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Original Research Paper

Performance Study on Microbial Fuel Cell Treating Restaurant Wastewater

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ABSTRACT

Microbial fuel cell is regarded as a new wastewater treatment technology, which has the advantages of high-efficiency, low energy consumption, clean and environmental protection. As a complex biological electrochemical reaction system, many factors will have significant impacts on its performance. Solving the bottleneck problem of microbial fuel cell, operation is the key precondition to promote its practical application. This paper studies the effect of electrolyte and electrode area on the microbial fuel cell for wastewater treatment through experiments, so as to provide the basis for applying microbial fuel cells into an actual wastewater treatment system. The experimental results show that using microbial fuel cells for restaurant wastewater treatment, we can achieve water purification effect in certain, and electrolyte and electrode area are important factors affecting the wastewater treatment performance. By choosing a suitable cathode electrolyte, the sewage treatment performance of the microbial fuel cell can be improved effectively.

INTRODUCTION

With the continuous growth of the world population and the rapid development of the global economy, human beings face the dual pressure of energy crisis and environmental pollution. The high energy requirement in the conventional sewage treatment systems is demanding for an alternative treatment technology, which will require less energy for its efficient operation and recover useful energy to make this operation sustainable. Application of microbial fuel cell (MFC) for wastewater treatment could be an attractive alternative to reduce the treatment cost and generate electricity (Li et al. 2014, Oh et al. 2010).

Microbial fuel cell is a kind of biological reaction device which converts chemical energy to electrical energy during substrate oxidation with the help of microorganisms. MFC produces electricity while purifying wastewater and cause no pollution to the environment during the power generation process (Logan et al. 2006, Singh et al. 2010, Rabaey et al. 2005). MFC is regarded as a new wastewater treatment process which has the advantages of high-efficiency, low energy consumption, clean and environmental protection (Du et al. 2007). In recent years, research on microbial fuel cell for wastewater treatment is gradually increasing (Mathuriya & Sharma 2010, Pandey et al. 2011), but these research works are still in the laboratory research stage.

Microbial fuel cell belongs to a complex biological electrochemical reaction system where many factors such as substrate concentration, environmental temperature, biological environment, load disturbance and some others will have significant impacts on its performance. Therefore, some problems of microbial fuel cell such as stability, reliability and efficiency must be resolved before putting it into a large number of applications (Das & Mangwani 2010, Oliveira et al. 2013).

This paper studies the purifying effect of MFC treated restaurant wastewater. A double chamber microbial fuel cell is used to run in different electrolyte and electrode, so as to find suitable operating condition for MFC.

MATERIALS AND METHODS

Construction of the Experimental System

The experimental system is composed of three parts: a dual chamber MFC reactor, an external load and a data acquisition system, as shown in Fig. 1. The voltage generated by the microbial fuel cell in the experiment is gathered by a data acquisition card and then transmitted to a computer for processing and display. The influent COD and the effluent COD are monitored respectively by a tester and then used for comparison.

Experimental Materials and their Pre-treatment

Sludge acclimatization: The activated sludge used in anode region is collected from the artificial lake in the campus, and restaurant wastewater in 2:1 dilution is used for its domestication and cultivation. The collected sludge and the configured sewage is put into the culture bottle; some nitrogen is added to remove the existing oxygen so as to make an anaerobic environment. Then this sludge is put into a biochemical incubator and the temperature is set to 20°C for further cultivation. During the cultivation period, carbon source, nitrogen, phosphorus and other nutrients are regularly added for the growth of microorganisms. When the sludge presents floc and suspends in culture medium, it can be used for experimental research.

Sewage disposition: The wastewater used in the experiment is collected from the school cafeteria swill, mainly the residue of food and soup. The concentration of canteen waste is more, and the biodegradable ingredients are high. After diluting, it is used as the experimental material in MFC system. The dilution water is composed of water and phosphate buffer solution (PBS) with the volume ratio configured as 1:1.

Electrode materials and pretreatment: Carbon felt are used as the anode and cathode material of the microbial fuel cell. The carbon felt needs pretreatment before use, so as to remove the surface impurities and metal ions. First, dip it in a hydrochloric acid solution with the concentration of 0.1 mol/L for 24 hours, then rinse it with distilled water. Next, dip it in sodium hydroxide solution with the concentration of 1.0 mol/L for 24 hours, and then rinse it with distilled water to reach neutral; finally dip it in deionized water to spare. The carbon felt is connected with copper wire to form electrode, and the junction between carbon felt and wire is fixed and sealed by silica gel, so as to prevent electrochemical corrosion in the process of experiment. In the experiments testing the effect of cathode electrolyte, the area of the electrode is kept at 7×7 cm^2.

Proton exchange membrane and its pretreatment: The proton exchange membrane used in the experiment is Nafion 117. The exchange membrane also needs to be pretreated before use. First boil it in H_2O_2 solution with the volume fraction of 5% for 1 hour for removal of organic impurities in the film, then rinse it repeatedly with deionized water, and then put it into H_2SO_4 at the concentration of 1.0 mol/L to boil for 1 hour, to make it transform into H^+-type, and then rinse it several times with deionized water. Then put it into deionized water to boil for 1 hour and finally rinse it with deionized water for 5-6 times to remove the residual H_2SO_4 in the membrane. Put the processed membrane in deionized water to spare.

EXPERIMENTAL RESULTS AND ANALYSIS

Start runs of a double chamber MFC

First, start the microbial fuel cell in a routine operational state. The data are recorded every minute for one experiment, and store to the computer automatically.

In order to analyse the sewage treatment effect of the microbial fuel cell, COD and BOD removal rates were tested. The influent wastewater and effluent BOD_5 were determined by the BOD_5 tester, OxiTop. The calculation formula is as follows:

$$BOD_5 = [FM_1(V_v + V_p)/V_p] - FM_2V_v/V_p \quad ...(1)$$

Where, F is a coefficient which is 20 in this study, M_1 is the digital display value of the BOD_5 tester, V_v is the vaccinating dilute water volume, V_p is the volume of wastewater, and M_2 is the displayed value of the dilution water, which is 1 in this study.

Because the cafeteria wastewater has a large biodegradability, its BOD value can be estimated as 80% of the value of COD. Then COD can be calculated as:

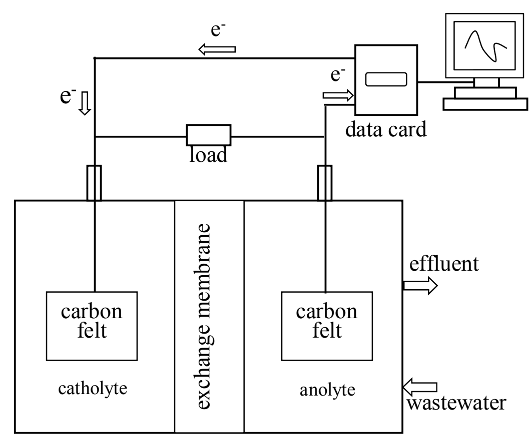

Fig. 1: Experimental system of microbial fuel cell.

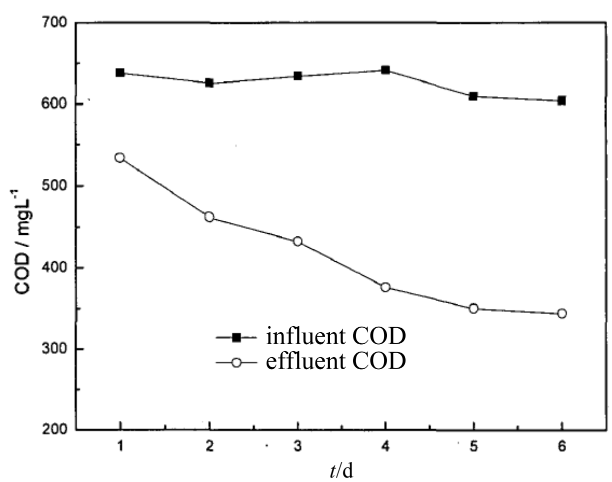

Fig. 2: COD variation with the change of time.

$$COD = \frac{BOD_5}{80\%} \quad ...(2)$$

The monitoring data graph of COD in the experiment is shown Fig. 2. The inlet of the microbial fuel cell is obtained by diluting the restaurant wastewater, and the value of COD is about 600-700mg/L. With the increasing time, the effluent COD of the MFC decreased obviously. Also with the increasing time, the COD removal rate for wastewater increased from 16.27% to 30.5%. Hence, we can say that, with the increasing time, a biofilm grows on the anode, and the wastewater treatment efficiency enhances.

Effect of Cathode Electrolyte on Wastewater Treatment Efficiency

Potassium ferricyanide as catholyte: The main role of the cathode is to accept electrons and protons released by the anode. In theory, all oxidants can be used as the cathode electron acceptor of the microbial fuel cell. As a liquid electron acceptor, potassium ferricyanide ($K_3[Fe(CN)_6]$) has the advantage of higher oxidation reduction potential, lower over potential and more stable performance, so it is the most used electron acceptor in researching two-chamber microbial fuel cell.

The removal rate curve of COD by microbial fuel cell with potassium ferricyanide as cathode solution is shown in Fig. 3. We can see that the removal rate of COD in this condition is about 23%. The experimental results show that the purifying effect of microbial fuel cell with potassium ferricyanide as cathode solution is well-tried. However, the potassium ferricyanide is relatively expensive and it has strong toxicity. Also, after long time operation, it easily diffuses into the anode chamber to endanger the microbial population and pollute the proton exchange membrane, which leads to a situation where the membrane cannot be used repeatedly. The potassium ferricyanide solution also cannot be recycled and thus the cathode solution needs to be replaced constantly. Owing to these problems the experimental system is quite complex and harmful.

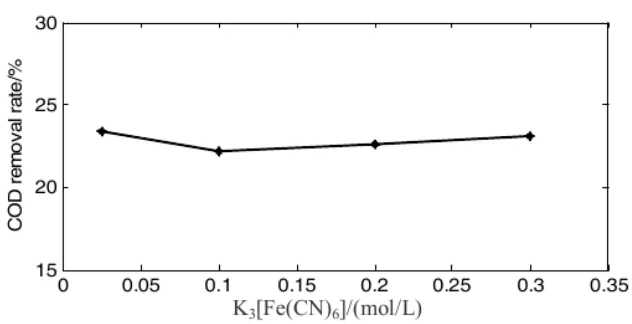

Fig. 3: Removal rate of COD with potassium ferricyanide as catholyte.

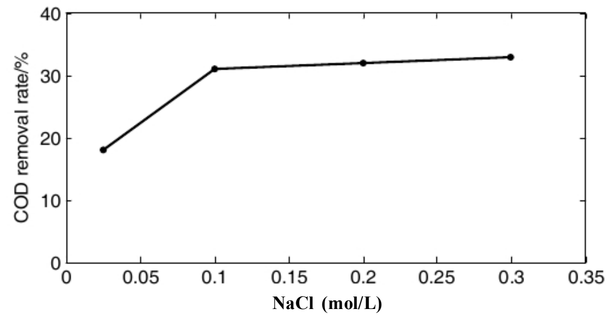

Fig. 4: Removal rate of COD with sodium chloride as catholyte.

Sodium chloride as catholyte: Sodium chloride (NaCl) solution is used as the cathode electrolyte to test the purifying effect of microbial fuel cell. The experimental result is shown in Fig. 4. The removal rate of COD is about 32%. The purifying ability of microbial fuel cell with sodium chloride as cathode solution is better than that with potassium ferricyanide as cathode solution. Moreover, sodium chloride is not consumed in the reaction process of microbial fuel cell. From the perspective of wastewater treatment, sodium chloride is more suitable to be used as catholyte than potassium ferricyanide.

Effect comparison of the two kinds of catholytes: The effect comparison of COD removal rate of microbial fuel cell with two different kind of catholytes is shown in Fig. 5. It can be seen from the figure that the COD removal rates with sodium chloride as catholyte are higher than those of potassium ferricyanide as catholyte most of the time, except when the concentration is 0.025mol/L. It can also be seen that when potassium ferricyanide is used as the electrolyte, the removal rate of COD almost does not change with the increase in electrolyte concentration; while when sodium chloride is used as electrolyte, the removal rate of COD increases with the increasing concentration of the electrolyte.

Effect of Electrode Area on Wastewater Treatment Performance

Because carbon felt has an advantage of high conductivity and suitability for bacterial growth, it has been used as an

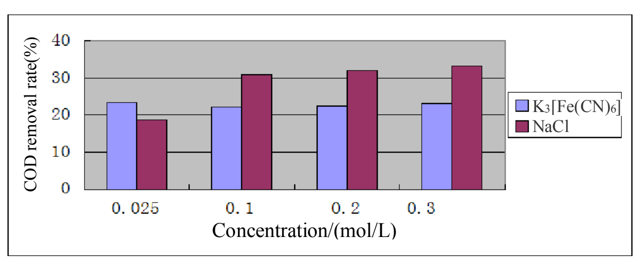

Fig. 5: Effect comparison of two kinds of catholyte.

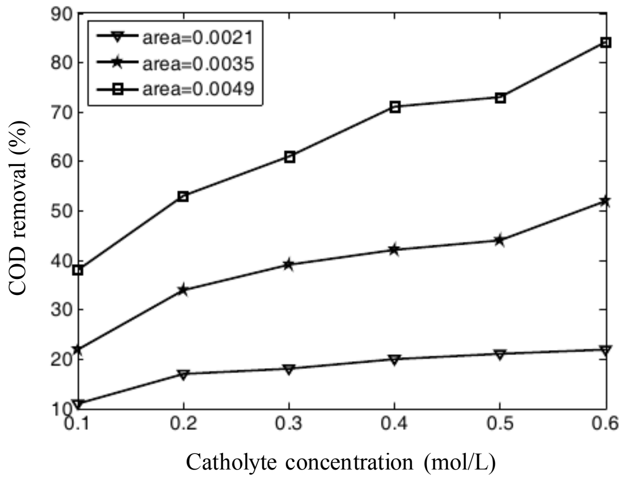

Fig. 6: Removal rate of COD with change of electrode area.

anode and cathode material in our experiments. In the course of the experiments, a single variable control method is used to test the effect of electrode area on wastewater treatment performance. That is, only one variable is adjusted but all others are set at the same conditions. Here, the type and concentration of electrolyte, concentration of substrate, temperature, and so on, are exactly the same; while the anode area is the only changed condition. In the experiments, three different sized carbon felts, i.e. 0.0021 m^2, 0.0035 m^2, 0.0049 m^2 are tested respectively. The experimental results are depicted in Fig. 6.

It can be seen from Fig. 6 that the COD removal rate increases with the increase in electrode area. Larger the electrode area is, the higher the removal rate is.

CONCLUSIONS

Use of microbial fuel cells for restaurant wastewater treatment can achieve good purifying effect. The electrolyte, electrode and other factors will have a great influence on the effect of sewage treatment. For promoting the microbial fuel cell into a practical wastewater treatment process, exploring more suitable electrolyte, electrode, membrane, substrate, etc. for the microbial fuel cell are necessary.

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