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Electricity generation by Nannochloropsis oculata providing oxygen at the different growth phases for microbial fuel cell

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***Abstract*—The advantages of *Nannochloropsis oculata* include fast growing and high oxygen production. The amount of oxygen production is higher than the dissolved oxygen saturation value of air in water. Therefore, this study aimed to build a photosynthetic fixed-biofilm microbial fuel cell (P-FMFC) system, which compare different growth period of *N. oculata* as the cathode, and performing power generation. The results showed that: (1) The dissolved oxygen of P-FMFC is 15 mg/L under steady state is better than control (7.1 mg/L); (2) Electricity generation was enhanced significantly with sufficient oxygen as the terminal electron acceptor in the P-FMFC system. Oxygen was provided via photosynthesis with *N. oculata* in the cathode chamber (3)The growth rate of *N. oculata* was intended 0.00754 hr^{-1} when in close circuit, higher than the open circuit 0.00680 hr^{-1}.**

Keywords*—*Nannochloropsis oculata, microbial fuel cell, dissolved oxygen, Electricity gerneration

I. Introduction

Microbial fuel cell (MFC) is an electrochemistry system, which can generate electricity from decomposing organics from microbes [1]. The theory behind electricity generation is that protons (H^+) and electrons (e^-) transferred from anode to the cathode, electrons through an external electric circuit, while the protons are transferred to the cathode through the proton exchange membrane (PEM). MFC is not only a new energy conversion system, but also is an environmentally friendly technology [2].

In the mass transfer process of dissolving gaseous oxygen in water, there is an obstacle to be overcome: water film [3]. This indirectly leads to low electricity generation efficiency of MFC system. In a traditional MFC system, the way to increase electricity generation efficiency is to increase cathode dissolved oxygen content using artificial aeration[4]. However, artificial aeration causes higher costs. Thus, a better way is to use an acceptor in cathode chamber with unfailing supply of electrons.

Nannochloropsis oculata include fast growing and high oxygen production through photosynthesis in the cathode chamber[5]. The amount of oxygen production is higher than the dissolved oxygen saturation value of air in water. It is suitable for MFC systems which require high oxygen content to reduction. The microalgae can provide oxygen by photosynthesis, hence the microalgae will set in cathode chamber [6].

There were two stages in this study. In the first stage, the electricity generation efficiencies with dissolved oxygen *N.* and artificial aeration as the electron acceptor. In the second stage, the electricity generation efficiencies and features of growth of *N. oculata* in different growth phases were discussed.

II. Materials and Methods

A. *P-FMFC setup*

The microbial fuel cell (Fig. 1) used in this study was made of polymethylmethacrylate (PMMA), with a PEM membrane (Nafion 117, Dubound) between two chambers. The volumes of both chambers were 630 cm^2. For each chamber, there were 6 vents for the purposes of electrode connection, oxygen measurement, and sample collection. Carbon rods were used for both cathode and anode.

Anodes of MFCs were inoculated bacteria (from domestic wastewater, Yuntech, Taiwan) and using glucose as fuel.The bio-carrier of anode was a filter material (ceramic ring) for microbes growing. The cathode of P-EMFC is *N. oculata* with optical density 0.2 at 683 nm [7], and with white LED light (3200 Lux). The dissolved oxygen contents and electricity generation efficiencies were analyzed and recorded. This study built a photo fixed-biofilm microbial fuel cell (P-FMFC) and conducted experiments with different cathode chamber environments (buffer solution and *N. oculata*)

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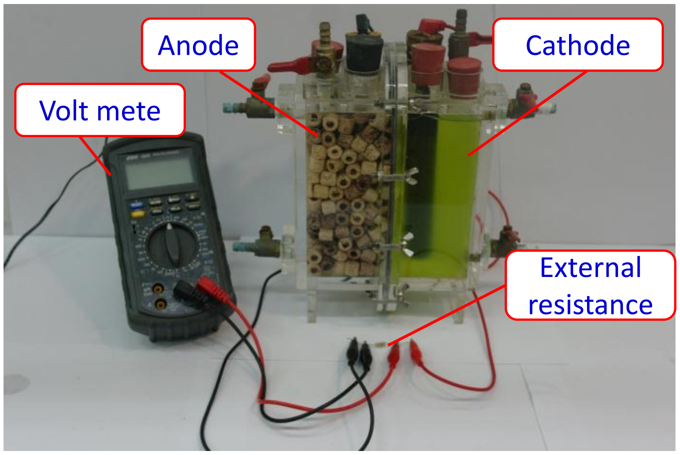

Fig. 1 The device of two chamber P-FMFC used for different growth phases tests.

In the anode chamber, the fuel used was artificial waste water with the main composition of glucose. The items measured in the system include cathode dissolved oxygen content and electricity generation efficiency (voltage, open circuit potential, open circuit potential (OCP) experiment, columbic efficiency, and internal resistance).

B. *Measurements*

When both the FMFC and the P-FMFC were running, the dissolved oxygen contents in the cathode were measured using a DO meter (YSI 550A, USA). An vacuum pump (UNIV-A α-9000, Taiwan) was used for artificial aeration for the cathode of the FMFC system, with the air flux of 1.2 vvm. Voltage outputs were recorded 15 min using digital electronic multimeter (CHY-48R, Taiwan). Current (I) was calculated according to $I=V/R$, where V is voltage, R is external resistance. Current density (CD) and power density (PD) was calculated according to $CD=I/A$ and $PD=IV/A$., where A is surface of anode.

Open circuit were determined by varying resistance between the electrodes stepwise from 3 kΩ to 1 Ω with a pause at each resistance over 15 min for each resistor to ensure a stable voltage. The internal resistance of the P-FMFC was estimated according to $R=(V_r-V_o)/I$, where V_o is the open circuit potential, V_r is the potential across the external resistance.

C. *Source of bacteria and microalgae*

The medium (anolyte) used to grow the bacteria contained: $C_6H_{12}O_6$: 2.0 g/L, $CaCl_2 \cdot 2H_2O$: 0.1 g/L, KCl: 0.1 g/L, $MgCl_2 \cdot 6H_2O$: 0.1 g/L, $MgSO_4 \cdot 7H_2O$: 0.1 g/L, $MnCl_2 \cdot 4H_2O$: 0.005 g/L, NaCl: 0.1 g/L, NaH_2PO_4: 0.6 g/L, $NaHCO_3$: 2.5 g/L, $NaMoO_4 \cdot 2H_2O$: 0.001 g/L, NH_4Cl: 1.5 g/L. The medium was adjusted to pH 7 with NaOH. The catholyte (buffer solution) was NaCl: 50 mM and NaH_2PO_4: 100 mM, the medium used to grow *N. oculata* is according to Walne's medium [8].

III. Results and Discussions

A. *Comparison of the Cathode Dissolved Oxygen between the FMFC System and P-FMFC System*

According to the results of the cathode dissolved oxygen experiment, the P-FMFC system was a lot higher than that of the FMFC system (Fig. 2). Due to the limitation of Henry's law, the highest dissolved oxygen content could not exceed the saturation concentration of the states (temperature, salinity, and partial pressure of oxygen of atmosphere) at that time, which was about 7.1~7.8 mg/L. In the P-FMFC system, the oxygen generated through the photosynthesis of the *N. oculata* could efficiently increase the dissolved oxygen content in the cathode. In the stationary phase, the dissolved oxygen content could be increased to 10~15 mg/L. After the P-FMFC system ran for 500 hours, the dissolved oxygen content suddenly dropped. This was when the death phase started when the saturation concentration of the *N. oculata* was reached.

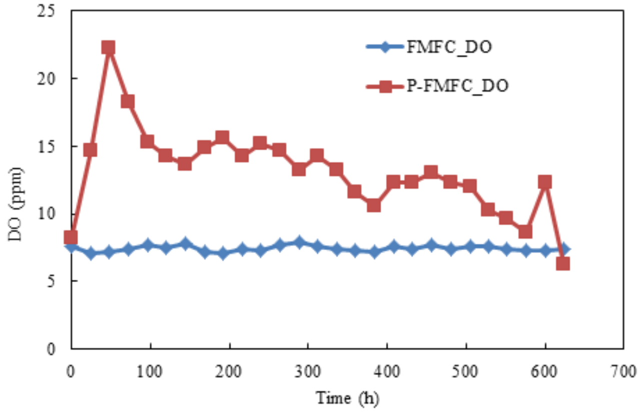

Fig. 2 Results of the cathode dissolved oxygen (P-FMFC and FMFC)

B. *Comparison of the Electricity Generation Efficiency between the FMFC System and the P-FMFC System*

The electricity generation efficiencies of the P-FMFC system were higher than the FMFC, and the maximum power density and current density were higher with the P-FMFC system as well. Photosynthesis of the algae increasing the dissolved oxygen content in the cathode chamber (Figure 2), leading to significant increase in the binding efficiency of electrons, hydrogen ions, and dissolved oxygen. Reaching the maximum value in the stationary phase of the *N. oculata* of P-FMFC, the voltage increased 26%, the current density increased 40%, the maximum power density increased 76%, and the internal resistance reduced by 51% (Table 1).

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TABLE 1 COMPARISON OF THE ELECTRICITY GENERATION EFFICIENCY BETWEEN THE FMFC SYSTEM AND THE P-FMFC SYSTEM

Run	Optimal external resistance (Ω)	Voltage (mV)	Current density (mA/m^2)	Maximum power density (mW/m^2)	Internal resistance (Ω)	Coulombic efficiency (%)
FMFC	91	163	144	23.6	160	0.77
P-FMFC	82	206	202	41.6	77.8	1.47

C. *Comparison of the Electricity Generation Efficiency with P-FMFC in Various Phase*

This study aimed to find the characteristics of electricity generation in various growth phase. The phase discussed included (1) buffer solution (control), (2) lag phase, (3) accelerating growth phase, (4) log phase, and (5) stationary phase (Table 2).

According to the result of the OCP experiment, given the external resistance of the FMFC of 91Ω, the maximum power density was 23.6 mW/m^2, the voltage was 163mV, the current density was 144 mA/m^2, the internal resistance was 160 Ω, and the columbic efficiency was 0.77%. With P-FMFC, during the accelerating growth phase of the *N. oculata* (the system was built for 24 hr), with the concentration 0.321 mg/L, given the external resistance of 91 Ω, the maximum power density was 26.7 mW/m^2, the voltage was 174 mV, the current density was 154mA/m^2, the internal resistance was 145 Ω, and the columbic efficiency was 0.85%. With P-FMFC, during the accelerating growth phase of the *N.oculata* (the system was built for 126 hr) with the concentration 1.32 mg/L, given the external resistance of 100 Ω, the maximum power density was 30.5 mW/m^2, the voltage was 195 mV, the current density was 157 mA/m^2, the internal resistance was 148 Ω, and the columbic efficiency was 0.88%.

With P-FMFC, during the log phase of the *N.oculata* (the system was built for 288 hr, with the concentration 2.33 mg/L), given the external resistance of 82 Ω, the maximum power density was 40.4 mW/m^2, the voltage was 203mV, the current density was 199 mA/m^2, the internal resistance was 80.9 Ω, and the columbic efficiency was 1.18%. With P-FMFC, during the stationary phase of the *N.oculata* (the system was built for 378 hr), with the concentration 2.75b mg/L), given the external resistance of 82 Ω, the maximum power density was 41.6 mW/m^2, the voltage was 206 mV, the current density was 202 mA/m^2, the internal resistance was 77.8 Ω, and the columbic efficiency was 1.47% (Fig. 3 and Fig. 4)

TABLE 2 COMPARISO COMPARISON OF THE ELECTRICITY GENERATION EFFICIENCY WITH P-FMFC IN VARIOUS PHASE

Run	Optimal external resistance (Ω)	Voltage (mV)	Current density (mA/m^2)	Maximum power density (mW/m^2)	Internal resistance (Ω)	Coulombic efficiency (%)
Buffer solution	91	163	144	23.6	160	0.77
Lag phase	91	174 (+6.7%)	154 (+6.9%)	26.7 (+13%)	145 (-9.4%)	0.85 (+10%)
Accelerating growth phase	100	195 (+20%)	157 (+9.0%)	30.5 (+2.9%)	148 (-7.5%)	0.88 (+14%)
Log phase	82	203 (+24%)	199 (+38%)	40.4 (+71%)	80.9 (-49%)	1.18 (+53%)
Stationary phase	82	206 (+26%)	202 (+40%)	41.6 (+76%)	77.8 (-51%)	1.47 (+90%)

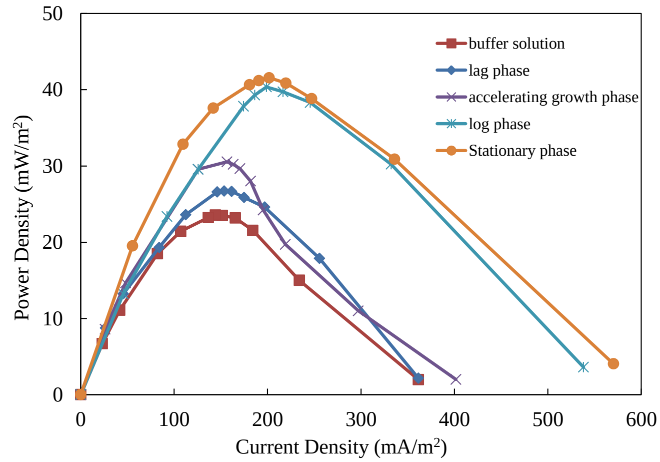

Fig. 3 Power density curves

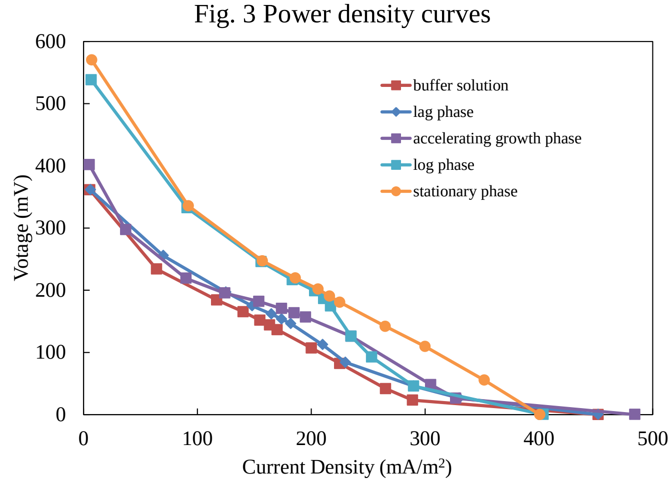

Fig. 4 Polarization curves

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IV. Conclusion

This study has demonstrated the characteristics of using *N.oculata* as cathode in P-FMFC of electricity generation in various growth phase. The fixed-biofilm as anode, which generate a stable power. During *N.oculata* of stationary phase to the catholyte increased open circuit potential more than did aeration of the cathode chamber. In the future, this study can be applied in other MFC which using algae as cathode, not only provided oxygen but also harvest biomass simultaneously.

Acknowledgment

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