

# Study on Enhanced Microbial Degradation of Petroleum Hydrocarbons in Ship Oily Wastewater by Electric Power

Zhulong Wang<sup>1, a</sup>, Chenyang Wang<sup>2, b</sup>, Jikuan Wang<sup>1, c</sup>

<sup>1</sup>School of Shipping, Shandong Jiaotong University, Weihai 264200, China

<sup>2</sup>School of Animal Science and Technology, Qingdao Agricultural University, Qingdao 266109, China

<sup>a</sup>1551300125@qq.com, <sup>b</sup>17860729509@163.com, <sup>c</sup>2861844943@qq.com

## Abstract

Modern ship oily wastewater often presents a complex and ever-changing trend, and single technology treatment generally has some technical defects that are often difficult to achieve the expected treatment effect. Therefore, it is necessary to combine multiple technology treatments to compensate for the technical defects of single technology treatment and effectively improve the treatment rate and efficiency. This article aims to explore the combination of microbial technology and electric power technology to improve the efficiency of microbial degradation of petroleum hydrocarbons, thereby accelerating the treatment of oily wastewater from ships. This article analyzes the effect of electrode material, electrode arrangement method, and electric field intensity on the removal rate of petroleum hydrocarbons from ship oily wastewater treated by microbial communities through experiments. Taking into account economic considerations, it is proven that graphite electrode, electrode hexagonal arrangement method, and electric field intensity of 1 V/cm are the optimal conditions. The removal efficiency of petroleum hydrocarbons from oily wastewater in seven days reaches 81.09%.

## Keywords

Oily Wastewater; Microorganisms; Electric Power; Petroleum Hydrocarbons.

## 1. Introduction

Due to the bioavailability of exogenous substances, the degradation efficiency of petroleum hydrocarbon pollutants by a single bioremediation technology is usually low. In order to solve the above problems, the electric field enhanced microbial remediation technology provides an effective new idea[1] by coupling electric remediation with microbial remediation, as shown in Figure 1. The combination of microbial method and electrodynamic method can make up for the limitations of microbial method and electrodynamic method, realize the rapid and uniform mixing of microorganisms, electronic receptors and nutrients with pollutants in oily sewage, and also stimulate microbial activity through the electric field effect, improve the repair efficiency, thus accelerating the microbial repair process[2]. The impact of electric fields on microorganisms mainly includes the following aspects:

(1) The absorption of nutrients by microorganisms Under the effect of appropriate electric field intensity, the permeability of microbial cell membrane may be enhanced, and its Ion channel protein will also be affected, so that it is easier to transport nutrients in the environment[3].

(2) The impact on microbial enzymes. When microorganisms are in a specific electric field environment, they may have a positive effect on enzymes within the organism, activating or enhancing the activity of certain enzymes, thereby promoting enzymatic reactions and improving microbial processing ability[4].

(3) Electric fields have a significant impact on the reproduction of microorganisms and cells. The cell Mitosis cycle is shortened under the stimulation of electric field, and the cell reproduction rate is accelerated, thus promoting microbial reproduction. In addition, the stimulation of electric fields may also cause chromosomal structure variations during growth or reproduction, thereby altering the function of microorganisms[5].

(4) For the growth environment of microorganisms, H<sub>2</sub> and O<sub>2</sub> generated during the electrolysis process can serve as nutrients for microbial growth[6]. On the other hand, there are organic compounds in the surrounding environment that are difficult to biodegrade or inhibit biological growth[7]. Through electrochemical degradation, intermediate products can also be utilized by microorganisms to promote their growth[8].

(5) The inhibitory effect of electric fields on organisms, as described above, is the positive effect of electric fields on organisms, and of course, electric fields can also have inhibitory effects on organisms. Under high voltage conditions, electrolysis can cause bacteria or viruses in water to die. The electrolytic sterilization of water can be divided into direct and indirect effects[9].

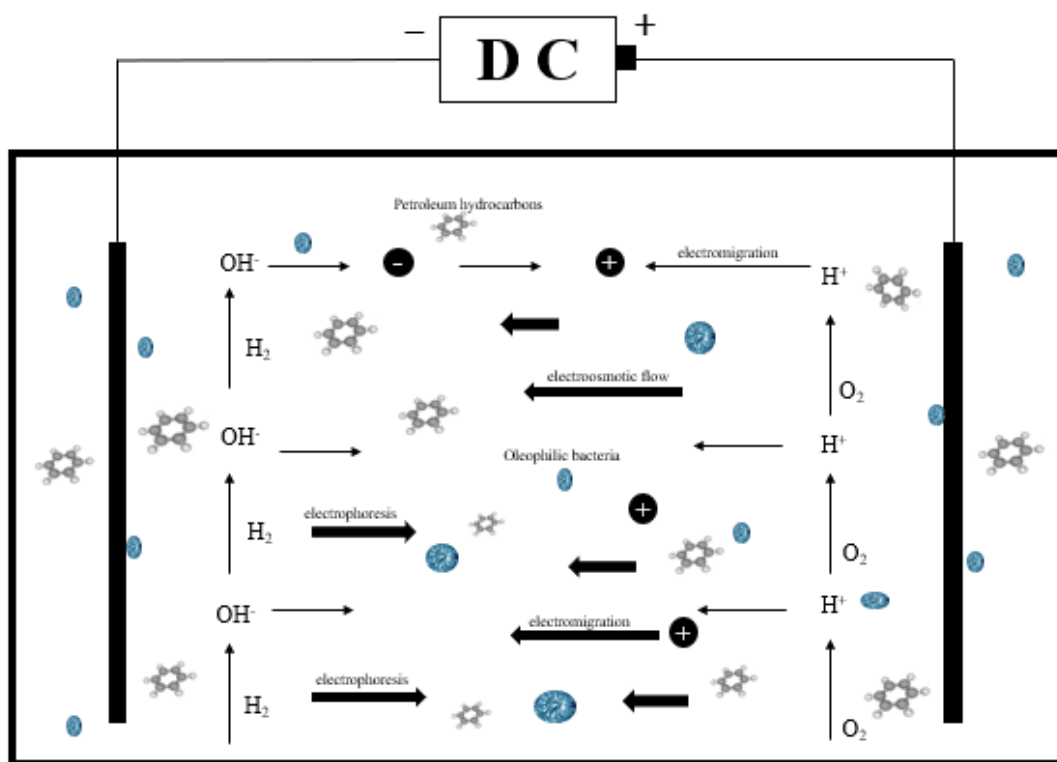


Fig 1. Schematic diagram of electrodynamic coupling of microorganisms

## 2. Experimental Materials and Methods

The oil sample used in the experiment is crude oil from Daqing Oil Field.

The formula and conditions of the culture medium used in the experiment are as follows:

Beef extract peptone liquid culture medium: beef extract 0.5 g, peptone 1.0 g, NaCl 0.5 g, distilled water 1000 mL, pH=7, high-pressure steam sterilization, 121 °C sterilization for 21 minutes.

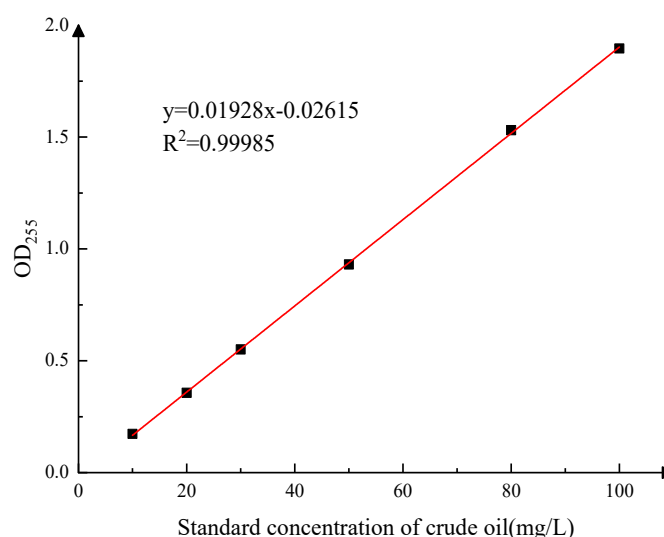
Inorganic salt culture medium: NaCl 0.5 g, (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> 0.1 g, MgSO<sub>4</sub>·7H<sub>2</sub>O 0.025g, NaNO<sub>3</sub> 0.2 g, KH<sub>2</sub>PO<sub>4</sub> 0.4 g, K<sub>2</sub>HPO<sub>4</sub>·3H<sub>2</sub>O 1.0 g, Distilled water 100 mL, pH=7, sterilized with high-pressure steam, sterilized at 121 °C for 21 minutes.

Oil containing culture medium: On the basis of inorganic salt culture medium, 1.0 g of crude oil is added to create oil containing culture medium with different initial concentrations.

Beef extract peptone solid medium: Add 1.5 g of agar to the beef extract peptone liquid medium. The experiment used microbial communities as the highly efficient marine oil spill degradation microbial community selected by the laboratory from marine oil spills.

The removal rate of petroleum hydrocarbons in ship oily wastewater is determined as follows: Weigh 0.100 g of petroleum and dissolve it in a volumetric flask containing 100 mL of Petroleum ether, dilute it and shake it up. Use a pipette gun to suck 1 mL of mixed solution into a centrifuge tube, add 100 mL of Petroleum ether, and fully shake it on a centrifuge. At this time, the concentration of the solution is diluted to 10 mg/L. According to the above operations, weigh the same amount of petroleum and dissolve it in 200, 300, 400, 500, 600 and 700 mL of Petroleum ether to obtain Standard solution of different concentrations. Pour the solution to be tested into a colorimetric dish and scan the optimal absorption wavelength and absorbance of different concentrations of solutions using a UV spectrophotometer to synthesize a petroleum standard curve.

The specific operation steps are as follows: Petroleum and its products have UV absorption characteristics, and the structures of compounds contained in different products are different, and the spectra of the UV absorption region are also different. The absorption spectrum was obtained by scanning the spectrum at 100-800 nm, and it was found that the oil had a clear absorption peak at a wavelength of 255 nm. Therefore, the measurement wavelength chosen for the experiment was 255 nm. Pour the petroleum Standard solution of different concentrations obtained from the above dilution into the cuvette, and calculate the ultraviolet spectrophotometry. The wavelength (255 nm) is the wavelength at which the maximum absorption peak occurs at all six concentrations. Finally, take the petroleum concentration (mg/L) and the corresponding absorbance as the horizontal and vertical coordinates, and draw the standard curve, as shown in Figure 2.



**Fig 2.** Standard curve of crude oil

Determination of degradation rate of ship oily wastewater after treatment: Using the petroleum standard curve fitted by the above experiment, the residual oil concentration in oily wastewater after 7 days of cultivation in petroleum culture medium was determined. The specific operation is as follows: inoculate 5 mL of bacterial solution into petroleum culture medium, and then culture it in a 35 °C constant temperature shaker for 7 days. During this period, the strain begins to contain petroleum in the culture medium. After 7 days, transfer the degraded bacterial

solution to a colorimetric dish, and use the non inoculated culture medium as the background control group. Use a UV spectrophotometer to observe its residual oil concentration, Calculate the degradation rate of petroleum hydrocarbons by electrokinetic enhanced microorganisms based on the petroleum standard curve in the above experiment. Each group of experiments mentioned above was tested twice using a colorimetric dish to prevent accidental results. Based on the plotted petroleum standard curve, the degradation rate of oil pollution in each experiment can be calculated, as shown in formula 1.

$$A = \frac{C_1 - C_2}{C_1} \times 100\% \quad (1)$$

$C_1$  in the formula represents the concentration of petroleum in the blank control group, and  $C_2$  represents the concentration of petroleum after degradation.

### 3. Main Factors Affecting the Degradation of Petroleum Hydrocarbons in Ship Oily Wastewater by Electrodynamics Enhanced Microorganisms

#### 3.1. Effect of Electrode Materials on Microbial Community Treatment of Oily Wastewater

The selection of electrode materials is crucial in the process of decontamination experiments, considering both cost factors and the impact of electrode conductivity on the decontamination effect during the experiment, as well as the corrosion phenomenon of water and solvent on the electrode materials during the decontamination process. Therefore, after considering the above factors comprehensively, copper, iron, and graphite were used as the experimental electrodes in this experiment. In order to reduce experimental errors, the iron, copper, and graphite electrodes were uniformly sized, as shown in Figure 3.



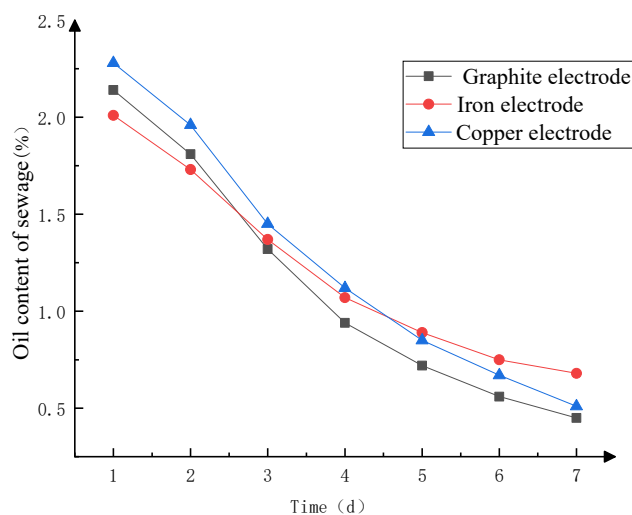
**Fig 3.** Copper, Iron, and Graphite electrodes

The parameters related to the three experimental electrode materials are shown in Table 1.

**Table 1.** Relevant parameters of electrode materials

Type of electrodes	Densityg cm <sup>3</sup>	Resistivity μΩ·m	Hardness HS	Flexural strength Mpa	Characteristic
Copper electrode	8.90	0.32	40	1042	Strong conductivity, corrosion resistance, and high price
Iron electrode	7.86	0.97	65	170	Good conductivity, low price, and easy corrosion
Graphite electrode	2.09	12	31	15	Corrosion resistance, good conductivity, and low price

The bacterial community was combined with bagasse based immobilized carriers by embedding method and placed in an experimental treatment tank. Under the condition of an electric field strength of 100 V/m, the experiment was conducted using a regular hexagonal electrode arrangement. The experiment lasted for 7 days and the oil content of the wastewater was measured. The effect of electrode materials on the degradation of oil content in ship oily wastewater is shown in Figure 4. As the reaction process progresses, the concentration of petroleum hydrocarbons in ship oily wastewater decreases to varying degrees. At the beginning of the experiment, the oil content of the oily wastewater treated with graphite electrode, iron electrode, and copper electrode is 2.14%, 2.09%, and 2.28%, respectively. After the experiment is completed, the graphite electrode, iron electrode, and The oil content of oily wastewater treated by copper electrodes decreased to 0.45%, 0.68%, and 0.51%, respectively. It can be seen that graphite electrode, iron electrode, and copper electrode have achieved oil removal effects of 79.97%, 67.46%, and 77.63% respectively in the treatment of ship oily wastewater using electrodynamic coupled biotechnology. According to the experimental results, the difference between the three is relatively small, but in terms of cost, graphite electrodes are relatively cheap compared to metal electrodes, especially copper electrodes. From an environmental perspective, graphite electrode materials do not pose a risk of environmental pollution. Metal electrode materials are prone to the risk of heavy metal entering water bodies during the electrification process, resulting in heavy metal pollution. In addition, graphite electrodes are inert electrode materials, and the voltage and current are relatively stable during the electrification process. Compared to metal electrodes, graphite electrodes are more corrosion-resistant and less prone to oxidation reactions. Therefore, based on the above considerations, graphite electrodes are chosen as the electrode material for electrodynamic coupling biotechnology.

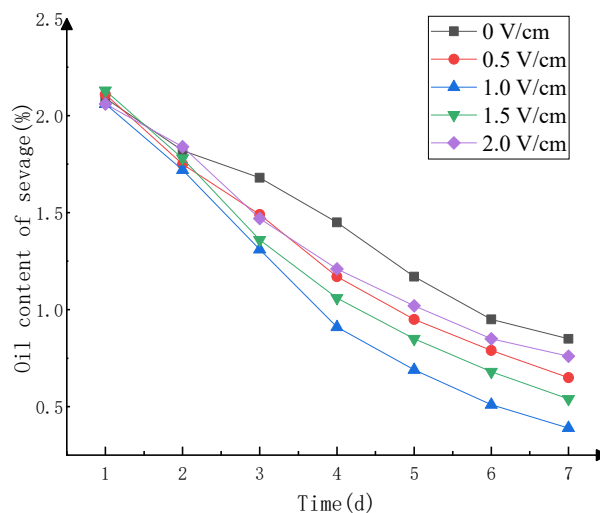


**Fig 4.** Effect of electrode materials on the degradation of oil content in ship oily wastewater

### 3.2. Impact of Electric Field Intensity on Microbial Community Treatment of Oily Wastewater

During the simulation process in the electrodynamic coupled biotechnology laboratory, safety considerations must be taken into account, so the maximum voltage in the experiment cannot exceed the safe voltage felt by the human body, which is 36 V. Therefore, in this experiment, the applied voltages of 0 V, 5 V, 10 V, 15 V, and 20 V were applied for a distance of 15 cm, with voltage intensities of 0 V/cm, 0.5 V/cm, 1.0 V/cm, 1.5 V/cm, and 2.0 V/cm, respectively. Using an experimental tank type indoor simulation, the electrode material is graphite electrode, and

an equal amount of bacterial community is added to combine the embedding method with sugarcane bagasse based fixed carrier. Parallel experiments are conducted for 7 days, with 2 hours of power on every day and sampling once a day. The petroleum hydrocarbon content in ship oily wastewater is measured according to formula 1, and the petroleum hydrocarbon removal rate of ship oily wastewater under different electric field intensities is calculated and determined.



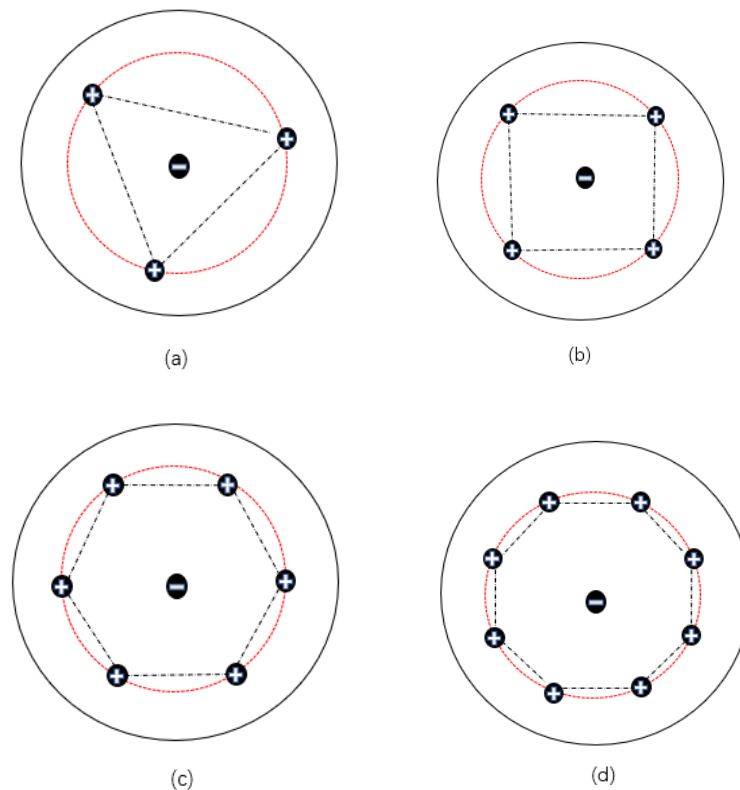
**Fig 5.** Effect of electric field intensity on the degradation effect of oil content in ship oily wastewater

From Figure 5, it can be seen that there is a significant difference in the oil removal rate among different treatment groups, that is, different electric field intensities have different effects on the oil removal efficiency of microbial degradation of ship oily wastewater. The oil removal rates are in order of  $1.0 \text{ V/cm} > 1.5 \text{ V/cm} > 0.5 \text{ V/cm} > 2.0 \text{ V/cm} > 0 \text{ V/cm}$ . When  $1.0 \text{ V/cm}$ , the oil removal rate is the best, with the oil content decreasing from the initial  $2.09\%$  to  $0.39\%$  and the oil removal rate reaching  $81.07\%$ . When the electric field intensity is  $1.5 \text{ V/cm}$ , the oil content decreases from the initial  $2.13\%$  to  $0.54\%$ , and the oil removal rate is  $74.65\%$ . When the electric field intensity is  $0.5 \text{ V/cm}$ , the oil content decreases from  $2.11\%$  to  $0.65\%$ , and the oil removal rate is  $69.19\%$ . When the electric field intensity is  $2.0 \text{ V/cm}$ , the oil content decreases from the initial  $2.06\%$  to  $0.76\%$ , and the oil removal rate is  $63.11\%$ . When the electric field intensity is  $0 \text{ V/cm}$ , the oil content decreases from the initial  $2.09\%$  to  $0.85\%$ , and the oil removal rate is  $59.33\%$ . From the experimental results, it can be concluded that the application of an electric field enhances the degradation of petroleum hydrocarbons by microorganisms. However, when the electric field intensity exceeds  $1.5 \text{ V/cm}$ , the oil removal rate slightly decreases compared to  $1.0 \text{ V/cm}$ , indicating that excessive electric field intensity may have an inhibitory effect on microbial treatment of petroleum hydrocarbons. Therefore,  $1.0 \text{ V/cm}$  was selected as the electric field intensity for the treatment of oily wastewater from ships using electrodynamic coupled biotechnology.

### 3.3. Effect of Electrode Layout on Microbial Community Treatment of Oily Wastewater

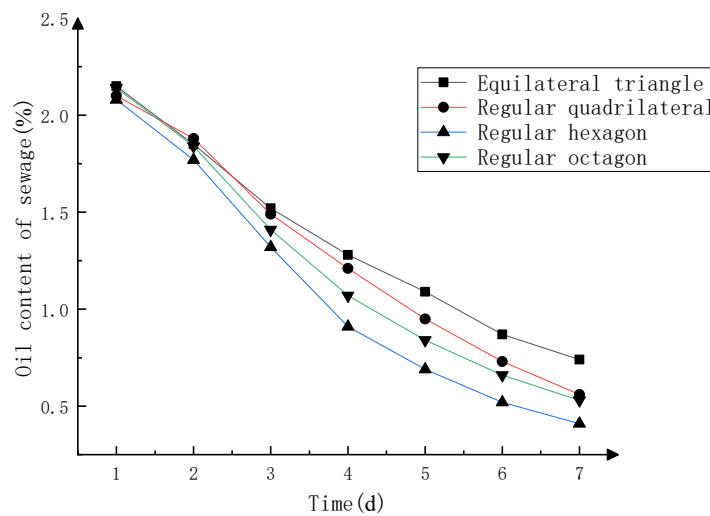
In the experiment of electrodynamic coupling biotechnology to treat oily sewage from ships, in order to obtain the best treatment effect, not only the selection of electrode materials and electric field strength, but also the study of electrode layout mode is needed. Four electrode layout modes are used in this experiment, namely, Equilateral triangle electrode layout, regular

quadrilateral electrode layout, regular hexagon electrode layout, regular Octagon electrode layout, as shown in Figure 6.



**Fig 6.** Electrode Layout

At an electric field intensity of 1.0 V/cm, a graphite electrode was selected, and an equal amount of bacterial community was added. The embedding method was combined with bagasse based immobilized carriers to conduct parallel experiments. After 7 days, the removal rate of petroleum hydrocarbons from ship oily wastewater was determined to determine the optimal electrode layout.



**Fig 7.** Effect of electrode arrangement on the degradation effect of oil content in ship oily wastewater

From Figure 7, it can be seen that until the end of the experiment, the oil content in the oily wastewater from ships showed a decreasing trend, with the most significant decrease being the arrangement of regular hexagonal electrodes. The oil content in the oily wastewater from ships decreased from 2.08% at the beginning to 0.41% at the end, with a oil removal rate of 80.29%. The Equilateral triangle electrode arrangement has the worst degradation effect. The oil content at the beginning drops from 2.15% to 0.74% at the end, and the oil removal rate is 65.58%. The oil removal rates of regular quadrangle and regular Octagon electrode arrangement are 73.33% and 75.23% respectively. Therefore, the hexagonal electrode arrangement method was selected as the electrode arrangement method for the treatment of oily wastewater from ships using electrodynamic coupled biotechnology in the experiment.

#### 4. Conclusion

This article explores the efficiency of diesel oil treatment under different electrode properties, non electric power transmission methods, and different electric fields by configuring ship oily wastewater with diesel oil culture medium and using sugarcane bagasse based immobilized carriers to efficiently remove petroleum hydrocarbons from ship oily wastewater. The results are as follows:

(1) In the laboratory simulation repair process of electrodynamic enhanced microbial treatment of ship oily wastewater, there was no significant difference in the use of iron electrodes, copper electrodes, and graphite electrodes in the repair of ship oily wastewater. However, due to the metal electrodes entering the water body during the repair process, it is easy to cause heavy metal pollution to the water body and the cost is expensive. Therefore, from an environmental and economic perspective, stable and most suitable high-temperature resistance should be selected Corrosion resistant inert graphite electrode.

(2) In the laboratory simulation repair process of electrodynamic enhanced microbial treatment of ship oily wastewater, Equilateral triangle, regular quadrilateral, regular hexagon and regular Octagon were used. After 7 days of degradation experiments, the oil content in ship oily wastewater showed a downward trend, of which the regular hexagon electrode arrangement was the most obvious. The oil content of ship oily wastewater decreased from 2.08% at the beginning to 0.41% at the end, and the oil removal rate was 80.29%. The Equilateral triangle electrode arrangement has the worst degradation effect. The oil content at the beginning drops from 2.15% to 0.74% at the end, and the oil removal rate is 65.58%. The oil removal rates of regular quadrangle and regular Octagon electrode arrangement are 73.33% and 75.23% respectively. Therefore, it has been verified that the hexagonal electrode arrangement method is the most suitable as an electrode arrangement method for electrodynamic enhanced microbial treatment of ship oily wastewater.

(3) In the laboratory simulation repair process of electrodynamic enhanced microbial treatment of ship oily wastewater, safety considerations were taken into consideration. In the design of this experiment, voltage of 0 V, 5 V, 10 V, 15 V, and 20 V were applied at a distance of 10 cm, with electric field intensity gradients of 0 V/cm, 0.5 V/cm, 1.0 V/cm, 1.5 V/cm, and 2 V/cm, respectively. It can be seen from the experimental results that different electric field intensities have different effects on the microbial remediation of oily sewage. The oil reduction rate is  $1.0 \text{ V/cm} > 1.5 \text{ V/cm} > 0.5 \text{ V/cm} > 2.0 \text{ V/cm} > 0 \text{ V/cm}$ . When the electric field intensity is 1.5 V/cm, the oil reduction rate decreases compared to 1.0 V/cm, indicating that excessive electric field intensity may have an inhibitory effect on the internal microorganisms of the system. Therefore, it is demonstrated that an electric field strength of 1.0 V/cm is the optimal electric field strength for repairing oily wastewater.

## Acknowledgments

ShanDong JiaoTong University 2023 Graduate Science and Technology Innovation Project, "Research on the Treatment of Ship Oily Wastewater by Electrodynamics Coupled Biotechnology" (Gant No. 2023YK100).

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