Bioresource Technology 203 (2016) 50–55

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Mutual facilitations of food waste treatment, microbial fuel cell bioelectricity generation and *Chlorella vulgaris* lipid production

Qingjie Hou [a], Haiyan Pei [a,b,*], Wenrong Hu [a,b], Liqun Jiang [a], Ze Yu [a]

[a] School of Environmental Science and Engineering, Shandong University, No. 27 Shanda Nan Road, Jinan 250100, China
[b] Shandong Provincial Engineering Centre on Environmental Science and Technology, No. 17923 Jingshi Road, Jinan 250061, China

HIGHLIGHTS

- A MFC was constructed with *C. vulgaris* for promoting food waste treatment.
- Optimal initial density of *C. vulgaris* in cathode chamber of MFC was 150 mg L^{-1}.
- Biomass productivity and total lipid content of *C. vulgaris* were promoted by MFC.
- Inoculated in MFC, *C. vulgaris* presented the higher biodiesel quality.

ARTICLE INFO

Article history:
Received 29 September 2015
Received in revised form 13 December 2015
Accepted 15 December 2015
Available online 18 December 2015

Keywords:
Food waste
Microbial fuel cell
Chlorella vulgaris
Optimal initial density
Lipid content

ABSTRACT

Food waste contains large amount of organic matter that may be troublesome for handing, storage and transportation. A microbial fuel cell (MFC) was successfully constructed with different inoculum densities of *Chlorella vulgaris* for promoting food waste treatment. Maximum COD removal efficiency was registered with 44% and 25 g COD L^{-1} d^{-1} of substrate degradation rate when inoculated with the optimal initial density (150 mg L^{-1}) of *C. vulgaris*, which were 2.9 times and 3.1 times higher than that of the abiotic cathode. With the optimum inoculum density of *C. vulgaris*, the highest open circuit voltage, working voltage and power density of MFC were 260 mV, 170 mV and 19151 mW m^{-3}, respectively. Besides the high biodiesel quality, promoted by MFC stimulation the biomass productivity and highest total lipid content of *C. vulgaris* were 207 mg L^{-1} d^{-1} and 31%, which were roughly 2.7 times and 1.2 times higher than the control group.

1. Introduction

Food waste is the largest component of municipal solid waste (MSW) in many urbanized societies (Lee et al., 2014). For example, in Hong Kong, there is approximately 3200 tons of food waste produced every day, constituting 35% of the total MSW (Li et al., 2013). It was reported that food waste accounted for about 60% of the total MSW collected and transported in China in 2006 (Zhang et al., 2010). Food waste large in quantity may be troublesome for handing, storage and transportation. There is a need to choose some inexpensive and easy treatment to minimize the quantity of food waste and also for satisfying discharge quality standards.

Food waste contains large amount of organic matter, which can serve as good organic feed stocks to drive electricity production in microbial fuel cells (MFCs) (Li et al., 2013). It has been proven that MFC could be implemented successfully in a solid fermentation process of food waste (Choi and Ahn, 2015). The benefit of MFC for food waste treatment are along the lines of safe, clean, efficient and direct electricity production along with organic matter removal. However, food wastes treatment in MFCs is still expensive since costly membranes and mechanical aeration is required (Gajda et al., 2015).

Microalgal technology for wastewater nutrients treatment using MFC has been recently developed, providing a novel, efficient and cost-effective solution for increasing the concentration of oxygen at the cathode (Kakarla et al., 2015; Rajesh et al., 2015). For example, some researchers have found obvious promotion for bioelectricity generation and COD removal efficiency with incorporation of *Chlorella vulgaris* into the MFC system through various configurations (Kokabian and Gude, 2013). On the other hand, it was proved that electric discharge was harmful to some algal growth (Sebastian et al., 2013; Zhang et al., 2014). Most of the previous studies focused on the facilitation of algae on MFC

* Corresponding author at: School of Environmental Science and Engineering, Shandong University, 27 Shanda Nan Road, Jinan 250100, China. Tel./fax: +86 531 88392983.
E-mail address: haiyanhup@126.com (H. Pei).

http://dx.doi.org/10.1016/j.biortech.2015.12.049
0960-8524/

performance. However, the effect of MFC on the growth and metabolism of *C. vulgaris*, as an important energy microalgal (Das et al., 2011), are rarely reported yet. Clearly, understanding interactions of food waste treatment, bioelectricity generation of MFC and biomass and lipid accumulation of *C. vulgaris* are necessary, especially facing the present hot topic of energy crisis.

The objective of this study was to investigate (i) the optimal inoculum density of *C. vulgaris* in the cathode chamber for promoting bioelectricity generation performance of MFC and food waste treatment; (ii) effects of MFC stimulation on the total lipid content and fatty acid compositional profiles of *C. vulgaris*. The optimized performance of the system was evaluated in terms of substrate (COD) removal efficiency and electrochemical properties (maximum power generation).

2. Methods

2.1. Food waste

Food waste as substrate in MFC was collected from a canteen catering several thousand people per day in Shandong University. The food waste generated was composite in nature including uneaten food and food preparation leftovers mostly comprising cooked vegetables (35 ± 5%; wet weight basis) followed by boiled rice (20 ± 5%), cooking oil (5 ± 2%), cooked meat (5 ± 2%), un-cooked vegetables (spoiled) (3 ± 1%), vegetable peeling (3 ± 1%), cooked fish (2 ± 1%) and boiled spices (1.5 ± 1%). The water content of waste varied between 15% and 50% in different seasons. Solid food wastes were collected by filtration to separate from liquid. Prior to feeding, the collected solid food wastes were mixed completely using electrical blender and remove inorganic material. Most oil present in the food waste separated using oil separating system, working based on gravity. Solid and liquid food wastes showed high concentrations of COD (513.9 and 103.8 g L^{-1}, respectively).

2.2. Reactor configuration and operation

The MFC reactors used for investigating the bioelectricity generation of two equal chambers made of glass separated by a proton exchange membrane (5.0 × 5.0 cm, Nafion 117). Each cell chamber had a working volume of 300.0 mL with 6.0 cm diameter. Anode was made of graphite, while cathode was constructed of sheet copper with effective area of 10 cm^2. A copper wire was inserted into the carbon felt to allow electrical contact with the external circuit. A fixed external resistance (1000 Ω) was used to facilitate the comparison of the electricity production in different treatments (as shown in Fig. 1). The reactors were operated at 25 ± 2 °C.

Before packing into the chambers, the graphite electrodes were submerged in 1 N HCl for 24 h, washed with deionized water, the submerged in 1 N NaOH for 24 h and finally washed several times in deionized water. Pre-treated PEM was attached to anode and cathode chambers. As described above, a fixed external resistance was used to facilitate comparison of the current production in different treatments.

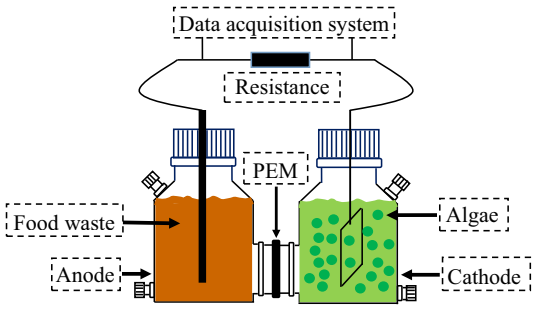

Fig. 1. Schematic detail of configure of MFC in this study.

Anaerobic sludge from an anaerobic digester with a total COD concentration of 13.1 g L^{-1} was used as inoculum, which was collected from a domestic wastewater treatment plant in Jinan, China. To start up the reactors, the cathode was filled with BG11 medium and aerated with air. The anodic half cells were fed with inoculums and food wastes (with a volume ratio of 1:10) and operated in batch mode for three cycles (the reaction times of three cycles of operation were 7.5, 6 and 6 d, respectively). At last when the anodic chambers inoculated with the same inoculum, the MFC has same COD removal rates.

2.3. Effect of C. vulgaris inoculum densities on MFC performance

Six groups were performed to determine the effect of *C. vulgaris* on MFC performance and food wastes treatment. To achieve different inoculum densities in the reaction solutions, 0 (stands for abiotic cathode), 50, 100, 150, 200 and 250 mg L^{-1} *C. vulgaris* (dry weight) were added into different cathode chambers which were filled with BG11 medium, respectively. The volume ratio of solid and liquid food waste was uniformly adjusted to about 1.5:1, followed by incubation at 25 ± 2 °C and light intensity of 60 μmol m^{-2} s^{-1} provided by daylight fluorescent tubes (Philips, 36W). During treatment, the concentration of DO, pH, voltage/open circuit voltage (V), current density (I) and power density were determined. Power density was obtained by varying the external resistances from 1000 to 50 Ω when stable voltage outputs were observed. After 144 h of cultivation, the growth and fatty acid profiles of microalgae and COD removal of food waste were calculated. The control group inoculated *C. vulgaris* in optimal initial density at 0 h, but without connecting anode and cathode, while other conditions were same as MFC reactors was performed.

2.4. Chemical and bio-electrochemical analysis

COD (including both soluble and particulate) was determined using a standard dichromate oxidation (open reflux method) method. Current output and substrate degradation rate (SDR) were considered as the two key parameters to evaluate the performance of MFC during operation (Mohan et al., 2010). To quantify the cell performance throughout the experiments, the potential difference between the anode and cathode (cell voltage, V) was recorded every 15 min using a data acquisition system (Keithley Instruments 2700, USA) connected to a personal computer. Current density (I) and power density (P) normalized to the volume of the chamber were calculated according to $I = V \cdot R^{-1}$ and $P = V^2 \cdot R^{-1}$, respectively, where R is the external resistance. Dissolved oxygen was measured by an HQ-30D (USA) probe.

2.5. Analysis of biomass components

At the end of cultivation, biomass of *C. vulgaris* was harvested by filtration through bolting-silk in 200 mesh, dried to constant weight at minus 50 °C in lyophilizer (FDU-1200, EYELA, Japan), and then ground to homogeneous powder to analyze its lipid. Total lipid of algae biomass was quantified gravimetrically following the extraction using a chloroform/methanol mixture (2/1, V/V) (Song et al., 2013). After the two-step *in situ* methyl esterification process, the fatty acids properties were examined through the GC–MS method as described by Ji et al. (2014). The biomass productivity (mg L^{-1} d^{-1}) of microalgae in each group was calculated according to the following formula (Ji et al., 2014):

$$P_b = (X_2 - X_1)/(T_2 - T_1) \quad (1)$$