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Araştırma Makalesi / Research Article

Investigation of Domestic Wastewater Treatment and Electricity Generation Using A Two Chambered Microbial Fuel Cell with Composite Anode Electrode

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Keywords
Microbial Fuel Cell;
Composite Electrode;
Domestic Wastewater Treatment;
Electricity Generation

Abstract

Microbial fuel cell is a bioelectrochemical system that generate electricity with the oxidation of organic substrates by exoelectrogenic microorganisms. It can be said that the studies on microbial fuel cells (MFCs) are generally aimed to increase the amount of energy produced. In this study, domestic wastewater treatment was investigated by using a two-chamber microbial fuel cell. Ankara Tatlar Wastewater Treatment Plant influent water was used as substrate. In order to reduce the diffusional resistance by reducing the distance between the anode and cathode electrode, the cathode chamber was placed in the middle of the anode chamber. Anode and cathode chambers separated by Nafion 117 membrane. In addition, an anode consisting of a stainless-steel mesh and a graphite supported catalyst has been developed to increase the electricity generation potential. During the experiment, the maximum voltage and the maximum power density values were obtained as 595 mV and 205.867 mW/m^2 respectively. COD value is a criteria which indicates the waste treatment ability of the systems. For this experiment COD values of the wastewaster were measured both the beginning and the end of the experiment as 451 mg/L O_2 and 361 mg/L O_2. These results proved that the developed electrode structure is at a comparable level with the values reported in the literature for two-chamber MFC studies.

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Kompozit Anot Elektrotlu İki Bölmeli Mikrobiyal Yakıt Pili Kullanılarak Evsel Atıksu Arıtımı ve Elektrik Üretiminin Araştırılması

Anahtar Kelimeler
Mikrobiyal yakıt hücresi;
Kompozit elektrot;
Evsel atıksu arıtımı;
Elektrik üretimi

Öz

Mikrobiyal yakıt hücresi, ekzoelektrojenik mikroorganizmalar tarafından organik substratların oksidasyonu ile elektrik üreten bir biyoelektrokimyasal sistemdir. Mikrobiyal yakıt pilleri (MYH) üzerine yapılan çalışmaların genel olarak üretilen enerji miktarını artırmaya yönelik olduğu söylenebilir. Bu çalışmada, iki bölmeli bir mikrobiyal yakıt hücresi kullanılarak evsel atıksu arıtımı araştırılmıştır. Substrat olarak Ankara Tatlar Atıksu Arıtma Tesisi giriş suyu kullanılmıştır. Anot ve katot elektrotu arasındaki mesafeyi azaltarak difüzyon direncini düşürmek için katot bölmesi anot bölmesinin ortasına yerleştirilmiştir ve bu bölmeler Nafion 117 membranı ile ayrılmıştır. Ayrıca elektrik üretim potansiyelini artırmak için paslanmaz çelik kafes ve grafit destekli bir anot elektrodu geliştirilmiştir. Deney sırasında maksimum voltaj 595 mV ve maksimum güç yoğunluğu değerleri 205.867 mW/m^2 olarak elde edilmiştir. KOİ değeri, sistemlerin atıksu arıtma kabiliyetini gösteren bir kriterdir. Bu deney için atıksuların KOİ değerleri deney başlangıcında ve sonunda 451 mg/L O_2 ve 361 mg/L O_2 olarak ölçülmüştür. Bu sonuçlar, geliştirilen elektrot yapısının iki bölmeli MYH çalışmaları için literatürde bildirilen değerlerle karşılaştırılabilir düzeyde olduğunu kanıtlamıştır.

1. Introduction

The increasing energy demand and depletion of fossil fuels can cause a global energy crisis that will affect both environmental quality and human health (Palanisamy *et al.* 2019). These problems have led to the search for alternative renewable energy sources (Priya and Setty 2019). Studies on alternative renewable energy sources are increasing day by day in the fields of tidal, solar, geothermal, biomass and wind power generation (Slate *et al.* 2019). The biofuel cell technologies are known as both renewable and eco-friendly technology, aiming to be applied as a power source for fuel cell application (Nasar and Perveen 2019) These cells convert fuel

into electrical energy through electrocatalysts performing separated electrode reactions. Biofuel cells use either cells, enzymes, microorganisms or organelles as biocatalysts to accelerate anodic fuel oxidation and cathodic oxidant reduction (Scheiblbrandner *et al.* 2022). Biofuel cells tend operate under mild conditions (20–40°C, near-neutral pH). These properties make biofuel cells an attractive development prospect for use in applications where generating high temperatures is difficult, or where harsh reaction conditions are undesirable (Bullen *et al.* 2006). The energy production levels of electrochemical sources such as biofuel are shown in Figure 1.

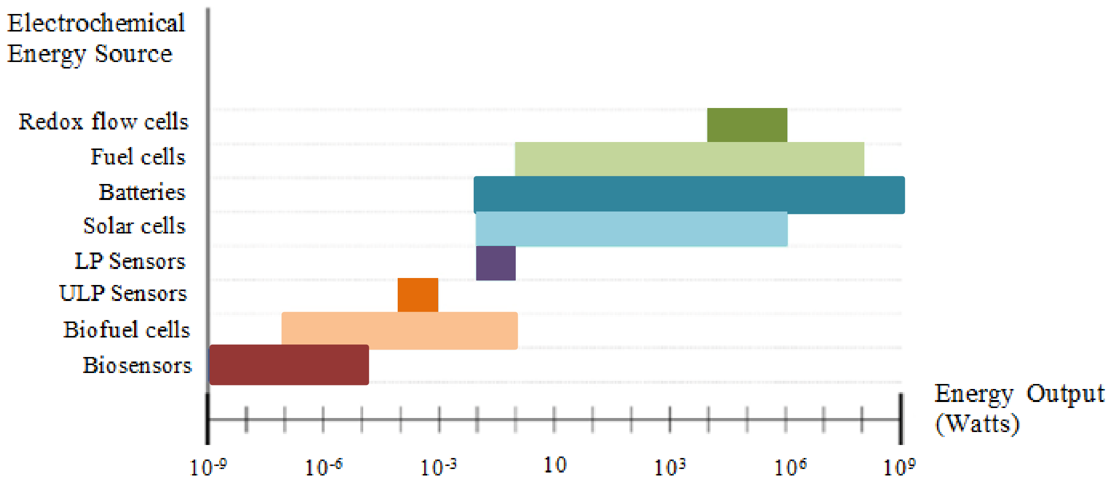

Figure 1. Energy production levels of electrochemical sources (Serra *et al.* 2020).

It is stated in Figure 1 that the energy production levels of fuel cells are an effective level among many types of cells and sensors. Generally, fuel cells are defined as electrochemical devices capable of converting a substrate into electrical energy (Ramesh *et al.* 2021). Besides that, the microbial fuel cell is accepted as a green technology for both biological treatment of pollutant and energy recycling (Tacas *et al.* 2021) that can convert organic materials into electrical energy and provide electrochemical wastewater treatment (Zhao *et al.* 2021). MFC is made up of anode and cathode chamber. It is generally divided by a semi-impermeable membrane (Bagchi and Behera 2021). In the anode chamber, electroactive microorganisms break down the substrates in an anaerobic environment and release electrons in the substrates. These electrons are transferred to the anode electrode via either a direct electron transfer mechanism or mediated electron transfer mechanism (Arkatkar *et al.* 2021). Electrons are transferred to the anode electrode by these mechanisms. Afterwards, these electrons are transferred to the cathode electrode by passing through an external circuit (Aiyer 2021) and energy generation occurs when this process complete (Arkatkar *et al.* 2020).

The applications and architectural structures of MFC have changed over the time (Gustave *et al.* 2021). Various examples of these structures can be given: Plant-MFC (Helder *et al.* 2010), benthic MFC (Karra *et al.* 2013), PEM MFC (Chakraborty *et al.* 2020) and soil MFC (Casula *et al.* 2021). In recent years, MFC technology has been successfully improved with different types of organic substrates such as farming (Ma *et al.* 2016), refinery (Srikanth *et al.* 2016), municipal wastewater (Liang *et al.* 2018) and dairy wastewater (Choudhury *et al.* 2021).

Table 1. A view of the performance of MFCs with different substrates.

Substrate	MFC Configuration	Anode	Power Density	Reference
Dairy wastewater	Annular single chamber MFC	The Ss mesh with graphite coating	20.2 W/m^3	Mardanpour *et al.* 2012
Dairy wastewater	Dual chamber MFC	Graphite plates	2.7 W/m^3	Elakkiya and Matheswaran 2013
Synthetic	Single chamber MFC	Titanium	57 µW·m^{-2}	Zhou *et al.* 2016
Food factory wastewater	Single chamber MFC	Karbon örtü	1007 mWm^{-3}	Mohamed *et al.* 2016
Textile wastewater	Single chamber MFC	Carbon fibres	123.2 ± 27.5 mW m^{-3}	Logroño *et al.* 2017
Domestic wastewater	Algal biofilm-assisted MFC	Carbon cloth	62.93 mW·m^{-2}	Yang *et al.* 2018
Nitrobenzene synthetic wastewater	MFC coupled constructed wetland	Graphite	1.53 mW/m^2	Xie *et al.* 2018
Activated sludge	Dual chamber air cathode MFC	Copper braid	75.64 W/m^3	Hayder and Dinçer 2019
Synthetic	Dual chamber MFC	Graphite fibre brush	3006 mW/m^3	Ali *et al.* 2019
Anaerobic sludge	MFC-Constructed wetlands reactors	Granular active carbon	0.27 W m^{-3}	Zhang *et al.* 2020
Sulfate-laden wastewater.	Dual chamber MFC	Graphite sheets	1188 mW/m^3	Kumar *et al.* 2020
Synthetic	Photosynthetic MFC	Graphite felt	15.21 W m^{-3}	Sharma and Chhabra 2021
Dairy wastewater	Single chamber MFC	Pt/C cloth	50 mW/m^2	Choudhury *et al*. 2021
Electroplating industry wastewater	Dual chamber anaerobic MFC	Carbon veil	260 mW/m^2	Karuppiah *et al.* 2021

The parameters that affect MFC performance are; fuel cell architecture, electrode materials, distance between electrodes, membrane or non-membrane systems, microorganisms, substrates and electron transfer mechanisms (Mohan *et al* 2014). In full-scale applications, parameters such as modifications of MFCs and anode and cathode materials greatly affect the efficiency (Munoz-Cupa *et al.* 2021).

In this study carried out under the light of the above information both electricity generation and domestic wastewater treatment were investigated in a two chambered MFC design. The cathode chamber was placed inside the anode chamber. Thus, more electron flow was aimed at decreasing the intracellular diffusion resistance. Because it is aimed to increase the electric potential by more collection of electrons; metal and carbon materials were used together for composite anode electrode design.

2. Material and Method

2.1. *Reactor Configurations*

In the study, a two chambered MFC was designed from plastic material. The anode chamber was rectangular and 2.5 L. The cathode chamber was circular and 200 mL. The cathode chamber was placed in the middle of the anode chamber and the anode and cathode chamber were physically separated by the Nafion 117 membrane (Ion Power Company, 720 Governor Lea Rd, New Castle, DE 19720). Before starting the experiment, the Nafion 117 membrane used in the reactor was activated by membrane conditioning and cut into 1 cm x 4 cm size and impedance analysis was performed.

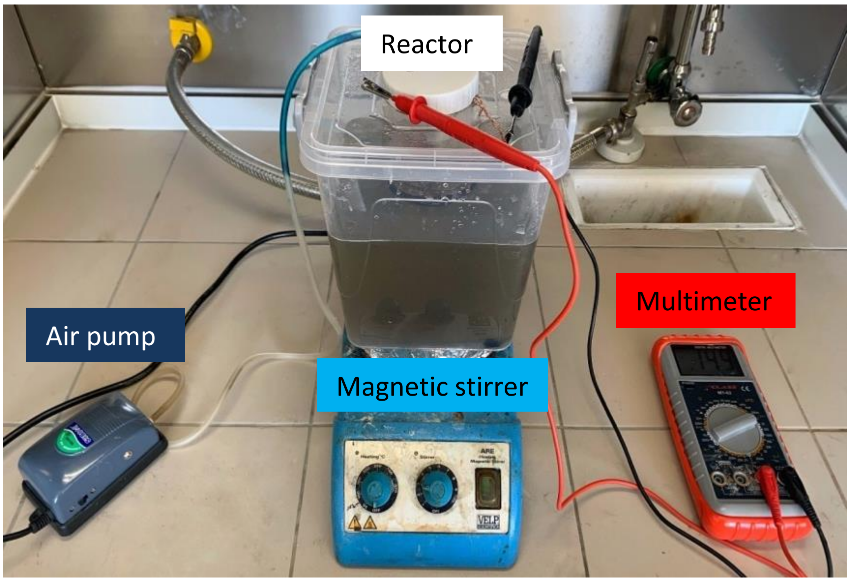

Figure 2. The experimental setup.

The reactor and experimental setup used in the study are shown in Figure 2. Ankara Tatlar Wastewater Treatment Plant influent water (2 liters) was used as a substrate in the anode chamber. The anode chamber was completely closed and maintained at anaerobic conditions.

The carbon rod is used as cathode electrode. The cathode chamber was filled with deionized water and vented with an air pump during the experiment. The reactor was stirred at the lowest speed during the operating period to ensure a homogeneous content.

2.2. *Anode Electrode Design and Modification*

Stainless steel (SS) mesh and graphite powder were used as anode electrode material. Stainless steel mesh was used as the current collector. This mesh properties can be expressed that 1.11 mS/m conductivity, plain weave, 40 mesh. Graphite powder (104206, Merck) properties can be expressed that 12.01 g/mol molar mass, 2.2136 g/cm^3 (25 °C) density, 5-6 (50 g/l, H_2O, 20 °C) (slurry) pH value and ≥ 99.5 % particle size (<50 µm). Ethyl cellulose, terpineol and cyclohexanone binders were applied to half of the SS mesh. Then, graphite powder was poured on both surfaces of the mesh and the prepared electrode was left to dry for two days. The designed anode electrode is shown in Figure 3.

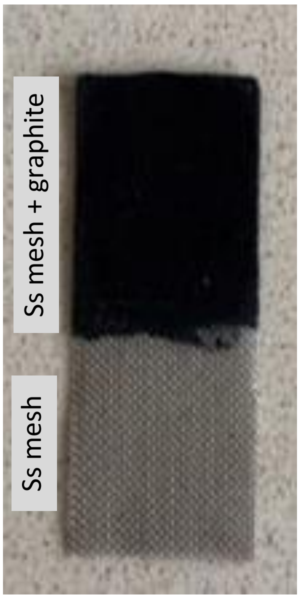

Figure 3. Stainles steel mesh + graphite electrode.

2.3. *Electrochemical Analysis and COD Analysis*

The current and voltage values were measured manually by a digital multimeter (Class MY-62) at 15 minutes intervals. The power density values are calculated using Equation (1).

$$P = I.V/A \tag{1}$$

where, P: Power Density W/m^2, I: Current, amper, V: Voltage, volt, A: Anode electrode area, m^2 (Aktan *et al.* 2011).

Impedance analysis of the membrane was performed by using combined Solartron 1260-

Solartron 1287 device, which has the ability to measure in the range of 1 Hz-1000 MHz.

Matriks MD-600 test kits were used for COD analysis of domestic wastewater used in the reactor. Before the reactor was put into operation, an initial COD analysis was performed by taking 2 mL sample from the wastewater. At the end of the experiment, 2 mL sample was taken again from the anode chamber and the COD analysis was repeated.

3. Results and Discussion

Impedance analysis was performed to determine whether the conditioned Nafion 117 membrane had sufficient ionic conductivity before the operation. The result of the impedance test is given in Figure 4.

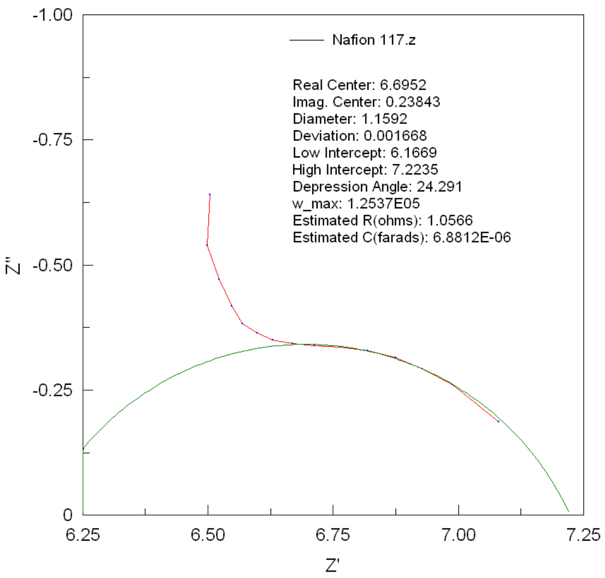

Figure 4. Nafion 117 impedance analysis graph.

When the impedance analysis graph is examined, it can be said that the activated membrane is conditioned (Rohm: 1.0566) and ready for use in the MFC. After all processes are completed, the MFC was operated for 7th day and the study was finished at the end of the 7th day since no current/voltage values were measured. During the experiment, voltage measurements were made only between 10:00 and 17:00 (every 15 min).

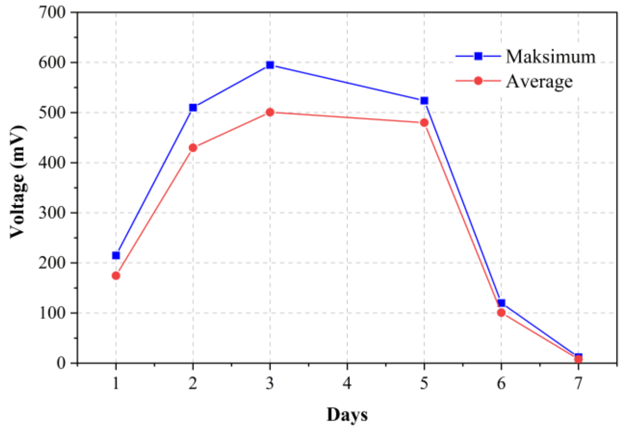

Figure 5. Voltage values graph.

Figure 5 shows that the substrate consumption increased with the adaptation of exoelectrogenic microorganisms to the environment and it was observed that the voltage values increased significantly on the 2nd day. This situation shows that an electrochemical biofilm structure occurred on the anode electrode. Electricity generation was observed several hours after the reactor was started and the maximum voltage value was reached on the 3rd day as 595 mV. Since the nutrient decreases in the wastewater, the voltage values started to decrease fluctuating after the 3rd day. At the end of the 7th day, the experiment was finished since no values were observed. The cathode chamber was placed in the middle of the anode chamber, reducing the distance between electrodes. The relatively small distance between the anode and cathode electrode is effective in the amount of electricity obtained in the study.

In the literature, Chandhuri and Lovley (2003) used graphite felt as the anode electrode and glucose as the substrate in their study. During the study, the maximum voltage was measured as 620 mV [25]. Wu *et al.* (2017), measured about 460 mV as the maximum voltage using combined small graphite fiber brush and carbon mesh as anode and municipal wastewater as substrate, in their study [26]. Nquyen and Min (2020) used carbon fiber brush as anode electrode, leachate wastewater as a substrate in their study and maximum voltage value was measured as 330 mV. Yu *et al.* (2021) investigated electricity generation with a graphite felt anode electrode in an SMFC using petroleum hydrocarbon contaminated soils as a substrate. The stable voltage 345 mV was measured [27]. When the literature studies were examined, it was seen that the maximum voltage value is quite high compared to other studies. Additionally, this value shows that the new composite electrode makes an important contribution to electricity generation. The mesh structure of the anode electrode increased the biofilm rate and provided high voltage. The power density was calculated by using current values and voltage values in Eq (1) and given in Figure 6.

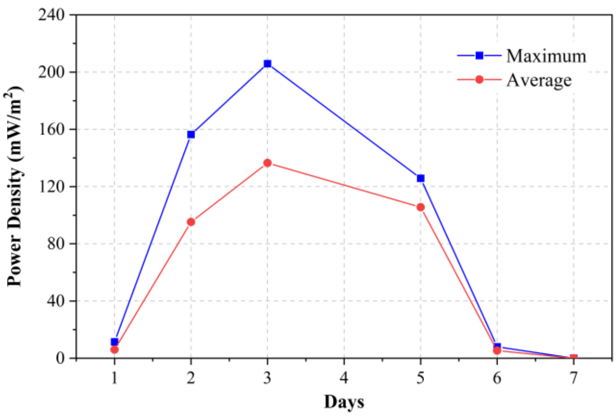

Figure 6. Power density values graph.

Decreasing the distance among the anode and cathode electrode was also effective in reducing the intracellular resistance. In this experiment, the increase in electricity generation continued until the end of the 3rd day and the maximum power density was reached on this day. Figure 6 shows that the maximum power density was calculated as 205.867 mW/m^2. High results were obtained by the current reactor design. Exoelectrogens transferred electrons from composite electrodes through some mechanisms and provided high power density. Rahimnejad *et al.* (2011) used graphite plates as anode electrode and glucose as a substrate. During the study, its maximum power density was calculated as 283 mW/m^2. Lakshmidevi *et al.* (2020) used as a substrate municipal solid waste landfill leachate and graphite as anode electrode and maximum power density was calculated as 95.63 mW/m^2. Various studies on power density have also been mentioned in Table 1. It is seen that the maximum power density value is comparable with literature. Finally, COD values were calculated at the begin/end of the experiment were measured as 451 mg/L O_2 and 361 mg/L O_2, respectively.

4. Conclusions

In this paper, electricity generation and domestic wastewater treatment performance were investigated using a two-chambered microbial fuel cell. Domestic wastewater was used as substrate in the reactor. A composite anode electrode was used which was designed by using graphite powder and SS mesh. The maximum voltage and power density were measured as 595 mV and 205.867 mW/m^2, respectively. The voltage and power density values are comparable with the literature. It can be said that the stainless steel mesh and graphite powder composite electrode will be an alternative anode electrode to other electrode types in the literature. Besides that the domestic wastewater causes serious environmental pollution and needs to be treated to a certain extent for discharge to surface waters. MFC can be also helpful for this problem. Improvements on the reactor configurations and electrodes can increase the efficiency of the MFC including electricity generation and wastewater treatment ability.

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