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Study on the Degradation of Ship Oily Sewage by Double-chamber MFC

Weijie Yang, Chun Zhao, Rui Sun, and Shaojun Zhang*

School of Shandong Jiaotong University, Weihai 264200, China

*Corresponding author

Abstract

With the rapid development of the global shipping industry, the pollution of marine ecosystems caused by ship oily sewage is becoming increasingly severe, and the traditional single physical, chemical and biological treatment technology has problems such as high energy consumption, easy secondary pollution and insufficient degradation rate of emulsified oil in the treatment of ship oily water. Therefore, this study focuses on the application of dual-chamber microbial fuel cells (MFCs) in the field of degrading oily sewage from ships. The surface modification of carbon felt anode materials was carried out by chemical activation method, and a two-chamber MFC device was constructed to further explore the effects of different anode materials on the power production performance of MFC and the degradation effect of oily wastewater. The experimental results show that the performance of phosphoric acid-activated carbon felt is particularly outstanding, with a maximum output voltage of 676 mV, which is 25.4% higher than that of unactivated carbon felt and 52.53% higher power density. In terms of the degradation of oily wastewater, it is also significantly better than other modified materials. It has been confirmed that phosphoric acid activation can effectively improve the power generation and degradation efficiency of MFC by increasing the hydroxyl functional group on the surface of carbon felt, improving hydrophilicity and electrochemical properties, and providing a promising technical solution for the treatment of oily wastewater from ships.

Keywords

Microbial Fuel Cell; Oily Sewage From Ships; Carbon Felt; Degradation Efficiency.

1. Introduction

In recent years, the two major problems that have plagued people are environmental issues and energy issues[1]. At present, fossil energy is still the core support of the global energy system, but the pollutants released during its combustion have had a significant negative impact on the atmospheric environment, coupled with the continuous consumption of non-renewable reserves, the transformation of the energy structure is imminent. In this context, Microbial Fuel Cell (MFC) technology has gradually become a research hotspot in the field of clean energy due to its unique environmental protection characteristics and energy conversion advantages, providing innovative solutions to solve the dual dilemma of environment and energy. Ship oily sewage has always been a difficult problem in wastewater treatment due to its wide range of sources, complex water quality, and large output. According to the location of ship oily water, ship oily water can be divided into three categories, namely oily tank washing water, ship ballast water, and engine room bilge water[2].

Oily tank water refers to the wastewater generated by ships during operations such as cabin cleaning and maintenance, which contains a large amount of oily substances, and the oil content of oily tank water can reach 2000~10000 ppm, which will lead to serious ecological and

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environmental damage if it is not treated in time and directly discharged into the ocean. There are two main reasons for the formation of oily tank water: first, when the ship transports different goods, there may be residual oil substances in the cargo hold, and in the process of cabin cleaning and maintenance, these oil substances are mixed with water to form oily tank water; Second, during the operation of the ship, the staff needs to repair and maintain the inner wall of the oil tank, and in the process of maintenance, a large amount of oily sewage will be brought out due to the cleaning of the inner wall and pipeline of the oil tank[3].

Ship ballast water refers to the water that is injected or discharged in the hold of a ship in order to maintain stability under different load conditions[4]. When seawater is injected into a cargo or ballast tank, this water binds with the viscous oil on the bulkhead to form an oily ballast water[5]. When the ship encounters extreme weather, sometimes ballast water will be injected into the oil tank of the ship to maintain the normal operation of the ship, and the oil content of the ballast water of the ship can reach 4000~7000 ppm.

Bilge water refers to the oily water formed after the ship's various types of wastewater and waste oil leak to the bilge. Ship bilge water is mainly formed by the mixture of two types of liquids: one is oily wastewater generated by equipment maintenance and cleaning operations, and the other is oil leakage caused by aging mechanical parts or seal failure. These liquids are collected through deck drainage holes, pipe gaps, and other channels to the low-lying part of the bilge, and eventually form an oily sewage mixture. The oil and water form a mixture in the bilge area of the ship, and under the mechanical stirring caused by the shaking of the hull during the navigation of the ship, a stable oil-water mixing system is formed, and the oil content of the bilge water can reach 2000~5000 ppm after testing and analysis.

A typical MFC setup consists of a cathode chamber and an anode chamber, separated by a proton exchange membrane (PEM) or ion exchange membrane. The power generation process of MFC mainly includes the following steps: (1) at the anode, the electrogenous microorganisms produce electrons and protons while decomposing organic matter through their metabolic action, and the electrons are transferred to the surface of the anode electrode under the action of microorganisms; (2) The protons produced in the metabolic activities of microorganisms migrate to the cathode region through the electrolyte solution, and the electrons enter the external circuit and begin to flow, generating an electric current; (3) At the cathode, the electrons recombine with protons and react with oxygen to form water. When an appropriate resistor or load is added to the external circuit, power output can be achieved and a continuous current can be obtained.

As the main site for the attachment and electron transfer of electrogenesis, the MFC anode determines the strength of the battery's power production capacity, and the ideal electrode material should have biocompatibility, excellent electrical conductivity, and stable chemical properties[6]. Different types of carbon materials, due to the difference in surface chemical properties, will show completely different performance in the selection of adsorption, catalytic characteristics, acidity and alkalinity and electrochemical properties, etc., in order to make carbon materials better fit various complex application scenarios, it is particularly important to modify their surface.

At present, for the surface modification of carbon materials, the common methods are mainly divided into the following categories: (1) surface oxidation modification, increasing the proportion of oxygen-containing functional groups on the surface of carbon materials, and the commonly used oxidants are sulfuric acid and nitric acid[7], H_2O_2[8] andO_3[9], etc.; (2) Surface reduction modification to increase the relative content of oxygen-containing alkaline functional groups on the surface of carbon materials, one method is to treat activated carbon in a high-temperature environment with the help of reducing agents such as H_2[10].and the other method is impregnation with ammonia[11]; (3) Supported metal modification, based on the adsorption and reduction characteristics of carbon materials themselves, the strong binding force between

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these metals or metal ions and specific adsorbents is used to load metals or metal ions onto the surface of carbon materials, thereby significantly enhancing the adsorption properties of carbon materials[12]; (4) Microwave irradiation modification, which uses the energy of microwave radiation to enable carbon materials to achieve efficient energy transfer and local thermal effects in a short time, thereby changing their physical and chemical properties, and improving their structural characteristics, conductivity, and porosity[13]; (5) Low-temperature plasma modification, which uses plasma to activate, etch, or chemically react on the surface of the material to change the surface chemical properties, structural characteristics, and other physical properties of the material[14].

2. Experiment Preparation

2.1. Construction of the Anode Chamber

(1) MFC anode pretreatment

In this experiment, carbon felt with excellent comprehensive performance was selected as the anode material of MFC device. During the production and storage process of carbon felt, impurities such as dust and oil will be adsorbed on the surface, which will occupy the active site on the surface of carbon felt, affect the attachment of microorganisms and the electron transport process, and reduce the performance of microbial fuel cells. Therefore, in order to give full play to the advantages of carbon felt as an MFC anode material, it is particularly important to pretreat the carbon felt electrode.Specific steps: according to the needs of the microbial fuel cell electric size, cut the carbon felt into a square of 1 cm × 1 cm, then put the cut carbon felt into the ultrasonic cleaner, add an appropriate amount of ethanol solution, ultrasonic cleaning for 30 min, so that the dust, oil and other impurities on the surface of the carbon felt fall off, after ultrasonic cleaning, take out the carbon felt, rinse it with deionized water, and finally dry it in the oven, and the drying temperature is set to 80 °C. The drying time was 12 h to remove the water and residual organic solvent in the carbon felt, and the pre-activated electrode was prepared for later use.

(2) Configuration of ship oily sewage

Combined with the special composition and properties of ship oily sewage, and with reference to the requirements of the simulated environment of ship sewage in relevant industry standards, the proportion of various solutes is adjusted in a targeted manner, so as to configure the artificial seawater of ship oily sewage. Add 29.52 g of sodium chloride to about 0.8 L of deionized water, stir to dissolve it, slowly add 0.05 L of standard solution A and 0.02 L of standard solution B again, stir well, add deionized water to 1 L to 1 L, and finally use 0.1 mol of sodium hydroxide solution to adjust the pH value to 8.2.

(3) Configuration of phosphate buffered acid (PBS)

PBS can resist the addition of a small amount of acid and alkali and play a role in maintaining the pH stability in the device, and $Na_2HPO_4 \cdot 12H_2O$, $NaH_2PO_4 \cdot 2H_2O$ and NaCl are used to prepare phosphate buffers.

(4) The configuration of microbial culture medium

The culture medium used in this experiment was mainly NB liquid medium.

Configuration of NB liquid medium: take 18 g of NB medium powder, add 1 L of distilled water, fully stir and dissolve in a beaker and then divide into multiple Erlenmeyer flasks, and seal the bottle mouth with breathing film and newspaper and place it in an autoclave, after 20 min sterilization, transfer it to a 35°C constant temperature incubator for continuous culture for 24 h, if the culture liquid in the incubator after 24 h is the same as before constant temperature culture, it is clear and transparent, then the NB liquid medium is successfully configured and can be used normally.

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2.2. Construction of the Cathode Chamber

(1) Preparation of MFC cathode catalyst

Manganese dioxide was used as a catalyst for oxygen reduction reaction, and its abundant redox active sites on the surface could effectively promote the four-electron reduction reaction of oxygen and significantly improve the electron transfer efficiency of the cathode. First, the carbon felt cathode was ultrasonically cleaned in ethanol and deionized water for 15 min to remove surface contaminants, and dried in an oven at 60°C for 2 h for later use. Then weigh 0.5 g$KMnO_4$ and dissolve it in 50 mL of deionized water, add 5 mL of 1 mol/L sulfuric acid solution, and immerse the pretreated carbon felt in the above solution at 80°C The water bath was heated and stirred magnetically for 2 h, and MnO_2 was deposited on the surface of the carbon felt by redox reaction, as shown in Equation 1.

$$3MnO_4^{2-} + 4H^+ \rightarrow 2MnO_4^- + MnO_2 \downarrow + 2H_2O \quad (1)$$

Finally, the carbon felt was removed and rinsed with deionized water to neutral, and the carbon felt loaded with MnO_2 was dried in a 60°C oven for 6 h, and the cathode catalyst was prepared at this time.

(2) Preparation of MFC catholyte solution

As an excellent electron acceptor, potassium ferricyanide can accelerate the electron transfer in the cathodic reaction, making the cathodic reaction efficiency of MFC higher, while the addition of KCl significantly improves the conductivity of the cathode solution and reduces the internal resistance of the electrolyte, thereby further improving the power density of the battery. Therefore, a mixture of 90 mM $K_3[Fe(CN)_6]$ and 60 g/L KCl was selected as the catholyte for MFC.

2.3. Preparation and Pretreatment of Proton Exchange Membranes

(1) Preparation of proton exchange membranes

The composite proton exchange membrane was prepared by solution casting method, firstly, ethanol and deionized water were mixed according to the volume fraction of 3:1, mixed with Nafion resin according to the mass ratio of 10:1, and then magnetically stirred at 50°C for 12 h to form a homogeneous and transparent solution, and then functionalized silica nanoparticles were added to the above solution at a ratio of 3.0 wt%, and sonicated2 h to ensure the uniform dispersion of the nanoparticles, the mixed solution was cast into the PTFE mold, dried by gradient heating (40°C→60°C→80°C) for 8 h to form a primary film, and then annealed at 120°C for 6 h to eliminate the residual stress and improve the crystallinity, thus completing the preparation of the proton exchange membrane.

(2) Pretreatment of proton exchange membranes

The residual organic solvents and unreacted substances in the process of proton exchange membrane formation can clog the proton conduction channel, and the Nafion membrane is usually in Na^+ or other inactive ionic form after preparation, which will significantly reduce the proton conductivity, so the pretreatment of the proton exchange membrane is a key step to ensure its stable performance.

Step 1: Activation. Use 600 mesh sandpaper to polish the edge of the proton exchange membrane until smooth to ensure that it matches the seal of the microbial fuel cell reaction chamber. The cut membrane was immersed in 3 wt% H_2O_2 solution and treated in a constant temperature water bath at 80°C for 1 h to decompose the residual organic solvent and activate the sulfonic acid group (-SO_3H).

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Step 2: Acid treatment. The activated membrane was transferred to 1 mol/L H_2SO_4 solution, treated at 90°C for 1 h, and repeated 3 times. The Na^+ type membrane is completely converted to the H^+ type by an ion exchange reaction, as shown in Equation 2. After treatment, rinse the membrane with deionized water until the pH of the rinse solution is neutral.

$$R\text{-}SO_3^-Na^+ + H^+ \rightarrow R\text{-}SO_3H + Na^+ \quad (2)$$

Step 3: Hydrothermal treatment and storage. The acid-treated and washed membranes were put into deionized water and hydrothermally treated at 90°C for 1 h to fully absorb water and expand the hydrophilic microchannels to form a continuous proton transport network. After the hydrothermal treatment, the membrane is removed, placed in deionized water to cool to room temperature, and finally the membrane is kept in deionized water to keep it moist and prevent the membrane from drying and deforming until use.

2.4. Selection of Sewage Pumps

Because the ship oily sewage contains acidic substances, oil substances, solid particles and other impurities, this puts forward high performance requirements for ship sewage pumps. Specifically, the wastewater pump not only needs to have the ability to pump liquids containing complex components such as particles, impurities, and oils, but also be able to effectively handle high-viscosity liquids and have self-priming capabilities, so as to ensure that the pump can operate stably and reliably under various complex working conditions. In addition, the pump shaft should be made of stainless steel to provide good wear and corrosion resistance, and be able to resist the corrosion of fresh and seawater. Based on the above requirements, BW300+JZ15A peristaltic pump was selected, which has the characteristics of less disturbance to liquid, flexible power supply mode and high flow control accuracy, and the maximum flow rate can reach 513.77 mL/min.

2.5. Structure and Design of MFC Battery Case

In this experiment, a double-chamber MFC reactor made of plexiglass was used, and the overall three-dimensional structure of the device was designed and modeled by SolidWorks, as shown in Fig.2.

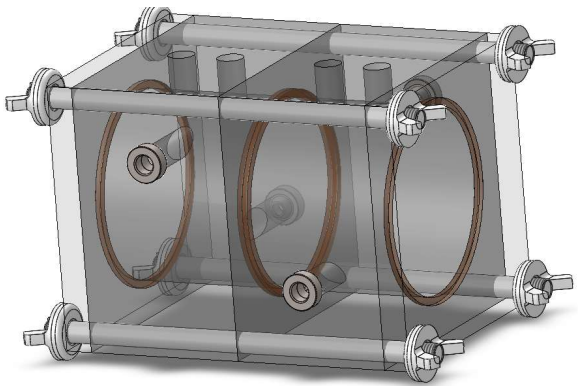

Fig.1 Double chamber MFC SolidWorks modeling diagram

The physical composition of this test is shown in Fig.2 shows that both the anode chamber and the cathode chamber are 8.0 cm × 8.0 cm×The 4.0 cm cuboid structure consists of round holes with a diameter of 4.0 cm, separated by a proton exchange membrane, and the volume is about 50.27 mL. In order to facilitate the injection of electrode solution and the installation of electrodes, four holes with a diameter of 1.0 cm were drilled at the top of the electrode chamber,

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and four holes with a diameter of 1.0 cm were reserved on the side to facilitate the inflow of oily water and the replacement of the catholyte solution. There are two baffles on the left and right sides of the MFC reactor, both with a length × width of 8.0 cm and a thickness of 1.0 cm, which are mainly used to seal the MFC reactor. In order to ensure the airtightness of the device, the sealing ring made of rubber is designed between the anode chamber baffle and the anode chamber, the anode chamber and the cathode chamber, and the cathode chamber and the cathode chamber baffle, and four small holes with a diameter of 1.0 cm are drilled at the four corners of the whole MFC reactor, and the MFC device is fixed as a whole by inserting four long screws with a diameter of 8 mm and four M8 bolts.

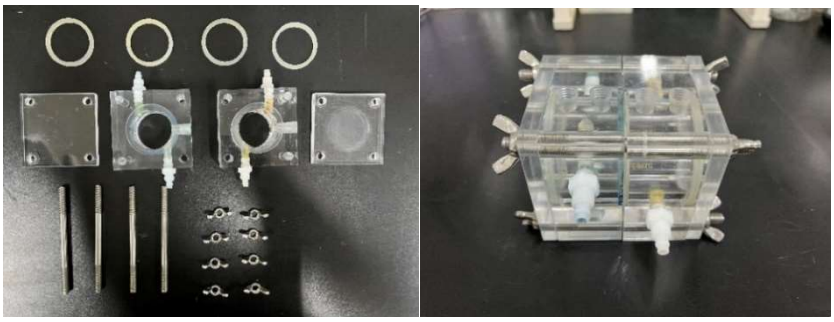

Fig. 2 Double chamber MFC physical picture

3. Output Performance of the MFC Device

3.1. The Output Voltage of the MFC Unit

Phosphoric acid-activated carbon felt (CF-H3PO4), melamine activated carbon felt (CF-C3H6N6), urea-activated carbon felt (CF-CO(NH 2)2), potassium hydroxide activated carbon felt (CF-KOH), hydrogen peroxide activated carbon felt (CF-H2O2) and unactivated carbon felt (CF) are used as the anodes of the first-stage MFC device and their output voltages are measured under normal working conditions, and their output voltages change curves with time are shown in Fig.3. In the early stage of the MFC device, the voltage rises rapidly, which is due to the fact that the microorganisms need time to attach to the surface of the anode and form an active biofilm, while the biofilm is not fully formed at the beginning of the reaction, and the electron transfer efficiency is low, but with the gradual maturity of the biofilm, the catalytic activity is enhanced, and the electron output efficiency is improved, resulting in the voltage rising. With the operation of the MFC unit, the output voltage of the MFC unit loaded with different activated carbon felt anodes reaches its peak, as shown in Table 1.It can be seen that the order of the highest output voltage of MFC loaded with different anode materials from high to low is CF-H_3PO_4 > CF-$C_3H_6N_6$ > CF-$CO(NH_2)_2$ > CF-KOH > CF-H_2O_2 > CF, where the output voltage using CF-H_3PO_4 is up to 676 mV, which is higher than the maximum output voltage of CF 5. The output voltage of the device decreased significantly with the increase of 39 mV by 25.4%, mainly because the organic matter in the anode chamber was rapidly consumed and not replenished in time, the microbial metabolic rate decreased, the electron output decreased, the voltage decreased, and the accumulation of metabolites changed the local pH or inhibit microbial activity, which indirectly leads to a decrease in voltage. Overall, phosphoric acid-activated carbon felt (CF-H_3PO_4) is an ideal material for MFC anodes that combines high initial voltage with excellent peak performance for better performance over longer operating periods. This is related to the surface etching of the material or the introduction of functional groups, increasing the specific surface area and active site.

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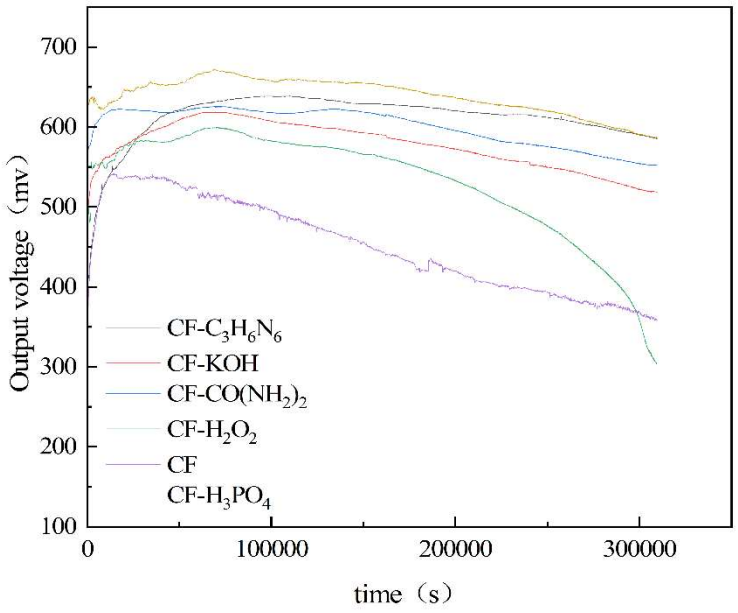

Fig.3 Output voltage of different anodes in MFC device

3.2. Power Density of MFC Installations

Finally, the power density curves of phosphoric acid-activated carbon felt (CF-H_3PO_4), melamine activated carbon felt (CF-$C_3H_6N_6$), urea-activated carbon felt (CF-$CO(NH_2)_2$), potassium hydroxide activated carbon felt (CF-KOH), hydrogen peroxide activated carbon felt (CF-H_2O_2), and unactivated carbon felt (CF) electrodes were measured. As shown in the figure, the maximum power density of CF-H_3PO_4 electrode is 2076.80 mW/m^2, the maximum power density of CF-$C_3H_6N_6$ electrode is 2003.62 mW/m^2, the maximum power density of CF-$CO(NH_2)_2$ electrode is 1928.98 mW/m^2, the maximum power density of CF-KOH electrode is 1900.43 mW/m^2, and the maximum power density of CF-H_2O_2 electrode is 1790.21 mW/m^2. Compared with the unactivated carbon felt (CF) electrode, the electrode was increased by 52.53%, 47.17%, 41.66%, 39.60% and 31.52%, respectively, which met the expected effect.

3.3. Degradation of Oily Wastewater by MFC Device

After 7 days of degradation test, the initial concentration of C_0 before treatment and C_1 after treatment of the oil sample were measured, and the degradation rate of the oily sewage treated by the MFC device was calculated. As shown in Fig.4, by comparing six sets of MFC devices with different anodes, it can be found that the chemically modified anodes all contribute to the degradation efficiency of the MFC devices, including the use of phosphoric acid-activated carbon felt (CF-H_3PO_4), melamine-activated carbon felt (CF-$C_3H_6N_6$), urea-activated carbon felt (CF-$CO(NH_2)_2$), potassium hydroxide activated carbon felt (CF-KOH), hydrogen peroxide activated carbon felt (CF-H_2O_2). The degradation efficiency of the first-stage MFC degradation pool of the unactivated carbon felt (CF) electrode as the anode of the device was 78.23%, 76.19%, 75.75%, 73.74%, 72.39% and 67.97%, respectively. Through comparative analysis, it was found that the lipophilic functional group of the carbon felt electrode after phosphoric acid activation increased, and the surface had excellent microbial adsorption capacity, which would promote the attachment and growth of microorganisms on the surface of the anode carbon felt, accelerate the start-up speed of MFC, and improve the overall degradation effect of MFC.

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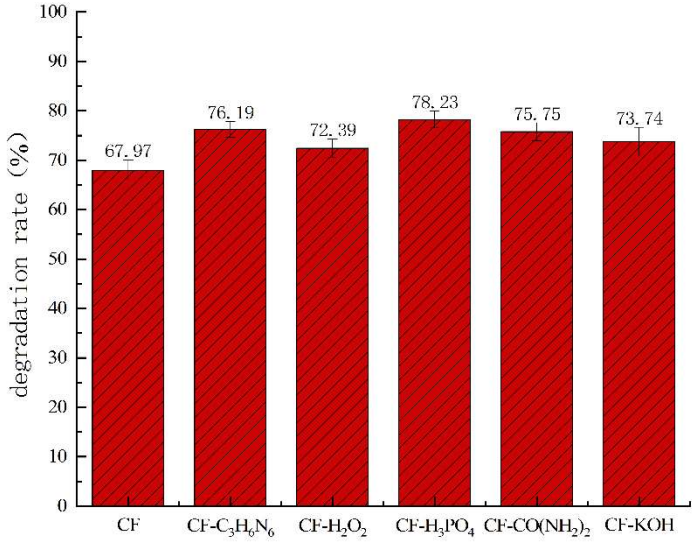

Fig.4 7d degradation rate of different anode materials

3.4. The Removal Rate of COD from Oily Wastewater by MFC Device

The COD removal rate was measured for 7 days in the MFC device loaded with different activated carbon felt anode materials, and the specific test results are shown in Fig.5.

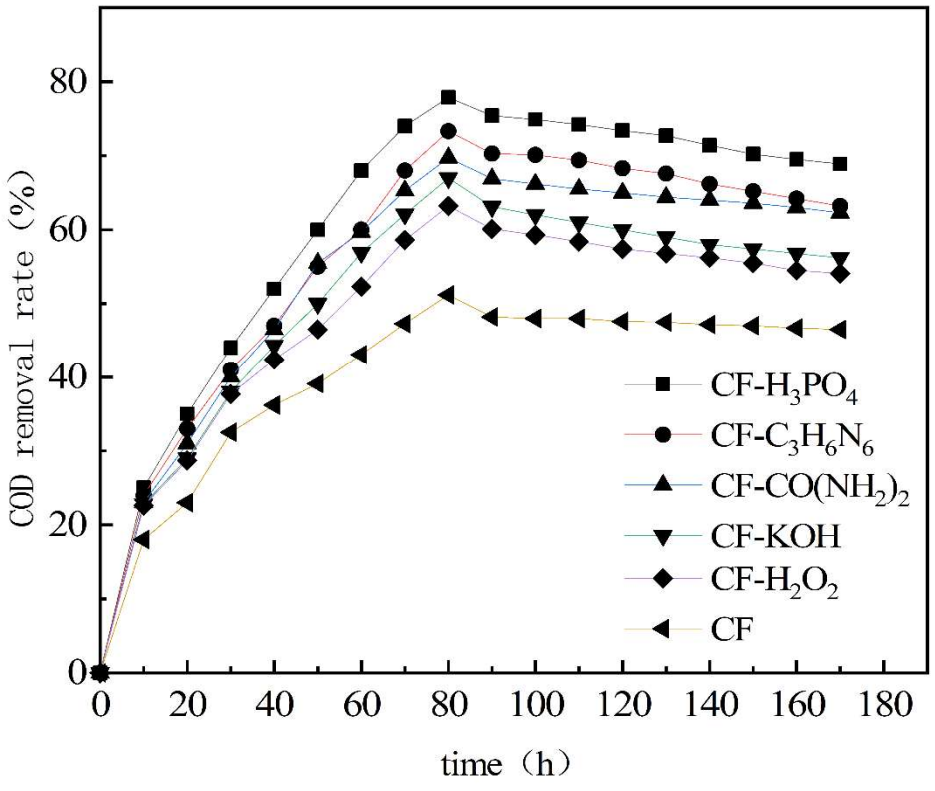

Fig.5 COD removal rate of oil wastewater by different anodes

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It can be seen from the figure that the COD removal rate curves of the six groups of MFC devices are about the same, and the COD removal rate of the MFC devices using different activated carbon felt before 10 h is small. After 10 h, the COD removal rate of the MFC devices rises rapidly. In particular, MFC devices using phosphoric acid-activated carbon felt (CF-H_3PO_4) accelerate microbial colonization due to their high specific surface area and high hydrophilic surface, and the COD removal rate has risen the fastest. The removal rate of COD reached the maximum value at about 80 h, then decreased slightly and gradually stabilized in the late operation. The six anode materials-phosphoric acid-activated carbon felt (CF-H_3PO_4), melamine-activated carbon felt (CF-$C_3H_6N_6$), urea-activated carbon felt (CF-$CO(NH_2)_2$), potassium hydroxide-activated carbon felt (CF-KOH), hydrogen peroxide-activated carbon felt (CF-H_2O_2)—showed COD removal rates of 77.87%, 63.21%, 69.72%, 66.97%, 73.31%, and 51.19%, respectively. The COD removal rate of phosphoric acid-activated carbon felt (CF-H_3PO_4) is significantly better than that of other materials and remains stable and efficient over time. This is because phosphoric acid activation through acid etching forms rich microporous and mesoporous structures on the surface of the carbon felt, which significantly increases the specific surface area and provides more attachment sites for electrogenesis, thereby enhancing biofilm generation and substrate contact efficiency. Additionally, the phosphoric acid treatment of carbon felt introduces ·OH and other oxygen-containing functional groups and phosphorus-containing functional groups. These groups can enhance the hydrophilicity of the electrode, promote the initial attachment of microorganisms, and act as an electron medium to accelerate the extracellular electron transport process.

4. Conclusion

This experiment focuses on the design, construction and performance optimization of microbial fuel cell devices, focusing on the modification of anode materials, the start-up and operation performance of MFC devices, and the degradation effect of the devices on ship oily wastewater. Through experimental verification, the following main conclusions are drawn from this experiment:

(1) Anode material is a vital component of the MFC degradation system, which directly affects the adhesion of microorganisms, electron transfer efficiency and the overall performance of the system. Through SEM and FTIR, it can be seen that the chemically activated carbon felt material has no obvious morphological change compared with the unactivated carbon felt surface, and there are no obvious corrosion traces on the surface, which is because the phosphoric acid, urea and other chemicals used in this experiment are relatively mild in terms of temperature, time and concentration, and the chemical activation focuses more on the modification of the chemical properties of the material surface, rather than the change of macroscopic morphology. The activated carbon felt material has absorption peaks at 3430 cm^{-1} that were enhanced to varying degrees, indicating that the hydroxyl functional groups on the surface of each activated carbon felt material increased after activation, especially the number of hydroxyl functional groups on the surface of the phosphoric acid activated carbon felt material increased most significantly. The contact angle test results showed that the contact angle of phosphoric acid activated carbon felt (CF-H_3PO_4) was reduced by 38.16%, indicating that its surface wettability was significantly enhanced, which was conducive to the attachment and electron transport of microorganisms.

(2) The electrochemical test results showed that the output voltages of MFC using different activated carbon felt anodes were in the order of phosphoric acid activated carbon felt (CF-H_3PO_4) > melamine activated carbon felt (CF-$C_3H_6N_6$) > urea-activated carbon felt (CF-$CO(NH_2)_2$) > potassium hydroxide activated carbon felt (CF-KOH) > hydrogen peroxide activated carbon felt (CF-H_2O_2) > unactivated carbon felt (CF). Among them, phosphoric acid

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activated carbon felt (CF-H_3PO_4) as an anode material, the maximum output voltage of MFC reaches 676 mV, which is 137 mV higher than that of unactivated carbon felt (CF), and the power density is increased by 52.53%.

(3) The MFC battery shell was modeled and designed by SolidWorks, and the first-stage MFC degradation pool was customized and installed, and the first-stage MFC degradation pool was successfully built. The experimental results showed that the oil absorption rate of phosphoric acid activated carbon felt (CF-H_3PO_4) was 12.39 g/g and the oil retention rate was 94.5%, which was higher than that of unactivated carbon felt (CF). The oil absorption rate increased by 10.2%, and the oil retention rate increased by 5.3%. When loaded with phosphoric acid-activated carbon felt (CF-H_3PO_4), melamine activated carbon felt (CF-$C_3H_6N_6$), urea-activated carbon felt (CF-$CO(NH_2)_2$), potassium hydroxide activated carbon felt (CF-KOH), hydrogen peroxide activated carbon felt (CF-H_2O_2) and unactivated carbon felt (CF) as the anode of the device, the 7-day degradation efficiency of emulsified diesel in the first-stage MFC degradation pool was 78.23%, 76.19%, 75.75%, 73.74%, 72.39% and 67.97%, respectively. Compared with unactivated carbon felt (CF) at 67.97%, the degradation rate of phosphoric acid-activated carbon felt (CF-H_3PO_4) was 10.26% higher. In addition, the removal rates of COD for the six anode materials [phosphoric acid-activated carbon felt (CF-H_3PO_4), melamine-activated carbon felt (CF-$C_3H_6N_6$), urea-activated carbon felt (CF-$CO(NH_2)_2$), potassium hydroxide activated carbon felt (CF-KOH), hydrogen peroxide activated carbon felt (CF-H_2O_2), unactivated carbon felt (CF) were 77.87%, 63.21%, 69.72%, 66.97%, 73.31% and 51.19%, respectively. The COD removal rate of phosphoric acid activated carbon felt (CF-H_3PO_4) was 26.68% higher than that of unactivated carbon felt (CF) at 51.19%. These results showed that the phosphoric acid activated carbon felt (CF-H_3PO_4) can not only effectively improve the power production performance of MFC, but also significantly enhance its degradation ability of ship oily sewage.

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