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Performance of Constructed Wetland-Microbial Fuel Cell for Promoting Nutrient Removal and Electricity Generation

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Abstract—Under the background of carbon neutrality, the constructed wetland-microbial fuel cell coupled system (CW-MFC) has attracted more and more attention in wastewater treatment. This study, the CW-MFC was developed for promoting nutrients removal in wastewater and electricity generation. The results showed that the average removal efficiencies of COD, NH_4^+-N and TP in CW-MFC were 85.20%, 75.99% and 59.20%, respectively. While the average removal efficiencies of COD, NH_4^+-N and TP in CW were 78.05%, 70.88% and 50.80%, which were all lower than those in CW-MFC. In addition, the maximum output voltage of 331 mV was achieved in CW-MFC, which could be used for the running of wastewater treatment plant in turn and further reduce the consumption of fossil fuel. Accordingly, the maximum power density of the CW-MFC system reached to 107.54 mW m^{-3}.

1. Introduction

The application of constructed wetlands (CWs) has been obtained more attentions due to low investment and operating cost, easy maintenance and no secondary pollution [1]. While potentials of the chemical/organic energy existed in wastewater are always been ignored. And the target of carbon neutrality of 2060 will inevitably result in profound change of wastewater treatment. Therefore, it is necessary to develop a sustainable and low carbon emission technology which can efficiently remove nutrients from wastewater, and reduce the consumption of fossil fuel for the running of wastewater treatment.

Microbial fuel cell (MFC), which can recover renewable energy from waste organic sources and convert chemical energy into electrical energy during wastewater treatment, has attracted more attention of researchers in recent years [2, 3]. Therefore, the integration of CW and MFC, which shows the prospect for traditional CW's updating, owns the unique features of treatment efficiency enhancement and extra energy production [4, 5]. In this study, the CW-MFC coupled system was constructed to promote the nutrients removal and generate the electricity.

2. Materials and Methods

2.1 Experiment setup

The CW-MFC and CW reactors were constructed with dimensions of ϕ 0.2 m × 0.37 m. From the bottom upward, the substrates were pebbles, activated carbon and quartz sands in turn, forming 4 L working volume. Cannas were planted into the layer of quartz sands as the CW plants. In the CW-MFC, carbon felt was used as the air-cathode on the top of reactor, activated carbon was the anode. The anode and cathode were connected by titanium wire through an external circuit with a load of 1000 Ω. The inoculums of two reactors were come from a domestic wastewater treatment plant (Hefei, China). The synthetic wastewater, which contained glucose, 200 mg L^{-1}; $(NH_4)_2SO_4$, 37.71 mg L^{-1}; NaH_2PO_4, 32.44 mg L^{-1}; Na_2HPO_4, 17.95 mg L^{-1} [6], was pumped continuously into the reactors from the bottom after inoculation. The hydraulic retention time (HRT) was 24 h. The data acquisition module (DAM-3055, Art Technology Co. Ltd, China) was used to record the voltage data of closed-circuit reactor.

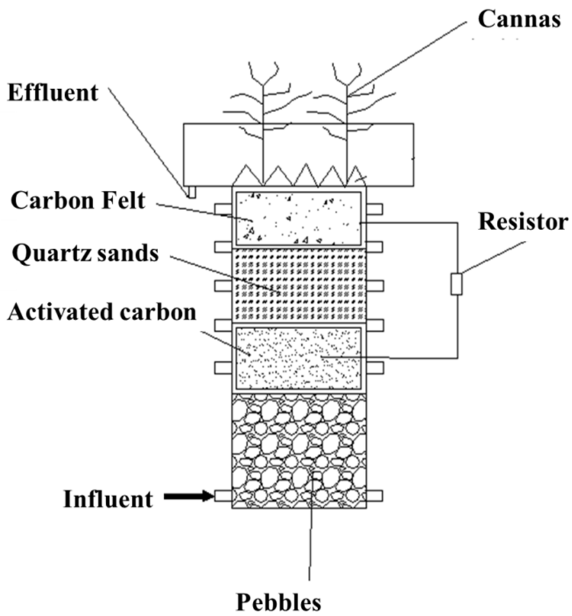

Fig.1 The structure of the CW-MFC

2.2 Analysis and Calculations

The obtained water samples were filtered by a 0.22 μm membrane and stored at 4 °C before analysis. The water quality index (COD, NH_4^+-N, and TP) were measured by the standard method (State Environmental Protection Administration, 2002).

The power density (mW m^{-3}) was calculated as follows:

$$P = \frac{{U_{cell}}^2}{R_{ex}V_{anode}} \tag{1}$$

where U_{cell} is the cell voltage (V), which was obtained from the data acquisition module, R_{ex} is the external resistance (Ω), V_{anode} is the volume of the anode zone of the CW-MFC.

The polarization curve was obtained by using different resistances between 100,000 and 5 Ω to determine the maximum power density and current density.

3. Results and Discussions

3.1 Nutrients removal

The COD removal efficiencies of the two reactors were shown in Fig. 2A. The influent and effluent

COD concentrations of CW system were 189.4±6.97 mg L^{-1} and 40.48±8.9 mg L^{-1}, respectively. The average COD removal rate of CW system is 78.05% (Table 1), while the influent COD concentration of CW-MFC system is 189.27±7.89 mg L^{-1}, and the effluent COD concentration is 29.39±5.11 mg L^{-1}. The average COD removal rate of CW-MFC system is 85.20%, which was higher than that in the CW. The results showed that the CW-MFC system could effectively improve the removal of COD due to the fact that the organic matter in the wastewater not only provided carbon source for the microorganisms in CW, but also used as carbon source and electron donor for the electricity producing microorganisms on the electrode surface of MFC. Oon et al (2018) also found that the existence of external circuit of MFC promoted the electron transfer process thus increased the redox reaction rate of the system [7].

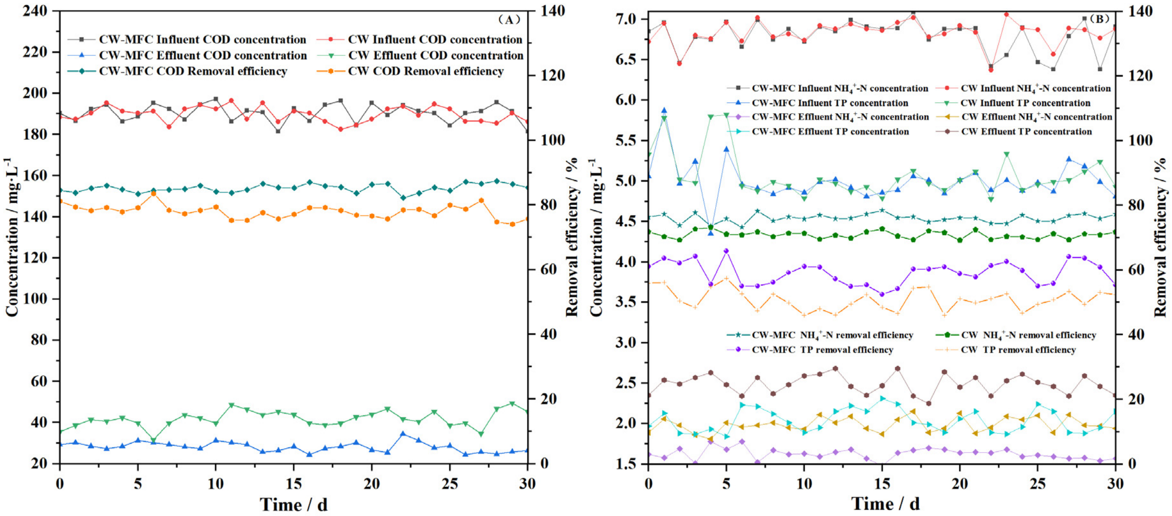

Fig.2 (A) COD and (B) nitrogen and phosphorus removal performances in CW-MFC and CW

As shown in Fig. 2B, the effluent NH_4^+-N concentrations of CW-MFC and CW decreased from 6.74±0.36 mg L^{-1} and 6.72±0.35 mg L^{-1} to 1.65±0.14 mg L^{-1} and 1.98±0.17 mg L^{-1}, respectively. The average removal efficiency of NH_4^+-N of CW-MFC was 75.99%, which was higher than that of CW by 70.88% (Table 1). The results showed that CW-MFC system had good removal performance for NH_4^+-N. The alternation of anaerobic and aerobic reactions is the key factor for the biological removal of nitrogen. In this study, a small amount of dissolved oxygen was carried into the bottom of the reactor with the influent of sewage, and nitrification could take place to remove a small part of ammonia nitrogen. Ju et al (2014) found that part of NH_4^+-N in the influent was degraded or transformed by the anammox bacteria due to the anoxic environment in the bottom of reactor [8]. In addition, owing to the photosynthesis of wetland plants, the roots of plants in the cathode layer could release oxygen, which promoted the reduction of NH_4^+-N by autotrophic nitrifying bacteria. On the other hand, TP concentration in effluent of CW-MFC and CW decreased from 5.11±0.76 mg L^{-1} and 5.31±0.52 mg L^{-1} to 2.08±0.24 mg L^{-1} and 2.47±0.22 mg L^{-1}, respectively (Fig. 2B). As shown in Table 1, the average removal efficiency of TP in CW-MFC was 59.20%, which is slightly higher than that in CW (50.80%). The slight difference between CW-MFC and CW might be due to the influences of plants on TP absorption and the adsorption and precipitation of substrates [9].

Table 1 Mean values of COD, nitrogen and phosphorus removal efficiencies in the CW-MFC and CW

Parameters	CW-MFC	CW
COD removal (%)	85.20%	78.05 %
NH_4^+-N removal (%)	75.99%	70.88%
TP removal (%)	59.20%	50.80%

3.2 Electricity generation and Electrochemical properties

The electricity generation performance of CW-MFC was shown in Fig. 3A, and the maximum output voltage reaches 331 mV, which indicated that CW-MFC could convert chemical energy into electric energy with nutrients removal. This was similar to the results obtained by Srivastava et al. (2015) [10]. The results revealed that CW-MFC was a new environment-friendly coupled technology which could recover energy and further reduce the carbon emission during the sewage treatment.

The polarization tests of CW-MFC were evaluated at the end of the experiment as shown in Fig. 3B. The polarization curve could provide very important information on major losses which might adversely affect the performance of electricity formation. The voltage of CW-MFC decreased with decrease in the loads of external resistances following the traditional trend [11]. The results suggested that the CW-MFC endured three major losses of activation, ohmic and concentration [12]. Similar results were also reported by other studies [10, 11]. The maximum power density was 107.54 mW m^{-3}, which was higher than that in previous experiment [10].

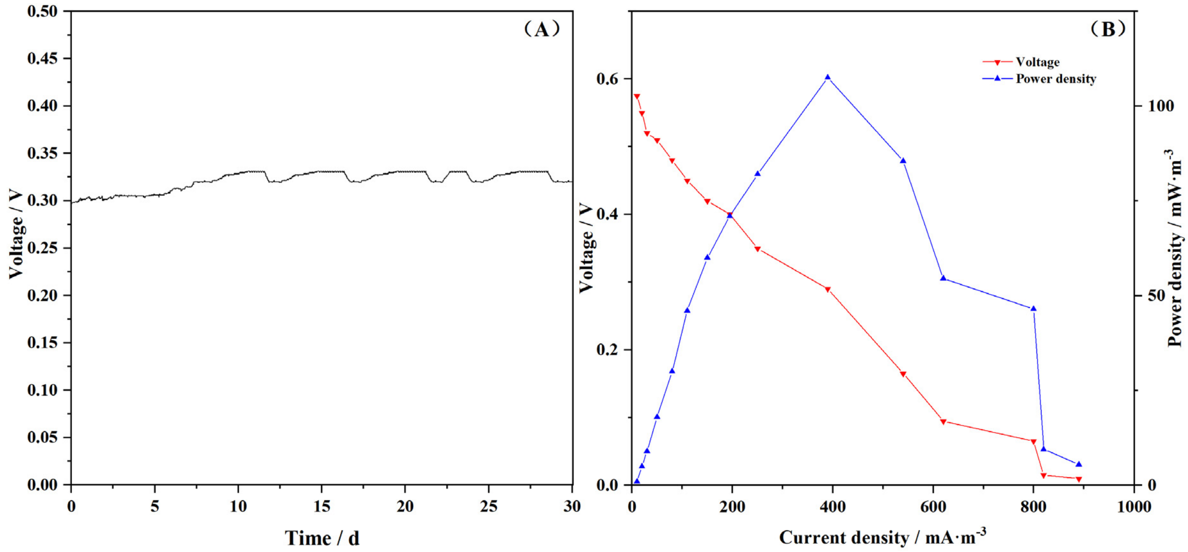

Fig. 3 (A) Electricity generation and (B) power density and polarization curve of CW-MFC.

4. Conclusions and outlook

This study successfully constructed the CW-MFC system and showed higher performance compared with CW system in terms of nutrients removal efficiency and electricity generation. The average removal efficiencies of COD, NH_4^+-N and TP in CW-MFC system were 85.20%, 75.99% and 59.20%, which were all higher than those in CW. Those might be because the organic matter in the wastewater provided carbon source for the microorganisms and electron donor for the electro- microorganisms on the surface of MFC electrode. In addition, the maximum output voltage reaches 331 mV. Accordingly, the maximum power density of the CW-MFC system reached to 107.54 mW m^{-3}. Therefore, CW-MFC could be a promising technology of sewage treatment, which targets to low-carbon lifestyle and carbon neutrality.

However, CW-MFC is still in the stage of lab-scale and many problems in details should be examined during its development including the bioelectricity generation performance, mechanistic information and pathway of the respective species. In order to achieve the practical application, further investigations on these aspects are needed to be warranted.

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