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Simultaneous processes of electricity generation and ceftriaxone sodium degradation in an air-cathode single chamber microbial fuel cell

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ABSTRACT

A single chamber microbial fuel cell (MFC) with an air-cathode is successfully demonstrated using glucose–ceftriaxone sodium mixtures or ceftriaxone sodium as fuel. Results show that the ceftriaxone sodium can be biodegraded and produce electricity simultaneously. Interestingly, these ceftriaxone sodium–glucose mixtures play an active role in production of electricity. The maximum power density is increased in comparison to 1000 mg L^{-1} glucose (19 W m^{-3}) by 495% for 50 mg L^{-1} ceftriaxone sodium + 1000 mg L^{-1} glucose (113 W m^{-3}), while the maximum power density is 11 W m^{-3} using 50 mg L^{-1} ceftriaxone sodium as the sole fuel. Moreover, ceftriaxone sodium biodegradation rate reaches 91% within 24 h using the MFC in comparison with 51% using the traditional anaerobic reactor. These results indicate that some toxic and bio-refractory organics such as antibiotic wastewater might be suitable resources for electricity generation using the MFC technology.

1. Introduction

As microbial fuel cell (MFC) is a device that transforms chemical energy stored in organic matter into electricity via electrochemical reactions for energy recovery, it is considered to be a promising bio-electrochemical power source for directly recovering electrical energy from organics [1,2]. It can also use wastewater as substrates to remove contaminants in wastewater and produce electricity simultaneously, thus decrease the operational costs of wastewater treatment. The study of MFC is gaining importance recently, but most studied were based on various biodegradable organic matter as substrates, for example, glucose, acetate, sucrose, domestic wastewater, brewery wastewater and starch processing wastewater [1,3–7]. There were only a few reports on bio-refractory compounds as fuel, for instance, phenol, furfural, pyridine, and p-nitrophenol [2,8–10]. These results indicated that some toxic and bio-refractory organics might be suitable resources for electricity generation using MFC technology in practical applications.

Although pharmaceuticals are not environmentally different from other chemicals, they should be paid more attention because recent studies showed that substantial quantities of these compounds and metabolites are discharged down the drain in sufficiently high concentrations to cause deterioration of the environment [11]. They enter the aquatic environment and eventually reach drinking water if they are not biodegraded or eliminated during sewage treatment.

As an important group of pharmaceuticals in human and veterinary medicine, large amounts of antibiotics are produced, consumed and widely used in controlling bacteria in humans and animals. Abuse of antibiotics and the existence of residual antibiotics in natural systems have accelerated the pollution of the environment. Hence, it is necessary to treat the effluents containing antibiotics before being discharged into the environment. However, toxic effects of common antibiotics on different organisms (aquatic organisms, plants, soil organisms and bacterial community, foodborne pathogens and spoilage microbe algae, Artemia saliva, *Daphnia magna*, etc.) have been found even at very low exposure doses [12–14]. These will make wastewater biological treatment more difficult. Nevertheless, biological treatment is still regarded as the most common and economical approach for the treatment of contaminants in wastewater, which may be one of the methods for the removal of antibiotics from wastewater. It was reported that wastewater containing antibiotics could be degraded efficiently in the biological system, such as up-flow anaerobic stage reactor (UASR) and sequencing batch reactor (SBR) [15–18]. Kim et al. have indicated that the acclimatization is the major phenomenon by which microorganism mitigates the toxic effects of inhibitors [12].

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β-Lactam antibiotics are among the most widely used antibacterial agents on account of their broad spectrum, such as penicillins, cephalosporins. As considered, in this work an air-cathode MFC inoculated with anaerobic microorganisms was therefore constructed to generate electricity from glucose–ceftriaxone sodium mixtures or ceftriaxone sodium. To our knowledge, ceftriaxone sodium ($C_{18}H_{17}N_8NaO_7S_3$) as the fuel in a MFC has not been reported previously. The present study aims to: (i) investigate the biodegradation feasibility of ceftriaxone sodium in the MFC; (ii) examine the influence of ceftriaxone sodium on MFC power electricity generation; and (iii) to evaluate the differences of ceftriaxone sodium degradation between MFC and traditional anaerobic reactor.

2. Materials and methods

2.1. Air-cathode MFC configuration

An air-cathode single-chambered MFC was constructed by a Plexiglas vessel with internal dimensions of 6 cm × 6 cm × 3 cm (total volume of 108 mL, working volume of 100 mL). The cathode was Pt-coated PTFE, (6 cm × 6 cm), prepared as Wen et al. [19], whereas the anode was carbon felt (6 cm × 6 cm). The surface areas per volume of the anode and cathode electrodes were both 36 m^2 m^{-3}. Two electrodes had a distance of 3 cm. Water inlet and outlet ports were set up on each side of the vessel. Two ports with an inner diameter of 1 cm were arranged for sampling and installing reference electrode. Insulated copper wires were used to connect the circuit with the external resistance (500 Ω unless specified otherwise) and all wire contacts were sealed with epoxy resin. The system was sealed carefully to maintain anaerobic microenvironment.

2.2. Microbial inoculum and MFC operation

Bacteria from another glucose-fed MFC were used to inoculate the MFC with a glucose solution of 1000 mg L^{-1} and an anodic solution. The MFC was continuously fed using peristaltic pump (BT100-1J, Baoding, China) at a flow rate of 12.5 mL h^{-1}. Anodic solution contained (per liter): KCl, 130 mg; NaH_2PO_4•H_2O, 4.97 g; Na_2HPO_4•H_2O, 2.75 g; and other trace elements required by microorganism growth as reported by Liu and Logan [20]. After stable voltage outputs were achieved, ceftriaxone sodium–glucose mixtures were used to replace the solutions in the MFC. The cefriaxone–glucose mixtures included 30 mg L^{-1} ceftriaxone sodium + 1000 mg L^{-1} glucose, 50 mg L^{-1} ceftriaxone sodium + 1000 mg L^{-1} glucose, 50 mg L^{-1} ceftriaxone sodium + 500 mg L^{-1} glucose, 50 mg L^{-1} ceftriaxone sodium + 250 mg L^{-1} glucose, 30 mg L^{-1} ceftriaxone sodium + 500 mg L^{-1} glucose. Again after stable voltage outputs were achieved, a ceftriaxone sodium solution with a concentration of 50 mg L^{-1} as the sole fuel was operated in the air-cathode MFC. Experiments were conducted in a room temperature (24 ± 1 °C), and pH of the analyte was 6.8–7.0.

2.3. Analyses and calculations

The output voltage (U) was measured across an external resistor (500 Ω, unless stated otherwise) using a data acquisition system connected to a computer. Current was calculated according to Ohm's law as $I = U/R$, where U is voltage and R is resistance. Power (P) was calculated according to $P = IU$. Polarization curve was obtained by varying the external resistance over a range of 1–9000 Ω and recording the voltage. The power was then calculated for each resistance as a function of the current. Current density and power density were normalized to the MFC volume or electrode surface area (100 mL or 36 cm^{-2}). The performance and electrode potential (anode and cathode OCPs; anode and cathode working potential) were measured using the variable resistor with an Ag/AgCl reference electrode.

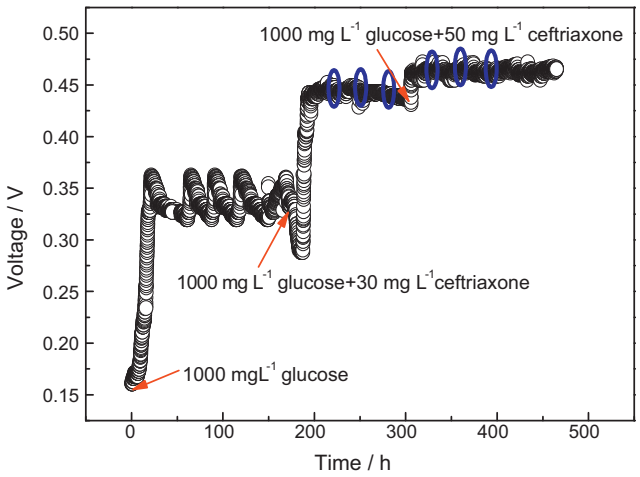

Fig. 1. Anode bacterial accumulation and continuous voltage outputs of MFC with different concentrations of ceftriaxone sodium at a fixed resistor of 500 Ω.

Electrochemical impedance spectroscopy (EIS) was performed over a frequency range of 0.01 to 10^5 Hz at open-circuit condition and a perturbation signal of 5 mV using a potentiostat (CHI760C, Chenhua Instruments, Shanghai, China). Two types of measurements were done, one using a whole cell, two-electrode configuration, and the other using a three-electrode configuration with a reference electrode (Ag/AgCl). The whole cell EIS measurements were done using the cathode as the working electrode and the anode as the counter electrode.

Samples from the anode solutions in the air-cathode single chamber MFC were treated by filtered through a 0.45 μm pore diameter membrane. Ceftriaxone sodium concentrations were analyzed using a liquid chromatography (Agilient 1100, USA). The mobile phase consisted of a mixture of 0.02 mol L^{-1} N-octyl amine and acetonitrile (73:27, v:v) and 254 nm wavelength was used to detect ceftriaxone sodium with a flow rate of 1 mL min^{-1}.

3. Results and discussion

3.1. Anode bacterial accumulation and voltage output from ceftriaxone sodium–glucose mixtures in the MFC

During the start-up phase, the anode in the MFC was colonized using a glucose solution (1000 mg L^{-1}) in a continuous feed operational mode. When 1000 mg L^{-1} glucose was pumped into the MFC, an initial circuit voltage of 0.161 V was immediately generated (Fig. 1). It might be due to the difference of the potential between the two electrodes based on chemical and biological factors [21]. Thereafter, because of biological activity, voltage increased with the increase of the time, and registered a maximum of 0.368 V within 22 h. During the next 148 h, the maximum voltage stabilized at 0.385 ± 0.005 V, indicating the exoelectrogenic biofilm formation and the finish of MFC start-up.

As is shown in Fig. 1, voltages were obviously decreased when ceftriaxone sodium–glucose mixtures were added into the MFC. The decreased voltages indicated that ceftriaxone sodium might reduce the electrochemical activity of bacteria on the anode. After 10 h acclimation and cultivation, voltages were then gradually increased with the addition of ceftriaxone sodium, indicating that the concentration of ceftriaxone sodium was within the range of adaptation of microbial culture. The maximum voltage outputs

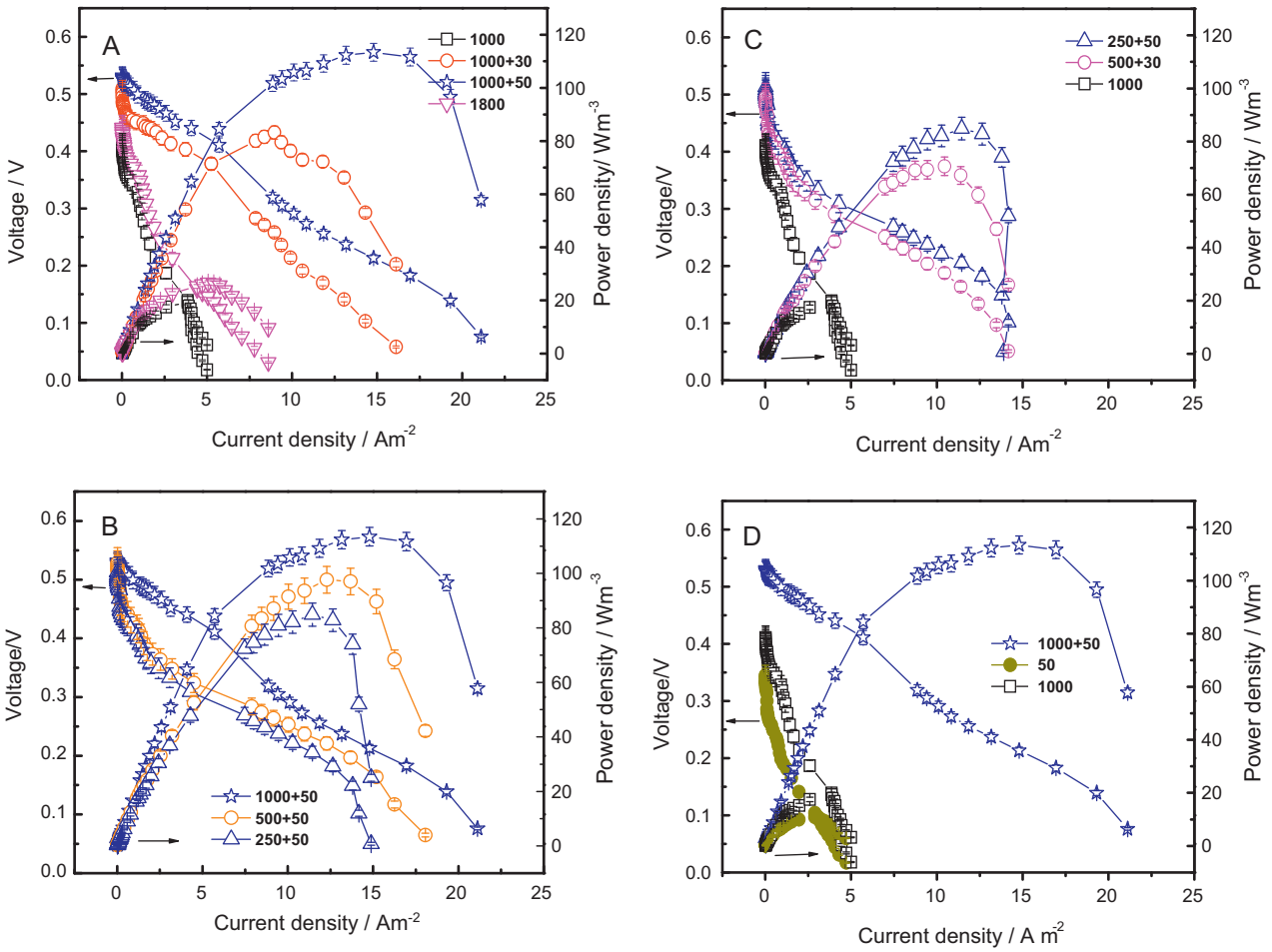

Fig. 2. (A) Power generation from different concentrations of ceftriaxone sodium mixed with 1000 mg L^{-1} glucose; (B) power generation from 50 mg L^{-1} ceftriaxone sodium mixed with different concentrations of glucose; (C) power generation from the almost same COD value (1000 ± 30 mg L^{-1}); (D) comparison of power generation for the MFC using ceftriaxone sodium–glucose mixtures, pure glucose, and pure ceftriaxone sodium as the fuel.

were 0.368, 0.453 and 0.472 V for the fuels with ceftriaxone sodium concentrations of 0, 30, and 50 mg L^{-1}, respectively. Results suggested that it was possible to operate the MFC in the presence of ceftriaxone sodium, demonstrating that electricity generating bacteria on the anode could be acclimated, cultivated and suitable for generating electricity. Meanwhile, each increase in the ceftriaxone sodium concentration gave an increase in voltage output. The gradual increase indicated the short cultivated time period for ceftriaxone sodium–glucose mixtures, which suggested that microorganisms in the MFC needed short time to adapt ceftriaxone sodium. In this study, the ceftriaxone sodium–glucose mixtures utilization by bacteria might be attributed to the use of mixed bacteria after a period of acclimation in MFC. It was also demonstrated that the mixed bacteria generate power from recalcitrant contaminants such as phenol, furfural, and pyridine [2,8,9].

3.2. Effect of different ceftriaxone sodium concentrations on voltage and power density

Polarization data were obtained to characterize the performance of the system at different ceftriaxone sodium concentrations. Fig. 2(A) shows the polarization and power density curves of a MFC operating on 1000 mg L^{-1} glucose containing ceftriaxone sodium with different concentrations. It can be seen that the presence of ceftriaxone sodium significantly affected the MFC polarization behavior, and large differences in power production were observed based on polarization data. The increased ceftriaxone sodium concentration caused a low polarization and a high power density. Maximum power densities produced with different ceftriaxone sodium concentrations (from 0 to 50 mg L^{-1}) varied over a large range of 19–113 W m^{-3}. It was apparently observed that power production depended on the ceftriaxone sodium concentration, with the largest maximum power density of 113 W m^{-3} produced with a mixture of 1000 mg L^{-1} glucose and 50 mg L^{-1} ceftriaxone sodium at a current density of 13 A m^{-2}. Thus, a 6-fold higher maximum power density can be obtained in the MFC system than that using individual 1000 mg L^{-1} glucose.

This power density (113 W m^{-3}) was high in comparison to other findings, particularly since the anode used was carbon felt. For example, Luo et al. achieved a power density of 18 W m^{-3} using 6.68 mM furfural as fuel with carbon cloth anode (anode surface area of 54 m^2 m^{-3}, i.e. 7 cm^2 × 13 mL reactor volume) and air cathode (carbon cloth with Pt catalyst). Luo et al. also achieved 103 W m^3 with 6.68 mM furfural as substrate using a brush anode and ferricyanide as the electron acceptor [8]. Interestingly, the maximum power density 113 W m^{-3} was 4-fold higher than that of 27 W m^{-3} produced from 1800 mg L^{-1} glucose (with almost the same COD (chemical oxygen demand) value of 1800 ± 50 mg L^{-1}).

Polarization data were then obtained to compare the performance of MFC over a series of glucose concentrations mixed with the same ceftriaxone sodium of 50 mg L^{-1}. As is shown in Fig. 2 (B), from the mixtures of 1000, 500, 250 mg L^{-1} glucose and 50 mg L^{-1} ceftriaxone sodium, the maximum power densities were 113, 98

and 85 W m^{-3}, respectively; the corresponding current densities were 14.8, 12.3 and 11.4 A m^{-2}, respectively.

In comparison with 1000 mg L^{-1} glucose without ceftriaxone sodium (19 W m^{-3}), the maximum power densities produced with other fuels were increased by 337% for 30 mg L^{-1} ceftriaxone sodium + 1000 mg L^{-1} glucose (83 W m^{-3}), 495% for 50 mg L^{-1} ceftriaxone sodium + 1000 mg L^{-1} glucose (113 W m^{-3}), 416% for 50 mg L^{-1} ceftriaxone sodium + 500 mg L^{-1} glucose (98 W m^{-3}), and 347% for 50 mg L^{-1} ceftriaxone sodium + 250 mg L^{-1} glucose (85 W m^{-3}) (Fig. 2(A) and (B)).

In order to investigate whether the different COD values influenced the results, power densities of 250 mg L^{-1} glucose + 50 mg L^{-1} ceftriaxone sodium (85 W m^{-3}), 500 mg L^{-1} glucose + 30 mg L^{-1} ceftriaxone sodium (71 W m^{-3}) and 1000 mg L^{-1} glucose (19 W m^{-3}) were compared with almost the same COD value (1000 ± 30 mg L^{-1}) (Fig. 2(C)). These glucose-mixtures generated a much higher power density than 1800 mg L^{-1} glucose as sole fuel (27 W m^{-3}) (Fig. 2(A)), with almost the twice COD value (1000 ± 30 mg L^{-1} vs. 1800 ± 50 mg L^{-1}). If COD value was a significant limited factor in this MFC system, the power densities with almost the same COD value would have been comparable, and the power density of 1800 mg L^{-1} glucose would be higher. These results demonstrated that it was the additional ceftriaxone sodium below a particular level substantially that enhanced power production instead of inhibiting. Nevertheless, the ceftriaxone sodium as the sole fuel produced a relatively low power density, as is shown in Fig. 2(D), the power density was 11 W m^{-3}. It was interesting to find that the power density (113 W m^{-3}) using ceftriaxone sodium–glucose mixtures as the fuel was 277% higher than the sum of power densities using individual glucose (19 W m^{-3}) and ceftriaxone sodium (11 W m^{-3}) as the fuel. These results suggested that the MFC using the mixtures might show different characteristics of power generation compared to using the pure organics. Similar to the phenol and pyridine results of Luo et al. [2] and Zhang et al. [9], co-substrates could enhance the energy output.

As can be seen from the above results, the activity of electricity generating bacteria in MFC was not inhibited and presented a high tolerance to ceftriaxone sodium in some extension with glucose as co-substrate. These experimental results were very useful in practice and showed the possibility of the MFC application on the industrial wastewater treatment containing ceftriaxone sodium.

3.3. Electrode potential analysis

Potential is one of the important parameters used to describe fuel cell efficiency. Individual electrode potential was investigated in order to examine the performance of each electrode at different ceftriaxone sodium concentrations (0, 30, and 50 mg L^{-1}) (Fig. 3). As 1000 mg L^{-1} glucose mixed with ceftriaxone sodium concentrations of 0, 30 and 50 mg L^{-1}, the open circuit potentials of anode were −300, −380 and −385 mV, respectively; while that of cathode were 111, 130 and 147 mV. At the current density of 5 A m^{-2}, the value of anode potential minus open circuit potential at each condition was 244 (0 mg L^{-1}), 110 (30 mg L^{-1}), and 48 mV (50 mg L^{-1}), whereas the value of open circuit potential minus cathode potential was 147 (0 mg L^{-1}), 104 (30 mg L^{-1}), and 93 (50 mg L^{-1}). It can be seen that increasing the concentration of ceftriaxone sodium improved both the anode and cathode performance, however, the cathode working potentials did not change significantly with increases of current density. The effect of ceftriaxone sodium on the anode and cathode led to the enhancement in power output of MFC, meanwhile, evidence from the anode and cathode polarization curves showed that the anode were responsible for the overall power output. As is known, anode potential is controlled by the kinetics of electron transfer from the microorganisms to the anode, so the significantly decrease in anode potential was possibly due to an improvement of electron supply in the glucose–ceftriaxone sodium fed MFC. The improvement of electron supply would enhance the redox reaction on the cathode and then resulted in the increased cathode potential.

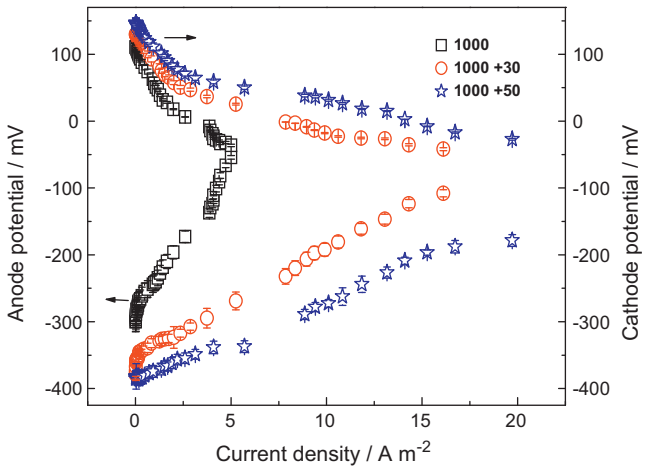

Fig. 3. Anode and cathode potentials as a function of current density for different concentrations of ceftriaxone sodium (0, 30, and 50 mg L^{-1}) mixed with 1000 mg L^{-1} glucose.

3.4. Electrochemical impedance spectroscopy (EIS)

The MFC requires a better understanding of the distribution of internal resistance within the MFC. Quantification of the changes in individual impedances corresponding to the anode and cell with process conditions is needed to improve our understanding of MFC. Therefore, changes in the anode and the whole cell impedances were measured using electrochemical impedance spectroscopy (EIS). In order to assess the impedances under different operation conditions, the EIS analysis was conducted at different ceftriaxone sodium concentrations. Fig. 4 showed that the impedance spectra for the anode and the whole cell decreased gradually as ceftriaxone sodium concentration increased from 0 to 50 mg L^{-1}. The Nyquist plot of the 1000 mg L^{-1} glucose showed that the whole cell resistance was about 19.4 Ω, while the anode impedance was 10.2 Ω. With the addition of ceftriaxone sodium, both of the impedances for the whole cell and anode were decreased. The total impedance for the mixtures of 1000 mg L^{-1} glucose and 30 mg L^{-1} ceftriaxone sodium was 16.2 Ω, which decreased to 8.0 Ω at ceftriaxone sodium concentration of 50 mg L^{-1}. The impedance associated with the anode also decreased from 7.2 to 3.0 Ω at ceftriaxone sodium concentration of 30–50 mg L^{-1}. In addition, the ohmic resistance of the MFC was also decreased from 8.4 to 5.3 Ω with the addition of ceftriaxone sodium from 0 to 50 mg L^{-1}. It can be said that there was a significant change in the anode and the whole cell impedances with cefriaxone addition. The increase in power density might be due to the decrease in the whole cell impedance.

3.5. Anode discharge performance in MFC

In order to evaluate the discharge performance of the anode with different ceftriaxone sodium concentrations in the MFC, the current from ceftriaxone sodium–glucose mixtures at a constant potential (0 V) was measured. As is shown in Fig. 5, the current ascended with the increased ceftriaxone sodium concentration. The current–time curves of glucose or ceftriaxone sodium–glucose mixtures were significantly different from each other. For the pure glucose, the current increased very slowly and the current was much lower than

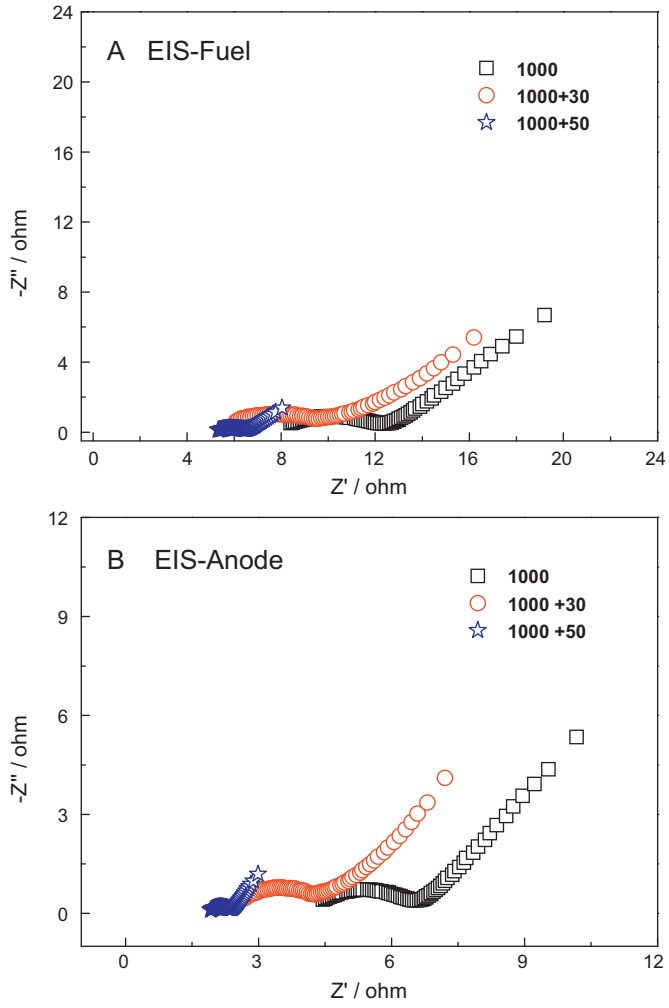

Fig. 4. Nyquist plot for the whole cell (A) and anode (B).

that in the presence of ceftriaxone. For the two concentrations of additional ceftriaxone sodium, when the current of the 30 mg L^{-1} ceftriaxone sodium reached a plateau, the current of the 50 mg L^{-1} ceftriaxone sodium was still increasing and the current density is higher than the former. For electricity production in an air-cathode MFC, electrons are produced during microbial metabolism. Specifically, organic matter is oxidized to produce electrons and

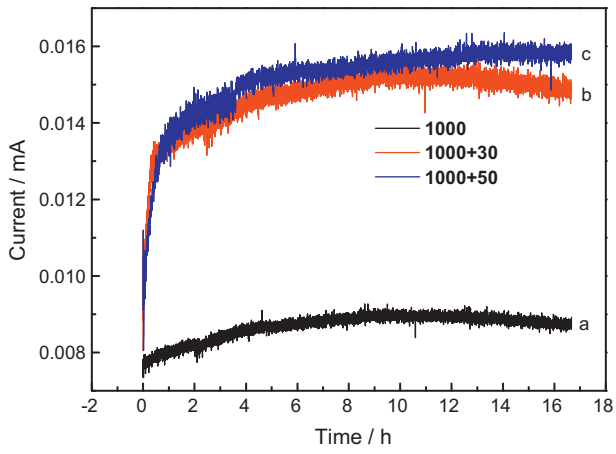

Fig. 5. Evolution of current density with time: (a) 1000 mg L^{-1} glucose; (b) 1000 mg L^{-1} glucose + 30 mg L^{-1} ceftriaxone sodium; (c) 1000 mg L^{-1} glucose + 50 mg L^{-1} ceftriaxone sodium, potential applied to the electrode was 0 V.

protons upon the catalysis of the microorganisms. Electrons are transferred from the cell to the anode electrode and collected in the anode, subsequently, arrive at the air-cathode where they combine with protons and oxygen to form water [22]. The analysis of the electron transfer mechanism of the MFC suggested that current production mainly relies on the electron transfer between bacterial cells and electrode. Fig. 5 indicated that anode discharge almost increased 2-fold when added 30 mg L^{-1} ceftriaxone sodium to 1000 mg L^{-1} glucose. It can be concluded that the additional ceftriaxone improved the ability of electrons transfer from microbe to anode.

Above all, results revealed that ceftriaxone sodium–glucose mixtures and pure ceftriaxone sodium could be used as fuels to generate electricity in the MFC. And it was interesting to discover that great improvements in power density, electrode potential, resistance and anode discharge were revealed with ceftriaxone sodium–glucose mixtures as fuels in comparison with glucose as the sole fuel (Figs. 2–5). These results may be due to the effect of ceftriaxone sodium on the electricity generating bacteria.

The β-lactam antibiotics work by inhibiting the formation of peptidoglycan cross-links in the cell wall of bacterial. The β-lactam functional group binds to the enzyme (DD-transpeptidase) that links the peptidoglycan molecules in bacteria, which weakens the cell wall of the bacterium [11,30–32]. In the MFC, the cell membranes and walls of bacteria contain non-conductive materials, such as lipid or peptidoglycan, which would result in the block of directly electron transfer between cell and outer membrane. In this study, the addition of ceftriaxone sodium (30–50 mg L^{-1}) in the MFC might destroy the integrity of the cell walls, but have no apparent influence on the activity of microbial cells, causing an improved diffusion of redox species and redox enzymes (mainly hemoproteins) in cell membrane [33]. Thus, direct electron transfer improved, resulting in an increase of anode discharge (Fig. 5). The improvement in electron transfer capability decreased the anode resistance and therefore reduced the overall internal resistance of the MFC (Fig. 4), which resulted in an increase current density and a decrease of polarization (Fig. 3), finally, the power generation increased (Fig. 2).

An analysis of the electricity generation of the MFC suggested that current production mainly relies on the electron transfer between bacterial cells and electrode. Considering that the cell walls and membranes of bacteria contain non-conductive materials, such as lipid or peptidoglycan, the direct electron transfer rate from microbe cell to anode is quite low. Despite the fact that in recent years the power generation from MFCs have improved considerably [23–29], it is still a big challenge. This study not only demonstrated the feasibility of electricity generation from ceftriaxone but also provided a new approach to increase electrons transfer rate through ruptures of cell walls. For further consideration, it could also improve electrons transfer through increasing the permeability of microbial membranes.

3.6. COD and ceftriaxone sodium degradation in the MFC comparison with the anaerobic reactor

In the field of wastewater treatment, substrate utilization and degradation are practically important. In order to investigate the substrate degradation capability in the MFC and the differences from anaerobic reactor (AR, MFC reactor with open circuit and everything else was exactly the same), the experiments were conducted to investigate the degradation of ceftriaxone sodium and COD. As is represented in Fig. 6, the removal efficiencies of both ceftriaxone sodium and COD in MFC were higher than those in anaerobic reactor at any given time during the 24 h experiment. At the substrates of 1000 mg L^{-1} glucose + 30 mg L^{-1} ceftriaxone sodium and 1000 mg L^{-1} glucose + 50 mg L^{-1} ceftriaxone sodium,

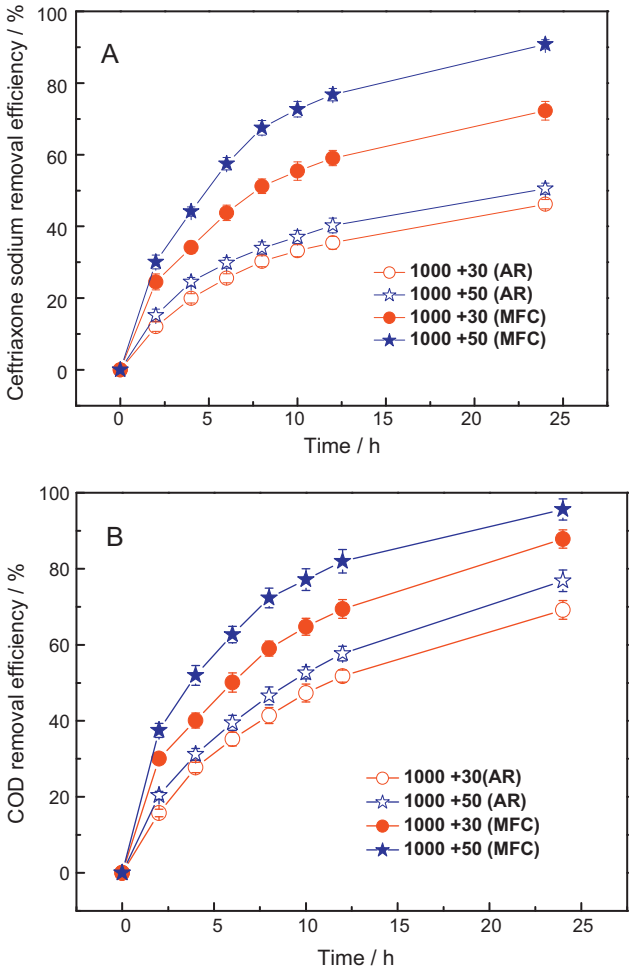

Fig. 6. Ceftriaxone sodium degradation (A) and COD degradation (B) with different substrates (1000 mg L^{-1} glucose + 30 mg L^{-1} ceftriaxone sodium, and 1000 mg L^{-1} glucose + 50 mg L^{-1} ceftriaxone sodium) in the MFC and anaerobic reactor (AR).

the ceftriaxone sodium removal efficiencies within 24 h in the MFC were 72% and 91%, respectively, and the corresponding COD removal efficiencies were 88% and 96%; while in anaerobic reactor, ceftriaxone sodium removal efficiencies were 46% and 51%, and the corresponding COD removal efficiencies were 69% and 77%. These results revealed that: (i) it was feasible to treatment wastewater containing ceftriaxone sodium in MFC; (ii) the removal efficiencies of ceftriaxone sodium and COD in MFC were higher than those in the anaerobic method. These results were similar to [9,34,35]. They all found that the degradation rates of substrates in MFC systems were better than traditional anaerobic reactor. The accelerated and improved degradation of ceftriaxone sodium in the MFC in comparison with traditional anaerobic treatment in this study might be attributed to the current generated in the MFC, which might have an active effect on the metabolism of electrochemically active microbes.

In this MFC, the removal efficiency of COD increased from 88% to 96% as the addition of ceftriaxone sodium increased from 30 to 50 mg L^{-1}, indicating that the interfering with integrity of the cells did not inhibit overall cell functioning. Although ceftriaxone sodium below a particular level (50 mg L^{-1}) did not have an inhibition to bacteria, it should be noted that with an increase in ceftriaxone sodium concentration, the inhibition on bacteria could be apparent and might destroy the system. The utmost of ceftriaxone sodium degraded in MFC system and the influence on bacteria in the MFC will need further research.

4. Conclusions

Electricity was successfully generated using ceftriaxone sodium–glucose mixtures or ceftriaxone sodium as the fuel in the air-cathode single chamber MFC. Interestingly, results demonstrated that the ceftriaxone sodium–glucose mixtures could improve the power density, for example, the maximum power density increased from 19 to 113 W m^{-3} when 50 mg L^{-1} ceftriaxone sodium was added to 1000 mg L^{-1} glucose. Moreover, 91% ceftriaxone sodium was degraded within the operation time in the MFC compared with 51% in the anaerobic reactor when 1000 mg L^{-1} glucose + 50 mg L^{-1} ceftriaxone sodium mixtures were used as the substrates. This study shows the potential of biodegradation of antibiotic wastewater (e.g. β-lactam class) and their possible electricity generation using the MFC.

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