Study on the Electricity Generation Characteristics of Microbial Fuel Cell with Different Substrates

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Abstract: We use anhydrous sodium acetate, glucose, lactose and Colocasia antiquorum Schott as anode substrate to study the periodic curve of battery voltage and stable output voltage of different substrates. The results showed that the four kinds of microbial fuel cells with sodium acetate, glucose, lactose and pretreated Colocasia antiquorum Schott as anode substrate had the following power generation periods: 23.98 d, 20.15 d, 18.84 d and 23.52 d, respectively, and the stable voltage at the two ends of the resistance of microbial fuel cells with four different anode substrates are 0.77 V, 0.75 V, 0.65 V and 0.70 V respectively. We found at the same carbon source concentration, MFC with sodium acetate as the substrate has the best electricity production characteristics. When the pretreated Colocasia antiquorum Schott is used as anode substrate, the time for cell voltage to rise from initial value to stable value is the shortest, and as a carbon source, it can also play a dominant role in the process of electric energy collection and utilization.

1. Introduction

By 2030, global energy consumption is predicted to increase 36%, which will cause serious global shortage of conventional fuels in the near future [1]. Therefore, the focus of global research has shifted to increasing the potential of renewable energy generation (from solar, wind, geothermal, tide and biomass etc.) and storage technologies as a comprehensive application of primary energy source [2]. As a new type of energy, biomass energy can not only generate electricity, but also effectively control environmental pollution and solve energy problems.

As one of the most abundant renewable resources, cellulosic biomass, including waste products of agricultural and industrial activities, is particularly attractive in this context due to its relatively low cost and plentiful supply [3] [4].

Using electrochemically active microorganisms as biocatalysts, microbial fuel cells (MFCs) are bioelectrochemical reactors that convert organic material directly into electricity [5]. Unlike chemical or enzyme based fuel cells, which are tailored to oxidize specific electron donors, MFCs have tremendous electron donor versatility. This includes simple substrates such as glucose, acetate, and lactate [6-8]; complex substrates such as municipal and industrial wastewaters [9] [10]; and even steam-exploded corn stover hydrolysate [11].

The Colocasia antiquorum Schott belongs to Angiospermae, which is distributed in the southern provinces. There are a large number of Colocasia antiquorum Schott in nature, which grows and
propagates rapidly and is easy to obtain. There are a lot of cellulosic substances in the stems of taro plants, whose sugar content is higher than that of sugarcane, which can provide sufficient substrate for microbial fuel cell. In this study, anhydrous sodium, glucose, lactose and pretreated Colocasia antiquorum Schott were used as anode substrate to explore the electricity production characteristics of different substrate batteries.

2. Materials and methods

2.1 Voltage monitoring
The voltage of the system is collected by PS-DAQ voltage data acquisition channel, and the collected data is connected to the computer through data lines for storage. In the measurement of MFC experimental voltage, the voltage data acquisition terminal can simultaneously measure the voltage at both ends of 24 groups of MFC. In the experiment of detecting the growth cycle of microbial fuel cell, the time interval of voltage collection at both ends of each MFC is 5 min. The recorded data can correctly reflect the change of voltage in the growth cycle of MFC.

2.2 Preparation of cathode solution and anode solution
In the start-up stage, it is necessary to add activated sludge into the nutrient solution configured in the anode chamber to access bacteria. So that microorganisms can effectively transfer electrons in the process of growth. In order to maintain the metabolism and growth of microorganisms, the anode solution formula (deionized water per liter) includes: \( \text{CH}_3\text{COONa} \) (0.82 g), \( \text{NaHCO}_3 \) (2.0 g), \( \text{Na}_2\text{SO}_4 \) (0.5 g), \( \text{MgSO}_4\cdot7\text{H}_2\text{O} \) (0.2 g), \( \text{KH}_2\text{PO}_4 \) (6.28 g), \( \text{K}_2\text{HPO}_4 \) (10.0 g), NaCl (0.5 g). In addition, a large number of electrons can be produced by the decomposition of organic matter consumed by microorganisms in the anode chamber, but we need the cathode to carry out the effective transmission of electrons. So we need to add other substance solutions (deionized water per liter): \( \text{K}_3[\text{Fe(CN)}_6] \) (32.9 g), \( \text{KH}_2\text{PO}_4 \) (6.28 g), \( \text{K}_2\text{HPO}_4 \) (10.0 g).

All tests are conducted at room temperature and standard atmospheric pressure.

2.3 The operation of MFCs
Take the sludge from the bottom of waste water and put it into a conical flask cleaned with distilled water for static culture. As the activity of sludge is generally only one to two weeks, the sludge should be used immediately. In the process of use, directly shake the sludge solution in the conical flask and pour it into the beaker. Use the dropper to take two to three pipes of sludge solution and add them into the anode chamber. After that, add a small amount of glucose into the conical flask and left it open in order to allow the growth of microorganisms in the sludge to have aerobic respiration.

Substrate: Sodium acetate, glucose, lactose, pretreated Colocasia antiquorum Schott, anode buffer solution (per litre of deionized water): \( \text{NaHCO}_3 \) (2.0 g), \( \text{Na}_2\text{SO}_4 \) (0.5 g), \( \text{MgSO}_4\cdot7\text{H}_2\text{O} \) (0.2 g), \( \text{KH}_2\text{PO}_4 \) (6.28 g), \( \text{K}_2\text{HPO}_4 \) (10.0 g), NaCl (0.5 g). Cathodic electrolyte solution (per litre of deionized water): \( \text{K}_3[\text{Fe(CN)}_6] \) (32.9 g), \( \text{KH}_2\text{PO}_4 \) (6.28 g), \( \text{K}_2\text{HPO}_4 \) (10.0 g).

In this paper, a 160 ml two chamber microbial fuel cell is used. The principle of MFC is shown in Figure 1. The newly inoculated MFC needs a culture cycle (about 15 d) to wait for the growth and reproduction of the microorganisms in the anode chamber. When the microorganisms continuously adhere to the porous carbon felt, the microorganisms can transfer the generated electrons to the electrode plate directly, and make it more effectively. The power generation performance (voltage, electric power density) of MFC was investigated by using sludge of different pretreatment methods as substrate of MFC in a two chamber MFC reactor. Under the condition of setting external resistance (1000 Ω), the curve of voltage rising to stable period was detected.
When measuring the MFC growth cycle curve of four substrates, connect 1 KΩ resistance at both ends of MFC. In the anode solution, sodium acetate, glucose, lactose and pretreated Colocasia antiquorum Schott, are used as anode substrates respectively, and potassium ferricyanide is used as the main substance for electronic transmission in the cathode solution. When the organic fuel in the anode chamber is consumed, replace a new anode organic solution. Add 150 ml of 0.82 g/l sodium acetate solution, 150 ml of 0.88 g/l glucose solution, 150 ml of 0.66 g/l lactose solution and 60 ml of pretreated taro solution (in addition, add 90 ml of domestic sewage without organic matters) to each cycle. Control the carbon source concentration of sodium acetate, glucose and lactose to 0.24 g/l.

After the organic matter is decomposed by microorganisms, electrons are generated, which makes the voltage at both ends of MFC rise rapidly. After a period of rise, the voltage at both ends of MFC enters a stable period. The time when the voltage of MFC is in a stable period is related to the amount of anode substrate added. When the anode organic matter is about to be consumed, the organic matter concentration of the anode solution will drop to a certain value, and the voltage at both ends of MFC will start to drop until the anode substrate is completely consumed, at that time the voltage of MFC will approach zero. That is a single growth cycle of MFC.

3. Results and discussion

3.1 Electricity generation cycle of MFC with different substrates

The voltage rise cycle of MFC with sodium acetate as substrate is 0.5 d (see Figure 2). In the culture cycle, the voltage at both ends of the microbial fuel cell rises from 0.05 V to about 0.77 V. When the voltage at both ends of the cell rises to 0.77 V, the voltage at both ends of the cell is basically stable, and the cell can maintain the voltage value of 0.77 V normally, and the maintenance time is about 23 d.

The sodium acetate in the solution can provide the normal growth consumption of microorganisms. When the concentration of sodium acetate in the solution drops to a certain value, the normal growth of microorganisms in the solution cannot be maintained. The energy consumption of microorganisms is insufficient, which makes the voltage at both ends of the cell start to decline. When the organic sodium acetate in the solution is gradually consumed, the voltage at both ends of the cell shows a downward trend. As shown in Figure 3, in the later stage, the electromotive force at both ends of microbial fuel cell shows a downward trend for 91.2 h, so the whole growth cycle of microbial fuel cell is about 27 d.

In the first cycle, the voltage stability time of four kinds of anode substrate MFC is 23.98 d, 20.15 d, 18.84 d and 23.52 d, respectively. The second cycle operation stability time of four kinds of anode substrate MFC is similar to the first cycle.
3.2 Electricity generation performance of MFC with different substrates

By analyzing the voltage changes of microbial fuel cell growth cycle with four different carbon sources, we found that the stable voltage at the two ends of the resistance of microbial fuel cells with four different anode substrates are 0.77 V, 0.75 V, 0.65 V and 0.70 V respectively. The MFC with sodium acetate as anode substrate has the highest output electromotive force (about 0.77 V) and the longest maximum voltage generation time when the voltage was stable. The output electromotive force of glucose is about 0.75 V, and it has good electricity production characteristics. When the pretreated Colocasia antiquorum Schott is used as anode substrate, the time required for the cell voltage to rise from the initial value to the stable value is the shortest. As a carbon source, it can also play its dominant role in the process of energy collection and utilization. As a disaccharide, lactose needs to be digested to decompose into glucose and galactose, and the output voltage value is relatively low. The experimental results show that when four different carbon sources are used as anode substrate, the output electromotive force of the cell with sodium acetate as substrate is the highest, and the voltage stable period is the longest.

It can be seen from Figure 4 that the stable period of the first cycle voltage of the cell is 23.98 d, and the output power is 0.593 mw. The energy generated in the stable period of the electromotive force is about 1228.62 J after replacing the anode solution of sodium acetate each time.

Electric current: \[ I = \frac{U}{R} = \frac{(0.77V)}{1000\Omega} = 0.77\text{mW} \]  

Power: \[ P = \frac{U^2}{R} = \frac{(0.77^2\text{V})}{1000\Omega} = 0.593\text{mW} \]  

Energy: \[ W = P \times t = 0.593 \times 23.98 \times 24 \times 3600\text{s} = 1228.62\text{J} \]
Figure 4. MFC cycle graph of different anode substrates

4. Conclusion

(1) The four kinds of microbial fuel cells with sodium acetate, glucose, lactose and pretreated Colocasia antiquorum Schott as anode substrate had the following power generation periods: 23.98 d, 20.15 d, 18.84 d and 23.52 d, respectively, and the stable voltage at the two ends of the resistance of microbial fuel cells with four different anode substrates are 0.77 V, 0.75 V, 0.65 V and 0.70 V respectively.

(2) The output power of the microbial fuel cell with sodium acetate as the substrate in the first cycle is 0.593 mW, and about 1228.62 J energy is generated in the voltage stable period after the anode solution of sodium acetate is changed every time.

(3) At the same carbon source concentration, MFC with sodium acetate as the substrate has the best electricity production characteristics. When the pretreated Colocasia antiquorum Schott is used as anode substrate, the time for cell voltage to rise from initial value to stable value is the shortest, and as a carbon source, it can also play a dominant role in the process of electric energy collection and utilization.

Acknowledgements

This work was financially supported by Fujian Science and Technology Guiding Project (2018Y0079), Natural Science Foundation Project of Fujian Province (2018J01527), Key Laboratory of Environmental Biotechnology (XMUT), Fujian Province University

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