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The influence of microbial synergistic and antagonistic effects on the performance of refinery wastewater microbial fuel cells

Xuan Guo, Yali Zhan, Chunmao Chen, Lijie Zhao, Shaohui Guo*

State Key Laboratory of Heavy Oil Processing, Beijing Key Lab of Oil and Gas Pollution Control, China University of Petroleum, 18 Fuxue Road, Changping District, Beijing 102249, PR China

HIGHLIGHTS

- Microbial synergistic and antagonistic effect does exist among diverse microbial strains in MFC.
- Microbial synergistic and antagonistic effect can directly influence key performances of MFC.
- Microbial synergistic effect improves performance of MFC but antagonistic effect degrades it.
- Petroleum hydrocarbons degradation by different microbial strains is different.

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ABSTRACT

This study provides a preliminary investigation of the synergistic and antagonistic effects of different microbial strains and their influence on electricity generation and wastewater treatment performances in microbial fuel cells (MFCs). Microbial metabolic characteristics of petroleum hydrocarbon pollutants are studied simultaneously to provide further insight into how microbial synergistic and antagonistic effects influence MFCs. We observed a synergistic effect between *Paenibacillus sp.* and *Deinococcus sp.* and an antagonistic effect between *Microbacterium sp.* and *Paenibacillus sp.* and *Deinococcus sp.* The microbial synergistic and antagonistic effects significantly influenced MFC performance directly. The best MFC performance was observed with *Paenibacillus sp.* + *Deinococcus sp.* due to their synergistic effect, where the power density output reached 102.93 mW m^{-3}, and the oil removal rate was 85.56 ± 1.10%. However, the performances of MFCs inoculated with *Microbacterium sp.* were considerably poorer because of its antagonistic effect on the other microbial strains, where the lowest power density output was 24.93 mW m^{-3}, and the oil removal rate was 65.88 ± 1.10%. The degradation characteristics of petroleum hydrocarbons differ between microbial strains; thus, the relative results can provide further insight into how microbial synergistic and antagonistic effects influence MFCs.

1. Introduction

A large number of chemical bond energy is stored in wastewater. Researchers have demonstrated that at least 2.2×10^{18} J of chemical bond energy is stored in municipal wastewater generated in the world every year, which is equivalent to approximately 70 GW of electrical energy and 52 million tons of oil [1]. This estimate is based on chemical bond energy stored in municipal wastewater alone and does not include agricultural wastewater and industrial wastewater. Therefore, chemical bond energy recovery together with wastewater treatment can be significant and could be applied to solve global issues, such as energy shortage and environmental pollution [2,20].

A microbial fuel cell (MFC) is a special fuel cell device that uses electricigens as a cheap anode catalyst. MFCs can directly convert chemical bond energy to electrical energy together with the purification of wastewater [3]. One of the key factors limiting the practical industrial application of MFC technology is the low power output and energy recovery efficiency [4–7]. How to improve the electricity generation and energy recovery performance is an important subject among MFC research fields. Various factors can influence the MFC performance, such as reactor configuration [8], electrode material [9], separating medium [10], anolyte pH [11], external resistance [12], and temperature [13]. Among them, electricigens are one of the most important factors that influence MFCs. To date, electricigen studies have focused on testing and improving the electricity generation performance of electricigen strains [14],

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* Corresponding author. Tel./fax: +86 10 8973 2278.
E-mail addresses: shguo@cup.edu.cn, cupgsh@163.com (S. Guo).

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screening new electricigen strains [15], microbial population and diversity evolution [16] and exploring the electricity generation mechanism of microbial strains [17]. However, detailed studies on the microbial synergistic and antagonistic effects and their influence on MFC performance remain lacking. Hassan et al. [18] attempted to use mixed and pure cultures of cellulose-degrading electricity generating bacteria from insoluble cellulose and demonstrated that in pure culture, the synergistic effect between cellobiose enzymes and pure bacteria was essential to generate electricity, but the synergistic effect between the different bacterial strains was not studied.

Refinery wastewater generated from petroleum processing contains plenty of organic pollutants, such as petroleum hydrocarbons, which are toxic to microbes and are poorly biodegraded [19]. The total emissions from refinery wastewater in China reach 500 million ta^{-1}. To date, traditional physicochemical and biological methods have been used most widely to treat refinery wastewater, but a large number of energy is consumed during the treatment process. When MFC technology is used to treat refinery wastewater, not only is the energy consumption of the traditional treatment process reduced but also the chemical bond energy stored in wastewater can also be recovered [2,20]. Therefore, it represents a viable pathway for wastewater resource utilization.

In this study, microbial strains were separated from a double-chambered refinery wastewater microbial fuel cell, which was stably operated for one year, and were used to inoculate MFCs to investigate the synergistic and antagonistic effects of different microbial strains and their influence of the electricity generation and wastewater treatment performances of MFCs. We investigated the microbial metabolic characteristics of petroleum hydrocarbon pollutants simultaneously to provide further insight into how the microbial synergistic and antagonistic effects influence MFCs.

2. Materials and methods

2.1. MFC construction

The configuration of MFC used in this study is presented in Fig. 1. It was made from glasses, and the volume of the two chambers was 400 mL. The anode chamber was sealed to maintain an anaerobic environment, and 100 mL of graphite granule or activated carbon granule was used as the packing materials (average grain diameter of 0.5–2.0 mm and porosity of 0.44). A graphite rod was used for the anode (0.6 cm × 18 cm). The cathode chamber was aerated continuously to maintain a constant dissolved oxygen concentration, a graphite plate was used as a cathode, and 20 mM Fe(III)-EDTA, which was a regenerable cathodic electron acceptor, was used as a catholyte [21]. The two chambers were separated by a proton exchange membrane (Nafion 117) and connected with a flange plate. The external resistance was 1000 Ω, and the operation temperature was 30 °C when unspecified.

2.2. Anolyte

The MFC anolyte was a mixture of refinery wastewater and phosphate buffer (1:1). The phosphate buffer was prepared refer following a previously published protocol [22], whereas the refinery wastewater was collected from the effluent of the flotation process in the Beijing Yanshan Refinery. The chemical oxygen demand of anolyte was 250 ± 40 mg L^{-1}, the oil concentration was 17 ± 1 mg L^{-1} and the pH was 7.1 ± 0.1. The anolyte was aerated with N_2 for 30 min to maintain an anaerobic environment.

2.3. Calculations

The MFC voltage output was recorded automatically with a data logger (e-corder, ED401, eDAQ Pty. Ltd, Australia) at 1 min intervals. The current density and power density was calculated with the following formulas:

$$I = UR^{-1}V^{-1} \tag{1}$$

$$P = UI \tag{2}$$

where I is the current density (mW m^{-3}), U is the voltage (mV), R is the external resistance (Ω), V is the working volume of the anode chamber (m^3) and P is the power density (mW m^{-3}).

The apparent internal resistance was determined according to the steady state discharge method [23].

2.4. Analytics

The chemical oxygen demand (COD) was measured by a 5B-6 COD speed meter (LianHua Tech, Lanzhou, China), the oil concentration was determined using an infrared oil analyzer (MC-OIL420, HuaxiaKechuang, Inc., China) after carbon tetrachloride extraction and the pH was determined with a pH monitor (PHSJ-4, Leici Instrument, Inc., Shanghai, China).

The organic composition of the refinery wastewater was analyzed by GC–MS. First, samples extracted from the wastewater by guarantee reagent methylene chloride were injected into a commercial quadrupole mass spectrometer (SSQ-710C, Thermo-Finnigan, San

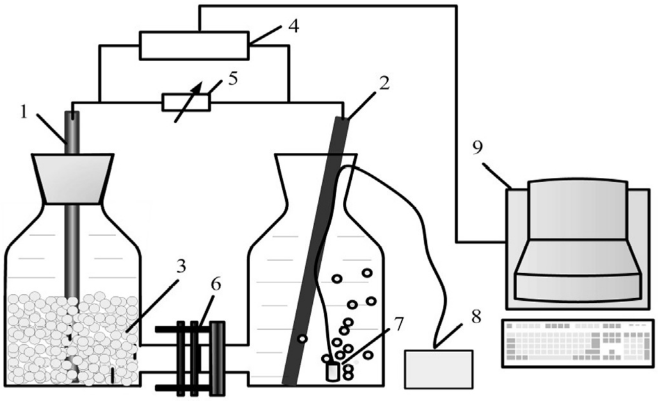

Fig. 1. Schematic diagram of the MFC double chambers. 1 anode; 2 cathode; 3 activated carbon; 4 data recorder; 5 resistance box; 6 PEM; 7 aerator; 8 air pump; 9 computer.