introduction

In recent years, microbial fuel cells (MFCs) have received much attention as a source of bioelectricity, and biohydrogen, and are also used in bioremediation and biosensors [1]. These cells directly convert chemical energy into electrical energy. Most of these cells work in anaerobic conditions and some in aerobic conditions [2]. MFCs consist of two chambers, an anode, and a cathode. These two chambers are separated by a membrane. There is an electrode in each of the chambers. Two electrodes are connected by an external electrical circuit. A good anode or cathode electrode should have characteristics such as high electrical conductivity, low electrical resistance, suitable biocompatibility, high chemical stability, non-corrosion, high specific surface area, mechanical strength, and appropriate toughness [3]. Microorganisms in the anodic compartment oxidize organic materials under anaerobic conditions and produce electrons and protons. The proton passes through the membrane and enters the cathode compartment. The electron is transferred to the surface of the cathode electrode through the anode electrode and the electric circuit. There, in the presence of protons, it will reduce the terminal electron acceptor on the surface of the cathode electrode. Electron acceptor can be various substances such as oxygen, ferric cyanide, nitrate, and sulfate, among which oxygen is the best option due to its high reduction potential, availability, and non-production of toxic products. One type of the microbial fuel cells is sediment microbial fuel cell (SMFC), where the anode electrode is placed in a sediment (e.g., sludge or river bottom sediments) and the cathode electrode floats in the water above it. In this type of fuel cells, there is no need for a membrane, and the existence of an oxygen gradient prevents the two phases of the anode and cathode from interfering. Among the advantages of sediment microbial fuel cells are the low operating costs and long lifespan for use in remote marine areas that require a low-voltage but long-life energy source [4]. One of the disadvantages of sediment microbial fuel cells is low voltage and output power, which is the result of different factors such as internal resistance, lack of electron acceptor, and etc.

Supplying oxygen as an electron acceptor in the catholyte is one of the challenges faced by sediment microbial fuel cells. Mechanical aeration has disadvantages such as lack of purity of incoming oxygen, operating costs, and energy consumption, which led to the use of other solutions for oxygen supply. Using microalgae as a catholyte is one of the ways to supply oxygen to the fuel cells, as the growing microalgae produce pure oxygen during photosynthesis. Also, they can consume the carbon dioxide produced during the oxidation of the substrate in anode section. Microalgae fix 25% of atmospheric carbon dioxide [5]. Microalgae growth depends on the species and is affected by factors such as nutrient availability (N, P, K, etc.), temperature, pH, salinity, inorganic carbon, oxygen, light, and CO2 [6].

Meanwhile, light is one of the most important factors in the growth and photosynthesis of microalgae. Light, itself includes three factors of light intensity, light spectrum, and photoperiod. Different microalgae can receive a specific range of light through their photoreceptors and use their energy for photosynthesis. This difference depends on the difference in the pigments and photoreceptors of each species of microalgae [5], [7].

Materials and methods

Microalgae culture

Microalgae strain *Chlorella* sp. has been isolated in Biotechnology Laboratory, Engineering Faculty, Ferdowsi university of Mashhad (Mashhad, Iran) GenBank: MG999574 [8] and was used in this study. It was cultured in both solid and liquid form. To prepare solid culture, agar was mixed with BG11 at a ratio of 1.5% weight/volume and autoclaved. After autoclaving and reaching the temperature of 85 degrees, it was poured into sterilized petri dishes with a diameter of 6 cm. The composition of BG11 medium was: NaNO3 (1.5g/l); MgSO4.7H2O (0.075g/l); K2HPO4.3H2O (0.04g/l); CaCl2.2H2O (0.036g/l); Na2CO3 (0.02g/l); FeCl3 (0.004mg/l); citric acid (0.006 g/l); EDTA

(0.001mg/l) and trace element (1ml/l) containing ZnSO4.7H2O (222mg/l); Na2MoO4.2H2O (39mg/l); CuSO4.5H2O (79mg/l); MnCl2.4H2O (1810mg/l); H3BO3 (2860mg/l) and Co(NO3)2.6H2O (4.9mg/l). After cooling of the agar culture medium in sterile conditions, the microalgae was removed from the solid bank using fildoplatin and was cultured by streaking method on the surface of the solid culture medium. Petri dishes were grown in an incubator under a light intensity of 2500 lux for 7-10 days with a light/dark cycle of 16/8 and then kept in a refrigerator. To prepare liquid culture, 1 liter of BG11 was autoclaved and cooled under sterile conditions. The surface of the Petri dish containing the grown microalgae was washed with 5 ml of BG11 and added to a 1.2-liter photobioreactor, the working volume then adjusted to 1 L using the autoclaved BG11. The initial optical density under 680 nm wavelength was about 0.07 to 0.1. The light intensity in the photobioreactor was 12,000 lux and the light/dark period was 8/16. After about 2 days, the microalgae reached the middle of its logarithmic phase of growth, where it was used for catholyte inoculation purpose.

PSMFC construction and operation

A one-liter plastic beaker was used as the PSMFC system. Each container had a plexiglass cover with a thickness of 3 mm and a diameter of 16 cm. Each electrode was made of circular carbon felt with a 5 cm diameter, 7 mm thickness, and a surface area of 0.005024 cm^2, which firmly attached to a stainless-steel wire. The electrodes were connected by an external resistance of 1500 Ω. 400 ml of homogenized sludge obtained from Parkandabad wastewater treatment facility (Mashhad, Iran) was poured into the bottom of the beaker. The microalgae from the liquid culture were inoculated into the BG11 medium to form 400 ml of catholyte (optical density 0.1 at 680 nm wavelength) and then was gently added to the top of the sludge. The electrodes are set in such a way that the anode electrode was 2.5 cm below and the cathode electrode was 2.5 cm above the surface of the sediment. In this study, 3 PSMFCs each under a different light spectrum and identical light intensities of 47.33±2.39 µmolphoton $m^{-2}s^{-1}$ were used. The light sources were light emitting diodes (LEDs) of white, blue, and red (EPILED, Taiwan).

Analysis

The voltage of each PSMFC the was continuously monitored and recorded using a data logger (Azhand Pazhooh Toos, Iran). Ag/AgCl reference electrode (Azarelectrode, Iran) and multimeter (Ziegler RM-18, Germany) were also used to measure the cathode potential. pH was measured daily by a pH meter (pH Lab-827, Switzerland). The light intensity was measured by a lux meter (Lutron LX-1108, Taiwan) and then converted to the photosynthetic photon flux density unit (PPFD) [9].

Results and discussion

Figure 1 shows the voltage changes over time. In general, with the beginning of the light period and the photosynthesis process in the cathode compartment, the amount of oxygen increases and along with it, the output voltage also increases and reaches a constant value. Then, with the beginning of the dark period and with the lack of microalgae photosynthesis, the oxygen in the cathode decreases, and the output voltage decreases. In the early days, it was observed that the voltages did not create regular peaks, which can be attributed to the uncoordinated activity of the anode and cathode. After the 5th day, all cells had regular activity and reached a pseudo-stable condition. During the first five days, the PSMFCs produced small amount of voltages at the end of the dark cycles, whereas in the next days the voltages reached to zero levels at the end of each dark cycle. The reason was the high activity of microalgae in the early days, which could produce a lot of oxygen in the light phase, and low levels of electron and proton generations in the anode, so that during this period the PSMFCs did not encounter oxygen shortage in the cathodes during the dark period. In the following days, however, due to the better performance of anode compartment, more electrons and protons were produced and in turn the consumption of oxygen in cathode increased, so the cells experienced lack of oxygen at the end of dark cycle, which led to zero voltages The average voltages of the peaks between 5 and 7 days under white, blue, and red light were 110.17±1.33, 95.2±2.85, and 99.31±1.48 mV, respectively.

On the tenth day of the experiments, the polarization test was performed. As can be seen in Figure 1, after polarization, the voltage of the cells under white and blue lights dramatically decreased, but the test did not have any negative effect on the voltage production of PSMFC under red light.

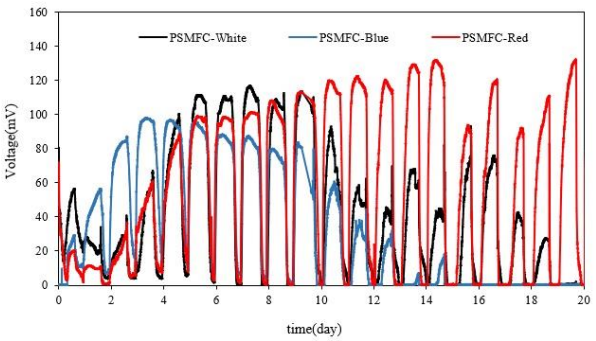

Figure 1 Changes in voltage with time.

Figure 2 shows the polarization curves. It can be seen that the open circuit voltage under white, blue, and red light is reported as 296, 252, and 416 V, respectively. The internal resistances, which were obtained from the slope of the polarization curves in the linear region, were determined to be 1908 Ω, 2547 Ω, and 1190 Ω, for the white, blue, and red light, respectively. Moreover, the maximum current densities under white, blue, and red light were 26.95, 18.46, and 33.68 mA/m^2, respectively.

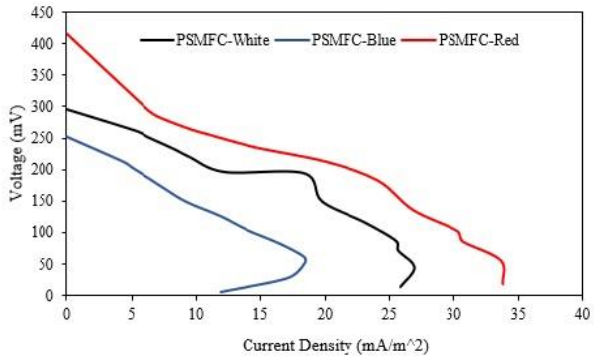

Figure 2 Polarization curve.

Figure 3 shows the power density curves obtained from the polarization results. The maximum power density produced under white, blue, and red light were 3.57, 1.5, and 4.39 mW/m^2, respectively. The results showed that the cell produced a higher power density under red light.

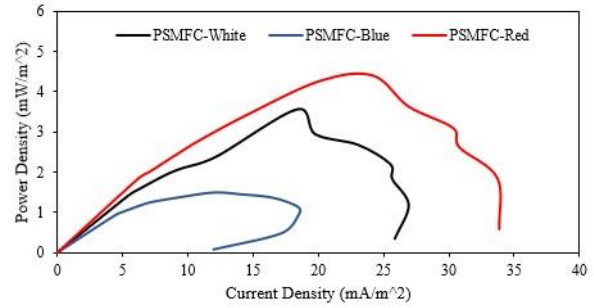

Figure 3 Changes in power density with current density.

Conclusions

In the present study, the effect of the light spectrum that illuminated microalgae in the catholyte of PSMFC systems was investigated. It was demonstrated that the PSMFC under red light could produce a stable voltage for longer period of times and the highest power density compared to PSMFCs with other light spectrums investigated. The results of this study can be helpful for the enhancement of PSMFC performance for electricity generation and bioremediation.

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