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The effect of different light intensities and light/dark regimes on the performance of photosynthetic microalgae microbial fuel cell

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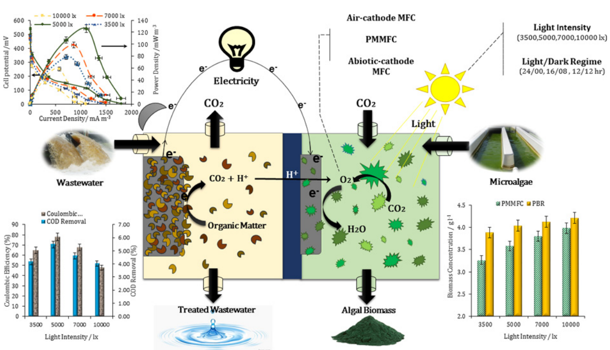
GRAPHICAL ABSTRACT



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ABSTRACT

This study develops a photosynthetic microalgae microbial fuel cell (PMMFC) engaged *Chlorella vulgaris* microalgae to investigate effect of light intensities and illumination regimes on simultaneous production of bioelectricity, biomass and wastewater treatment. The performance of the system under different light intensity (3500, 5000, 7000 and 10,000 lx) and light/dark regimes (24/00, 12/12, 16/8 h) was investigated. The optimum light intensity and light/dark regimes for achieving maximum yield of PMMFC were obtained. The maximum power density of 126 mW m^{-3}, the coulombic efficiency of 78% and COD removal of 5.47% were achieved. The maximum biomass concentration of 4 g l^{-1} (or biomass yield of 0.44 g l^{-1} day^{-1}) was obtained in continuous light intensity of 10,000 lx. The comparison of the PMMFC performance with air–cathode and abiotic-cathode MFCs shows that the maximum power density of air-cathode MFC was only 13% higher than PMMFC.

1. Introduction

Photosynthetic microalgae microbial fuel cell (PMMFC) is an attractive technology in academic research (Baicha et al., 2016; He et al., 2017; Luo et al., 2017; Saba et al., 2017; Saratale et al., 2017) that using microalgae with the aim of supplying substrates in the anodic compartment (Dong et al., 2017; Salar-García et al., 2016; Walter et al., 2015; Xu et al., 2015), oxygen production in cathodic compartment (Colombo et al., 2017; Gajda et al., 2015; Rago et al., 2017), wastewater treatment (Commault et al., 2017; Yang et al., 2018), biofuels production (Khandelwal et al., 2018; Ma et al., 2017; Uggetti & Puigagut, 2016) and carbon dioxide capturing (Hu et al., 2015; Ma

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et al., 2015).

The influence of light availability on the PMMFC performance is introduced as a substantial factor that may affect the microalgae growth as well as the amount of the released oxygen through metabolic pathways and photosynthesis of the microalgae (Luo et al., 2017; Saba et al., 2017; Saratale et al., 2017).

The effect of light intensity (Gouveia et al., 2014; He et al., 2014; Juang et al., 2012; Wu et al., 2014), wave length (Lan et al., 2013), and illumination period (del Campo et al., 2015; Lobato et al., 2013; Wu et al., 2013; Xiao et al., 2012) on photo microbial fuel cells (MFCs) characteristics such as produced power, wastewater treatment efficiency and biomass production were investigated in previous studies (Naraghi et al., 2015).

Wu et al. (2014) studied photo-MFCs performance inoculated with Desmodesmus sp. A8 algae via produced power under different light intensities. They concluded that an increase in the light intensity could enhance electricity production due to the rising of dissolved oxygen production. However, the effect of light intensities on the biomass production and wastewater treatment was not considered.

Gouveia et al. (2014) investigated the effect of two different light intensities on the bioelectricity generation and biomass production in the PMMFC simultaneously using Chlorella vulgaris as biocatalyst in the cathodic compartment. They observed that an increase in light intensity from 26 to 96 $\mu e\, m^{-2} s^{-1}$, leads to significant enhancement (about 6-fold) in power generation. They suggested that there is an optimal light intensity which may be related to microbial and operational conditions. Nevertheless, they did not determine optimal amount of light intensity.

In contrast to this finding, Juang et al. (2012) reported that the PMMFC produced higher power density at lower light intensities. Their results indicated that a MFC in presence of light of 6 and 12 W showed higher potential, power density, coulombic efficiency compared to MFC in presence of light with higher power of 18 and 26 W. The effect of light intensity on biomass production for more clarification was not investigated.

The effect of light/dark cycle on cell performance is another substantial point that could not be negligible in assessment of PMMFC performance. Wu et al. (2013) developed a PMMFC and investigated two kinds of cathode electrodes including carbon paper coated with platinum and carbon felt without platinum coating. A photo tubular reactor as the cathode compartment which uses Chlorella vulgaris as an oxygenator, illuminated continuously and under 16/8 h light/dark cycle at defined light intensity. Although, the produced power density under continuous illumination was 12.7% more than the produced power density under intermittent cycle, but intermittent illumination had positive effect on microalgae healthiness. As the dark period is necessary to maintain the health of the population of photosynthetic microorganisms, a decrease in duration of the light/dark cycle reduces the production of electricity and biomass. Therefore, the performance of the PMMFC under 16/8 h light/dark cycle was reported as optimal condition. It should be noted that in addition to assessment of PMMFC performance involves consideration of wastewater treatment and biomass production, the investigation of these operational parameters are critical that should be considered in future works.

Del Campo et al. (2015) studied the photosynthetic MFC performance under same time of light/dark cycle (i.e. 12/12 h) during 10 months. In spite of the effluent characteristic such as chemical oxygen demand (COD) at the anodic compartment was constant, but during the light phase, the electricity generation was higher than dark phase. This was attributed to photosynthesis of microalgae and oxygen production that facilitated cathodic half reaction. It should be noted that the effect of the intermittent illumination on biomass production and determination optimum light/dark regime were not considered in their experiments.

With regard to the importance of oxygen concentration in cathodic compartment and its critical role in cell performance, Kakarla et al. (2015) studied the MFC that oxygen required for cathode reduction reaction provided from atmospheric and alga breath from alga bioreactor (ABR). The investigation of the effect of different DO concentration on potential, power density and internal resistance of MFCs showed that the MFC with oxygen concentration of 39.2% produced from ABR generated approximately 30% higher power density than MFC engaged with atmospheric.

The review of previous studies that focus on assessment of PMMFC performance, suggest that there is an optimal light intensity and light/dark regime. These depend on the configuration of PMMFC elements, the operational parameters and biological conditions of microalgae species. To the best of author's knowledge, there is no complete study on that involves light intensities and light/dark regimes on PMMFC performance, simultaneously.

The main objective of this study is to present a suitable and complete illumination pattern in terms of electricity generation, wastewater treatment and biomass production simultaneously. The optimum light intensity and light/dark regimes for achieving maximum yield of PMMFC were investigated. An integrated energy system based on MFC and microalgae bioreactor is designed and as well as assessment of microalgae growth to improve the system efficiency, the effect of illumination on dissolve oxygen concentration in cathode compartment, electricity production, wastewater treatment and biomass production in the PMMFC utilizing *Chlorella vulgaris* microalgae were studied. In addition, three different MFC including air–cathode MFC, abiotic–cathode MFC and PMMFC developed to investigate the electrochemical and biological characteristics of all cells under different DO concentrations.

2. Materials and methods

2.1. PMMFC construction

A two-compartment MFC was designed and constructed with plexi glass and the cylindrical anodic and cathodic compartments were fabricated with dimensions of internal diameter of 7.1 cm; exterior diameter of 9 cm and height of 4 cm. The stainless steel mesh as anode electrode (with mesh size of 400, length of 70 cm, width of 3.5 cm, and apparent surface area 245 cm^2) is formed in spirally pattern in the anode compartment and connected to the external resistor using copper wire. Also the stainless steel mesh cathode electrode (with mesh size 400, diameter of 7 cm, width of 3.5 cm and apparent surface area 38.46 cm^2) is formed in circularly and located next to the membrane and connected to the external resistor with copper wire.

The anode and the cathode of the PMMFC were made of stainless steel mesh (SSM). The lower cost and higher mechanical strength compared with conventional material such as carbon cloth and graphite sheet, substantially decreased the overall construction cost and strengthen ease of application for fabrication of the PMMFC.

Nafion 212 with a working area of 38.46 cm^2 was used as the PMMFC membrane. For membrane activation, nafion was pretreated by submerging it into solutions of H_2O_2 3% (v/v), and washing with distilled water. Then, the pretreated membrane was protonated with H_2SO_4 0.5 M and distilled water for 1 h at 80 °C (Ghasemi et al., 2013). Finally, activated membrane was inserted between the anode and cathode compartments.

The structure of abiotic–cathode MFC was the same as the PMMFC structure, but the cathodic compartment of abiotic–cathode MFC contained distillated water and phosphate buffer (4.58 $g\, l^{-1}$ Na_2HPO_4, 2.45 $g\, l^{-1}$ $NaH_2PO_4 \cdot H_2O$, 0.31 $g\, l^{-1}$ NH_4Cl, 0.13 $g\, l^{-1}$ KCl). It should be noted that all parts of the air–cathode MFC was fabricated with the same procedure of the PMMFC and the abiotic–cathode MFC but there was no cathodic compartment for the air–cathode MFC.

2.2. PMMFC microbial culture

The municipal wastewater as PMMFC substrate was obtained from