Research on Microbial Fuel Cell in Water Treatment and Power Generation

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Abstract. With the development of economics, water pollution is becoming increasingly serious, and the existing sewage treatment technology has high energy consumption. Therefore, the development of low energy consumption, safe and environmental protection technology is the trend of in further. Microbial fuel cell (MFC), as an emerging comprehensive technical method for wastewater disposal, shows great application prospects. In this work, the working principle and function of different types of MFC, the application of MFC in sewage treatment field, and the shortcomings of MFC devices to be perfected in the market are discussed.

Keywords: single-chamber microbial fuel cell, double-chamber microbial fuel cell, nitrogen removal, heavy metal-rich wastewater.

1. Introduction

Water is a basic component for human survival and an indispensable material resource for social development. Water resource is an important factor to maintain industrial, agricultural and energy production, and promote social and economic development. Along with the economic development, inevitably is the pollution of water resources, industrial wastewater and domestic sewage are the two major influencing factors of water pollution, according to the United Nations statistics, 2 billion tons of effluent and other waste water are dumped into the oceans worldwide everyday, leading to health pressure and environmental pressure [1]. Improper management and disposal of industrial and agricultural waste is the biggest source of water pollution. More than 80% of waste water is discharged untreated into the hydrosphere [2]. The waste water penetrates into the soil and damages groundwater resources, which causes serious damage to the natural environment.

At the same time, energy shortage is also important problem humans are facing at present. At present, especially in developing countries, economic development relies on non-renewable traditional energy, burning fossil fuels and polluting the atmosphere with carbon dioxide. According to the International Energy Agency's projection on carbon dioxide emissions for 2021, the energy industry contributed 36.3 billion tons of carbon dioxide to world emissions [3]. The growth of green and clean energy is the general tendency in response to the concern of energy scarcity and air pollution.

Wastewater treatment and the development of new energy sources are important issues of national concern. As a new technology, MFC has a broad prospect for sewage treatment and electricity generation. MFC utilize microorganisms as anode catalysts to degrade organics and treat wastewater through REDOX reactions, while generating electrons and capturing electricity. In this paper, the principle of MFC, the structure of MFC, and treatment of wastewater via MFC are discussed.

2. The working principle and structure of MFC

2.1. Principle about double chamber work

The two-compartment MFC is consisted of an anode chamber (anaerobic chamber) and a cathode chamber (aerobic chamber) as shown in Fig.1. Working principle of double chamber MFC as follows, in the anaerobic chamber, using microorganisms as catalytic oxidation of organic and inorganic substances and release electrons and protons, the electronic through microbial respiratory enzyme is transferred to the anode, the anode chamber and cathode interior ministry is proton exchange

membrane separating, external loop circuit via wire connection, electrons are connected by a conducting material of cathode current formation, Water is created when protons travel from the cathode through the proton exchange membrane.

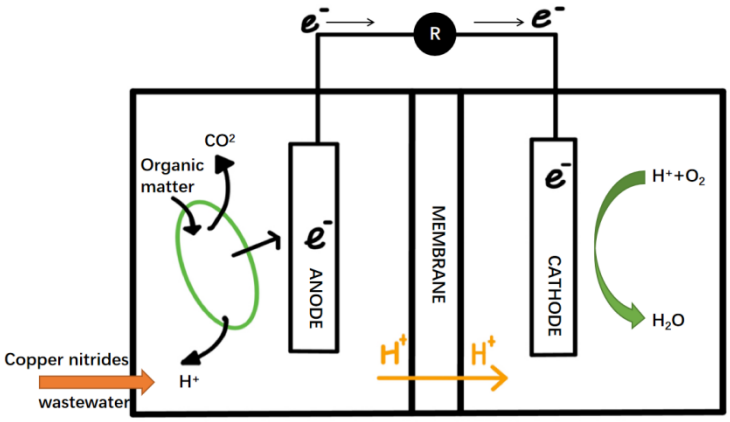


Fig.1 Structure diagram of microbial fuel cell

2.2. Double chamber structure

Two-compartment MFC is mainly composed of anode, biofilm, cathode and electrogenic microorganism. The selection of the anode material has a significant impact on how microorganisms attach, developing, and transfer electrons. Graphite, carbon sheet, carbon felt, and other carbon-based substances are currently the most common electrode materials utilized in the anode of microbiological fuel cells, but they are expensive. Huang Xia et al. select four different anode materials to compare the MFC's electrical capabilities [4]. The effects of porosity, surface area, and power density on anodic electric production were examined in a two-compartment MFC. The specific surface area of grain graphite (2-5mm) is 0.623 m^2/g, and the porosity is 55%, and the power density is 26.1 W/m^3. The specific surface area of carbon felt cube (2-5mm) is 0.845 m^2/g, and the porosity is 55%, and the power density is 27.9 W/m^3. Granular activated carbon (2-5mm), with a battery capacity of 31.5 W/m^3, a surface morphology of 686 m^2/g, and a porosity of 60%. The larger the specific surface area (SSA) of the material, the higher the conductivity and the higher the power density, the more electricity will be generated. It can be determined that the choice of granular activated carbon as anode material is the most appropriate. Meanwhile, the modification of the anode material can also improve the electric generation efficiency, increasing the superficial area of the anode material, improving the reactivity, changing the surface functional groups, accelerating the speed of anode electron transfer, improving the electrochemical performance of the pole, and effectively enhance the electric production. Carbon nanoparticles as anode materials, good electrical conductivity and biocompatibility, is an excellent choice of anode materials. Zhu K. studies the performance changes of the anode material carbon cloth modified by porous carbon nanoparticles [5]. Through experiments, it was found that the area power density of the carbon cloth modified by HPCNs was 1.72 W/m^2, and the area ampere density was 4.52 A/m^2. Compared with the pure carbon cloth, the electron transfer speed and cell viability were greatly increased, and the nanoscale and porous structure increased the anode surface area. The reaction rate was increased and the direction for the preparation of anodic materials with good performance was provided.

The electric efficiency is also affected by the biofilm, and the material and area of the biofilm affect the proton migration resistance. Sun uses microfiltration membrane as biofilm, and the maximum power density of MFC when microfiltration membrane is used is 2 times higher than that of traditional proton membrane [6]. Kong Xiaoying et al study the electric generation rate of ordinary bipolar membrane, special bipolar membrane and proton exchange membrane with potassium ferricyanide solution as electron acceptor and CH_3COONa as carbon source, and found that the proton exchange membrane had the smallest internal resistance of 79.29 ohms and get a highest energy

density of 3.75 W/m^2 [7]. Rossi R. studies the comparison of anion exchange membrane (AEM) with cation exchange membrane (CEM) and non-ion selective ultrafiltration membrane (UFM) when phosphate buffer medium was used [8]. The results indicate that: The watt density of AEM is 8.8+0.5 W/m^2, and CEM is 3.1+0.1 W/m^2, and UFM is 2.4+0.1 W/m^2. It can be concluded that the watt density of CEM or UFM is less than one-third that of AEM., which can make MFC generate more stable power. Therefore, different materials of biofilm can produce different electricity efficiency.

2.3. Principle about single chamber work

The cathode and anode of single-compartment MFC are in the same reaction chamber, which does not require a biofilm. Organic material on the anode is oxidized by microorganisms, and conductive materials carry electricity toward the cathode, protons are transferred directly to the negative pole, and oxygen acts as the electron acceptor for MFC.

2.4. Single chamber structure

The single-compartment structure has 3-in-1 MFC. As a new type MFC, it combine anode, cathode and PEM in a reaction chamber. The output efficiency of this device is very high because its internal resistance is very small. The two-in-one MFC directly combines the cathode and proton membrane together, and the anode is independent. There are also membrane-free cathodes, which lack PEM membranes and have the advantage of increasing the maximum watt density of the battery. Cathode performance is the factor that affects the energy generation efficiency of single-cavity MFC. The cell's maximum voltage is impacted by the voltage differential between the electron acceptors on the cathode and anode. In MFC, the anode substrate is mostly organic matter, and the potential difference of organic matter is not large. Therefore, the limit voltage value of MFC is determined by the type of cathode electron acceptor. The cathode electron acceptor is usually oxygen, potassium permanganate and hydrogen peroxide. As the cathode, oxygen is clean, pollution-free and cheap. However, the reaction speed of oxygen is slow, and a catalyst is needed to improve the rate, which boost the operation expense of MFC equipment. Therefore, choosing cathode materials with low cost and high reaction rate, such as MnO_4 or TiO_2, can make MFC more efficient. Amit C. studies the electrocatalytic performance of the synthesis of Co and Ni nanocatalysts used by TiO_2 nano-tube for single-compartment MFC. The results show that TiO_2NTs is an efficient and cheap cathode catalytic material. Similarly, improving the cathode can also improve the operation efficiency of the MFC device [9]. The electrochemical tests conducted by the Shaoan Cheng study on carbon cloth electrodes coated with various quantity of DLs found that when the negative pole of the air driven microbial fuel cell increased to 4-dL, the CE increased by 171% and the maximum power density increased by 42% [10]. The REDOX rate and electron transport capacity of MFC device can be significantly improved by improving the cathode. Cathode plays an important role in MFC property.

2.5. Single-compartment versus two-compartment comparison

Comparing the internal resistance, power density and Coulomb efficiency of single-compartment and double-chambered MFC, the internal resistance of single-chambered MFC is lower than that of double-chambered MFC. Compared with two-compartment MFC, single-compartment MFC has smaller distance between anode and cathode, and no proton exchange membrane resistance. Under the same fuel condition, according to the principle that the higher the resistance, the lower the power density, the greater the resistance of two-compartment MFC is, so the power density of two-compartment MFC is smaller than that of single-compartment MFC. The coulombic efficiency of single-compartment MFC is lower than that of two-compartment MFC because the oxygen in the single-compartment cathode oxidizes the reactive material.

3. Utilization of MFC in wastewater treatment

3.1. Principle of application

Wastewater can be divided into two categories according to whether it can be biodegraded. The degradable wastewater is treated in the positive electrode compartment of the MFC device, while the refractory wastewater needs to be degraded under the condition of co-metabolism. Biodegradable wastewater contains electron-rich small molecules of organic matter and carbohydrates, which are often used as anode substrates. The refractory wastewater contains phenols, heavy metals and other substances that degrade slowly naturally. Microorganisms on the electrode surfaces oxidize and break down organic material in MFC under anaerobic conditions, generating protons and electrons. At the cathode, these electrons conduct REDOX reactions with electron acceptors. MFC can degrade organic matter in water, remove nitrogen and desulfurization, REDOX metals and remove harmful metals.

3.2. Microbial fuel cell biosensor

Microbial fuel cells can purify sewage and obtain transmission voltage and electrical signal by using the electron transfer process of electrochemically active bacteria, so that the chemical energy contained in organic matter in sewage can be converted into electric energy, and the COD content can be monitored according to the generated electrical signal. The traditional sewage monitoring methods have high accuracy, but the cost is high and the operation is complex. The microbial fuel cell monitoring of nitrogen compounds and heavy metals in sewage is fast, convenient and accurate. Biosensor research has been extensively described in the published papers on microbial fuel cells. Do M. studies the copper content of wastewater by using a two-compartment microbial fuel cell biosensor (DC-MFC-B) [11]. The experiment demonstrated that the maximum voltage of the sensor was linearly related to the concentration of heavy metals, with copper having a linear coefficient of 0.989, and that the output voltage of the DC-MFC-B declined as copper concentration increased. Microbial fuel cells have a broad prospect in heavy metal monitoring. Do M.studies the monitoring of ammonium content in municipal wastewater by microbial fuel cells, and the experiments were conducted under different ammonium concentrations [12]. The study showed that the ammonium concentration was negatively linear with voltage, and when PH=7, R=1000 ohm and HRT=24h, it was the best condition for the biosensor to monitor ammonium ion. The above two studies proved the feasibility of MFC biosensor for metal substance monitoring in wastewater, and the reliability of the biosensor was illustrated by comparing with the traditional method.

3.3. Removing pollutants in wastewater and generating electricity

3.3.1 Treatment of nitrides in wastewater

Excessive nitrides discharged from industrial wastewater and domestic sewage will harm water bodies and cause eutrophication. The use of MFCS to treat nitrogen-containing wastewater has been widely studied because of their cleanliness and their ability to produce electricity while treating sewage. Vanatpornratt reduces nitrogen content in wastewater by single-chamber air MFC [13]. The influence of COD consistence on MFC denitrification efficiency was studied. The elimination rate of COD was 69% at a COD consistence of 500 mg/L, the greatest figure for the COD removal rate is 79% when the COD consistence is 1000 mg/L, the COD clearance rate falls to 58% at a COD consistence of 2500 mg/L. This study shows that COD concentration has a great impact on MFC nitrogen removal. When the concentration is 1000 mg/L, the removal efficiency of nitrogen pollutants is the highest and MFC performance is the best. Not only COD concentration can affect the efficiency of nitride removal in wastewater, but also resistance can affect the efficiency of nitride removal and power generation. In single-chamber air MFC, Vanatpornratt contrasts the ability of two types of resistors to generate electricity and purify water [14]. With a 500-ohm resistance, MFC's maximum watt density was 12.5% greater than with a 1000-ohm resistance, and the current output was increased by 23.3%, indicating that MFC with 500-ohm resistance had better power generation performance

and higher COD removal rate. Both COD concentration and battery resistance can affect the rate of nitride removal from wastewater. Likewise, the selection of bacteria also affects the wastewater treatment results. Because the traditional denitrification bacteria grow slowly and have poor adaptability to surrounding environment, researchers have developed a new biological decarbonization technology, which can carry out nitrification and denitrification at the same time and has stable characteristics. In the study of nitrification reaction of novel cuprum-resistant bacilli, it mentions heterotrophic nitrification aerobic denitrification, the denitrification effect is very good, when the C/N is 12-28, the denitrification rate is above 95% [15].

3.3.2 Treatment of wastewater containing heavy metals

Heavy metals have become the one of the main factors of current water pollution. The common harmful heavy metals are copper and chromium. If discharged into water without treatment, they will not only cause ecological damage, but also irreversible damage to human health. MFC can remove heavy metals through REDOX reactions. Using carbon nanotubes and MnO_2/CNTs modified graphite anode, the maximum output voltage obtained by Zhou J. is 0.67 V, and the highest efficiency is 1044.21 mW/m^2, and the copper removal rate was 98.93% [16]. Liu S. develops a modified clay cup (MCC) as the cathode of membrane-free microbial fuel cells (ML-MFC). Within 7 days, the power density of ML-MFC was 113.7 mW/m^2, and the Cu^{2+} removal rate was 96.5%. Additionally, the ML-internal MFC's resistance can be decreased and the energy yield increased by the Cu_2O produced by the REDOX reaction [17]. Lin C. inoculates Cu-reducing white rot bacteria on ceramic microbial fuel cells to obtain a higher removal rate of Cu. The data show that the maximum power density of FEA-MFC is 41.3 mW/m^2, the removal rate of Cu^{2+} (50-200mg/L) is up to 99%, and the current is increased by 1.65 times [18]. Cr^{6+} pollution has become one of the most serious heavy metals, which has strong carcinogenicity to human body. MFC device is used to reduce the toxicity of Cr^{6+} and remove Cr elements from water. With a PH of 2, Li Z. investigates the consequences of employing graphene sheet as the negative electrode material, when the initial concentration of Cr containing wastewater was 204 ppm by MFC, the greatest power density was 1600 mW/m^2, the clearance rate of Cr^{6+} was 99.5%, and the total Cr removal rate was 66.2% [19]. Using MFC to remove and recover heavy metals from water is an innovative technology with broad market prospects, which is of great significance for water resources protection and metal resource recovery.

4. Development trend

MFC is a recent biotechnology that produces electricity while treating wastewater. It has a broad prospect for solving water pollution and energy shortage, and is also a hot technology in the environmental field. So far, MFC technology has been developed rapidly. A lot of research has been done on optimizing reactor design, optimizing biofilm, developing electrode materials, and improving battery power density. The research results have provided sufficient theoretical support for productivity and solving wastewater problems. However, MFC have not yet been commercialized, and its use in sewage wastewater treatment research is currently limited to small-scale laboratory experiments, mainly considering the following factors.

MFC devices require relatively expensive materials. Due to the high cost of biofilms, they cannot be applied in practice. Therefore, the market needs to focus on the research and development of cheap and efficient biofilms and catalysts.

The technology is not mature enough, it is necessary to continue to optimize the reactor structure, decrease the device’s reactance, increase output energy capacity, increase the rate of chemical energy into electric energy, so that the power generation capacity is stronger, and the application efficiency is higher.

To expand the selection of microbial species, the electron-producing mechanism of electron-producing bacteria should be studied, the genes of high-efficiency electron-producing bacteria should be modified, and the electron-producing bacteria with higher efficiency and stronger tolerance should be cultivated. By striving to solve the cost problem, selecting efficient electrogenic bacteria and

optimizing the structure of the device, MFC will be applied in the field of new energy and sewage treatment as soon as possible.

5. Conclusion

MFC is a technology that combines generating new power source and dealing with environmental pollution. In this paper, sewage treatment and power generation with MFC is discussed. Firstly, the structure of MFC is introduced from two aspects, including the structure of single room and double room structure are analyzed. Secondly, the different kinds of MFC dealing with waste water and nitrides, metal material is discussed. MFC technology is still in the experimental stage and has not yet been widely used, however, with the improvement of the technology, it has a good prospect in capacity generation of electricity, sewage treatment and biosensors.

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