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EXTENDED ABSTRACT

Evaluation of Electromigration Mechanism of Heavy Metal from Marine Sediments by Microbial Electrokinetic Cell

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1. Introduction

Electrokinetic remediation is one of the methods for cleaning of soil and sediments (Rozas and Castellote, 2012). In this case, by applying a weak electric field using the external power supply, the pollutants are separated from the soil or sediment by various mechanisms, especially electrical migration. But due to the cost of supplying electricity, it is not affordable(Acar et al., 1995). On the other hand, in the microbial fuel cells, bacteria release electrons by consuming organic matter and producing electric current. Therefore, in this study, microbial fuel cells process with three different electrodes at the anode and combination with granular activated carbon was used to produce green weak electric field. Based on the electrical migration mechanism, the removal rate of hexavalent chromium from marine sediments was evaluated by combining three physical, chemical and biological processes.

2. Material and methods

2.1. MEC Construction

Microbial Electrokinetic Cells (MECs) in the present study were fabricated through clamping three cubic Plexiglas chambers. The working dimensions of side and middle chambers (contain sediment) were 5×5×3 and 5×5×4 cm3. The anolyte, middle chamber and catholyte were physically separated by ion exchange membrane.

Three different types of the electrode, denoted by plate graphite, roughened surface graphite, and combination of roughened surface graphite and granular activated carbon, were used as anode electrode in the experiments.

2.2. MEC Operation

In the first step of experiment, actual domestic wastewater obtained from the local municipal wastewater treatment plant (WWTP) was used as the anolyte solution. Sewage sludge (5%, v/v) acquired from an anaerobic digester was inoculated into anode chamber during both steps. The phosphate buffer solution (3.4 g $K_2HPO_4.3H_2O$ and 4.4 g KH_2PO_4) was used in all reactors in the cathode chamber during whole steps of the experiment. The cathode solution was aerated by the air diffuser pump (RS Electrical RS - 510 Aquarium Air Pump, Zhejiang, China) to supply dissolved oxygen as an electron acceptor.

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2.3. Sediment collection and preparation

Sediment samples were selected and obtained from the southern coasts of the Caspian Sea, Iran. Sampling was done manually from the surface layers (0-10 cm) and samples were stored into polyethylene containers in a clean, cool, and dark environment and then were transferred to the laboratory and kept at 4 °C. The physical and chemical properties of the used sediments and the granular activated carbon are shown in Tables 1, 2 & 3, respectively.

Table 1. Physical Specifications of the sediment sample

Properties	pH	EC (mS/cm)	Zeta Potential (ξ)
Value	≃6.8	0.4	21

Table 2. Chemical Specifications of the sediment sample

Properties	SiO2	Al2O3	Na2O	L.O.I
Value	54.24	5.96	1.17	13.77

Table 3. Specification of GAC

Properties	Surface area (m^2/g)	Pore valume (cm^3/g)	Muisture content (%)
Value	1000-1150	0.44	5%>

3. Results and discussion

3.1. Electricity generation

MECs were operated for more than two weeks in order to reach a stable operation under open-circuit mode. The maximum open-circuit voltage of over 0.960±0.02 V was produced through MEC 3. Previous study reported a maximum OCV of 0.680 V in a three-chamber microbial fuel cell coupled by electrokinetic using paddy soil (As shown in Fig. 1).

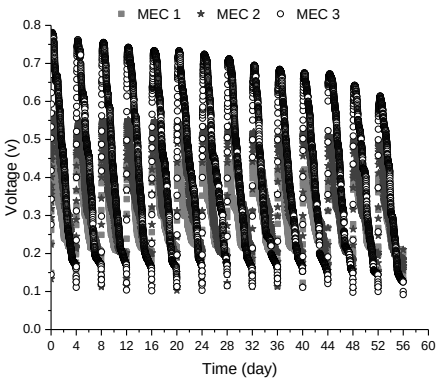

Fig.1. Closed circuit voltage change respect to time in MECs

3.2. Polarization and power density curve

When a stable performance was observed in voltage generation during open circuit mode, the polarization curves and power density variation were plotted with changing applied external resistance from 50k to 10 Ω stepwise in 20-min intervals (Watson and Logan, 2011). As shown in the Fig. 2, the maximum power density was measured by applying different external resistance via a resistance box. Results showed that MEC 3 achieved the high power density of 10 W m^{-3} under the external resistance (Fig. 2, 3). The power density curve is helpful for specifying maximum power transfer in Microbial fuel cells. Also, a polarization curve displays the voltage of the MFC as a function of the current density.

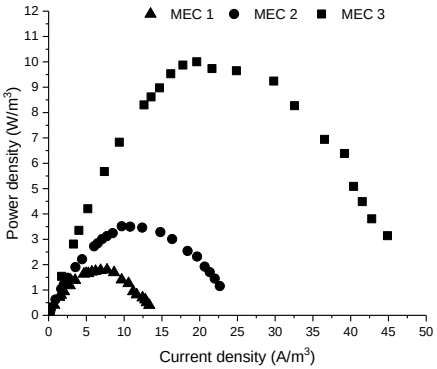

Fig. 2. Power density variation in MECs

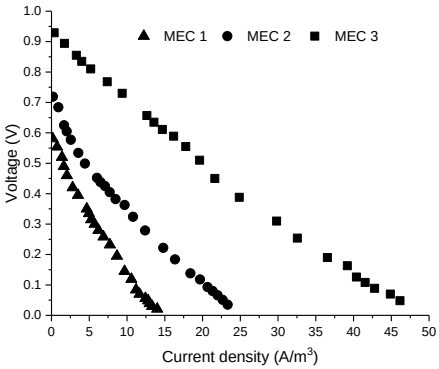

Fig. 3. Polarization curve of MECs

3.3. COD removal

The COD removal efficiencies of the three reactors are shown in Table 3. The organic matter in the anode chamber 3 was substantially consumed by the microbial population grown on the surface of the activated carbon granule electrode. The results showed that COD removal was higher in Reactor 3 than in two reactors 1 and 2. As is known, the lowest COD removal in all reactors occurred within the first 24 hours, which could be due to the high growth of methane-producing bacteria due to the high concentration of substrate in the anolyte. However, the removal rate has gradually increased, which is due to the adaptation of the bacteria to the conditions in the reactor. The higher COD removal rate in the reactor 3 may be due to the greater microbial population on the very large surface of activated carbon granules as well as the scratches on the graphite surface. Thus, the bacteria were able to release higher rates of electrons and generate higher cell voltage.

Table 4. Average COD removal efficiencies over two months

Cell	Time of each cycle (day)			
MEC 1	1	2	3	4
	27.1±3.7	43.9±2.3	55.2±7.4	62.3±3.8
MEC 2	31.8±3.26	49.2±5.9	64±5.5	73.3±4.25
MEC 3	35.1±2.34	54.8±3.56	71.2±1.23	84.6±3.5

3.4. pH variation in sediment sample

The maximum range of pH changes in sediment occurred in MEC3 reactor. At the anode state, the acidic condition was produced while the alkaline area was produced at the cathode region; thus, pH was increased in the cathode and decreased in the anode.

3.5. Metal migration

At the end of the process, distributions of Cr^{6+} in different sections of the sediment samples were measured. The initial concentration of Cr^{6+} in the sediment samples before remediation was equal to 365 ± 0.5 μg g^{-1}. The results showed that during the experiments, the Cr^{6+} in the sediment samples had been continuously transferred from anode to the cathode region. pH can be considered as a key factor in chromium migration from anode to the cathode. In low pH, the ionic form of chromium, dissolute in sediment pore water and migrate to the cathode region.

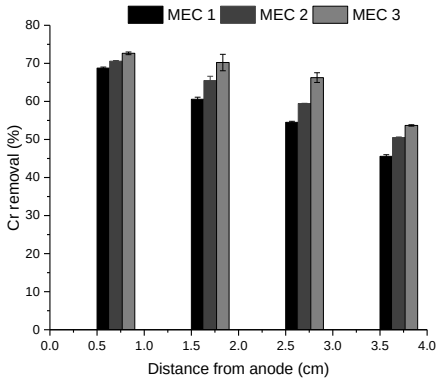

Fig. 4. Chromium removal within the sediment sample

4. Conclusions

In the presence study, the performance of MEC reactors for Cr^{6+} removal from sediments was assessed by three types of electrodes (plate graphite, roughened surface graphite, and roughened surface graphite via granular activated carbon). The results demonstrated that MEC by RSG-GAC electrode produced the maximum power density of 10 W m^{-3}. It also achieved up to 73% and 54% Cr^{6+} removal in anode and cathode region during the operation in the sediment chamber, as well. The new surface design of anode electrode (roughened surface graphite) and adding GAC lead to a better performance of MEC. Actually, by increasing bacterial adhesion to the electrode, the rate of transportation of electron to the electrode was enhanced. Also, the results delivered a concept that MEC has a high potential to be used for efficient sediment remediation and to promote environmental health.

5. References

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