Electricity generation and wastewater treatment using microbial fuel cells with graphite and aluminum electrodes

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Abstract*– A microbial fuel cell (MFC) is a system that can integrate electricity generation and, at the same time, contribute to decontaminating wastewater, becoming an eco-friendly technology with the environment. In this research, microbial fuel cells with graphite and aluminum electrodes were used at different sizes: 9, 25 and 64 cm^2, and a wastewater sample obtained from a rural location in Peru was used as substrate. The MFCs parameters of voltage, current and conductivity were monitored for 12 days, for the generation of electricity; and the parameters of Chemical Oxygen Demand (COD), Thermotolerant Coliforms, Turbidity and pH, for wastewater treatment. The MFCs with electrodes of 64 cm^2 were the ones that had the highest efficiency in the production of electricity, because they generated higher voltage, current and conductivity throughout the days evaluated, with peaks of 0.22 V, 0.08 mA and 1.05 mS/cm, respectively. Likewise, a reduction in the content of COD, Thermotolerant Coliforms and Turbidity of the substrate used (70, 73 and 36%) was achieved, while the pH remained slightly stable, with values from 7.39 to 6.49 during the days evaluated. The MFCs are a promising approach to a sustainable future in which energy can be generated from the use of household wastewater, while simultaneously treating these effluents.

***Keywords*-- microbial fuel cells, wastewater, electricity, wastewater treatment, graphite**

I. Introduction

Industrial development and population growth have brought with them a vertiginous increase in water and electricity consumption [1]. Electric power is supplied, for the most part, by fossil fuels, which are a non-renewable energy source and cause a lot of damage to the environment due to the release of greenhouse gases during their use [2]. On the other hand, the demand for water has increased exponentially with the increase in population, which has led to the generation of numerous problems related to its scarcity and quality [3,4]. In Peru, the demand for electricity has experienced growth rates of 7% per year due to the remarkable population growth of recent decades [5]. This demand was covered, in part, by the development of hydroelectric plants, but despite this, the national energy system still faces a great challenge, which is the expansion of energy supply in rural areas [6]. Likewise, the treatment of wastewater is another critical problem in Peru, due to the precariousness of the sanitation service and the poor development of wastewater treatment plants, so that most of these effluents are discharged into the environment. natural without receiving any treatment [7].

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Due to this, it is not feasible to continue generating electricity in this way, for which it is necessary to investigate other alternative sources that are renewable, accessible and eco-friendly [8-10]. Thus, the environmental challenge of developing technologies that can generate electricity and, at the same time, decontaminate wastewater arises, and one of them is the Microbial Fuel Cells (MFCs). An MFCs is a system in which chemical energy is transformed into electrical energy through redox reactions [11]. They are made up of an anode and a cathode, where the electrons are released through a microbial reaction and are transported to the anode by mediators or direct transmission, then, with an external resistance, the electrons are directed to the cathode where they are consumed [12]. The substrate provides energy to microbial fuel cells and provides nutrients to microorganisms, the most used are: glucose ($C_6H_{12}O_6$), ethanol (C_2H_5OH) and lactate ($C_3H_6O_3$) [13].

Currently, the use of microbial fuel cells has been investigated by many specialists, due to the various applications that can be given, such as bioelectricity production and wastewater treatment. Saima et al (2022) worked with microbial fuel cells with aluminum, zinc and iron anodes in sizes of 12, 16 and 20 cm^2 in shapes (circular, rectangular, square), showing the ability of the zinc anode to produce a higher voltage, with a voltage of 1.75 V and a current of 0.23 A [14]. While Nookwam et al (2022) used integral MFCs, for the production of bioelectricity, wastewater treatment and biodiesel production, with effluents from the rubber industry; obtaining a power density of 55.43 ± 1.08 W/m^2, eliminating nitrogen, phosphorus and COD and generating bioelectricity, due to the communities of bacteria present [2]. On the other hand, Debaiyoti et al (2019) used microbial fuel cells with platinum and activated carbon catalysts for electricity generation, obtaining a power density of 800 ± 20 and 450 ± 10 mW/m^2, and an efficiency in the decontamination of residual water of 60% [15]. Microbial fuel cells are a promising approach to a sustainable future in which energy can be generated using wastewater from households and industries, because these systems can integrate electricity generation and, at the same time, contribute to decontaminating wastewater; various by-products have been generated and certain materials have been decontaminated using MFCs technology [16,17].

The objective of this research is to evaluate and demonstrate the performance of wastewater within Microbial Fuel Cells by measuring voltage, electrical current and conductivity for electricity generation, and by measuring pH, turbidity, chemical oxygen demand (COD) and thermotolerant coliforms for wastewater treatment, to demonstrate that MFCs are one of the best alternatives to generate electricity and treat wastewater.

II. Materials and Methods

A. Wastewater sample collection

Seven liters of wastewater were collected from a storage pond located in Urpay, Pataz, La Libertad, Peru (see Figure 1). The containers were washed with distilled water and sterilized using the water bath method, to eliminate the microorganisms present and/or any contaminant that could infer the results, finally they were left to dry at 21 °C for 12 hours.

Fig. 1. Location of the wastewater sampling site, where (A) Wastewater storage pond.

B. Construction of the Microbial Fuel Cells

Nine microbial fuel cells with a volume of 0.5 liters each were made using polypropylene (PP) containers of 1089 cm^3, for the electrode's aluminum (Al-cathode) and graphite (C-anode) plates of 0.02 cm thickness were used. Three different electrode sizes (9, 25 and 64 cm^2) were adhered with glue to the internal walls of the cell, in which three holes were made in the central part, to pass a copper wire (Cu) to the outside of the MFC. A cross section was also made at each end of the MFCs so that the electrodes are in contact with the outside (see Figure 2).

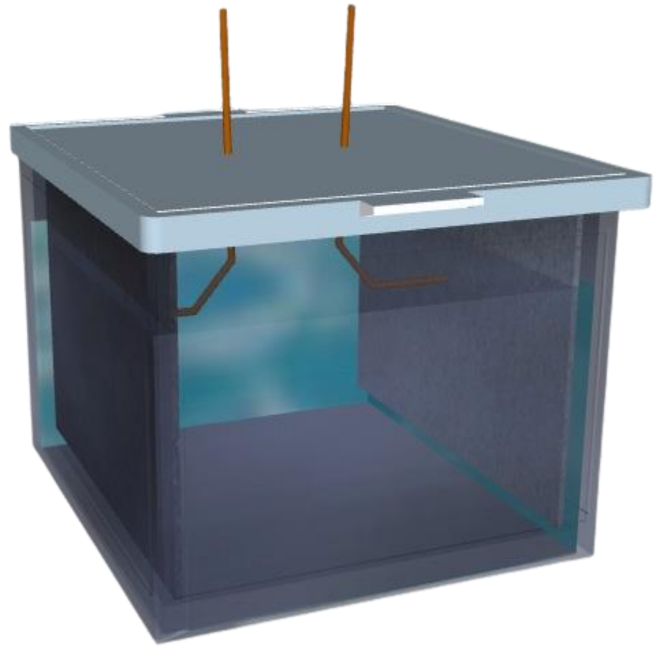

Fig. 2. Prototype Microbial Fuel Cells.

C. Characterization of Microbial Fuel Cells

C.1 Electric power generation

The voltage and electrical current of the Microbial Fuel Cells were measured with a multimeter (Truper MUT - 830) daily for a period of 12 days, for 30 minutes at room temperature (21 °C). The conductivity (conductivity meter CD-4301) of the sample incorporated into each cell was also monitored.

C.2 Waste water treatment

An initial analysis of Chemical Oxygen Demand (COD) and Thermotolerant Coliforms was performed on the collected wastewater sample under the open reflux method and the standard membrane filter procedure, respectively. Likewise, measurements were taken for 12 days of the pH and turbidity values of each substrate incorporated into the cells, with the equipment (pH-meter 110Series Oakton) and (turbidimeter HI-98703C), respectively. Subsequently, 0.5 L of residual water was incorporated into each cell and after finishing with the measurements for the generation of electricity, the aforementioned parameters were re-evaluated to observe the effectiveness in reducing these residual water contaminants within the MFCs.

III. RESULTS AND ANALYSIS

Figure 3 (a) shows the voltage generation of the MFCs for 12 days. It can be seen that the MFCs with 64 cm^2 electrodes were the ones that obtained the highest voltage, given that on days 7 and 12 they had their highest peaks (0.22 V). Likewise, the MFCs that contained electrodes of 25 cm^2 were the second most effective, since they obtained a higher voltage on day 12 with 0.21 volts. It can be seen that both the MFCs with electrodes of 64 and 25 cm^2 tend to increase their voltage with the passing of days. Ru et al. (2022) refers that the size of the anode is one of the key factors in the efficiency of the MFCs for the production of voltage, that is why the MFCs with larger electrodes generated higher voltage than those with larger electrodes [18].

Likewise, Meixue et al. (2022), explains that the presence of organic compounds in the residual water in the anode leads to an increase in aerobic heterotrophs in the cathode, and this, in turn, reduces the oxygen concentration in the cathode and generates voltage fluctuations [19]. Figure 3 (b) shows the electrical current values generated by the MFCs with different electrode sizes, as can be seen, the highest current values were obtained with the 64 cm^2 MFCs with values of 0.07 and 0.08 mA, on days 2 and 5 of monitoring, respectively. Akansha and Rakesh (2022), mention that the efficiency of the metabolism of various exoelectrogenic microorganisms, help the use of the substrate and the generation of current [20]. The current is related to the voltage values, due to the potential difference of the anode and cathode [21]; that is, the electric current is generated due to the use of electrons transported from the anode to the cathode through an external connection, respectively from graphite to aluminum [22]. The conductivity values of the MFCs substrate are shown in Figure 4 (a), as can be seen the MFCs with 64 cm^2 electrodes, show higher conductivity values throughout the 12 days evaluated with data ranging from 0.96 and 1.05 mS/cm; the electrical conductivity is enhanced by the formation of microbial biofilms. Furthermore, the anode material must have certain characteristics of superconductivity, biocompatibility, chemical stable, non-corrosive resistance, and rigid [23]. The performance of the MFCs works more optimally when it has a higher conductivity, which is why the cells with the 64 cm^2 electrodes were the ones that obtained a better performance in the parameters evaluated in the generation of electricity. This is because when there is a higher conductivity, which translates into a higher energy production [24,25].

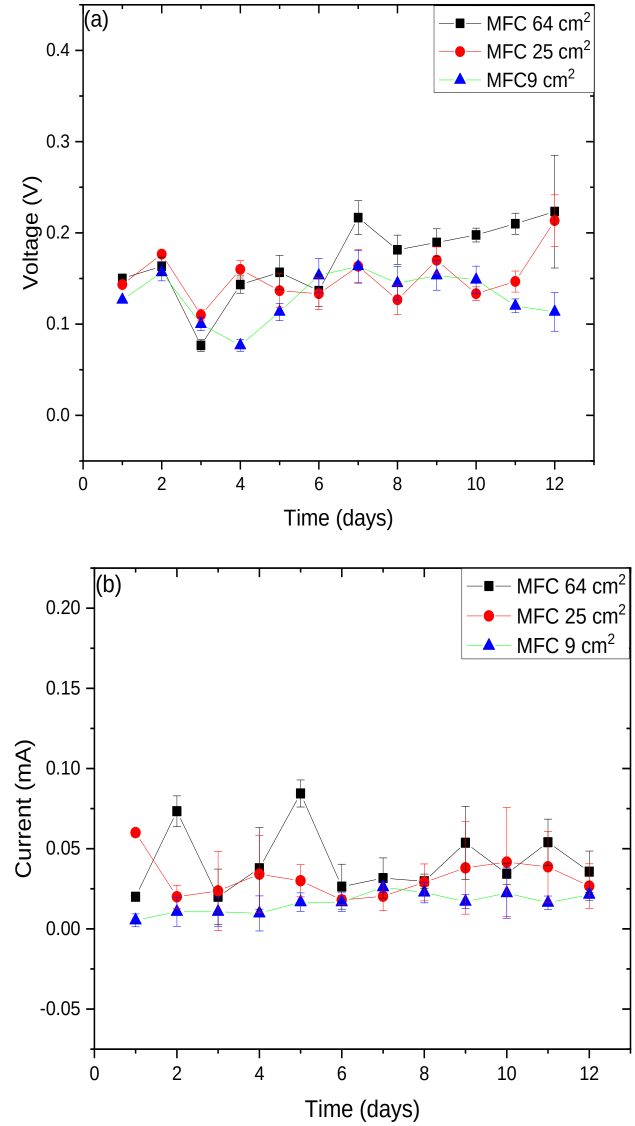

Fig. 3. Monitoring of the (a) current and (b) voltage generation of the MFCs during 12 days.

Figure 4 (a) shows the pH values of the wastewater added to the microbial fuel cells during the monitoring days, it is observed that the three types of MFCs showed a slight decrease in pH with the passing of days, being thus, on day 12, the MFCs with electrodes of 9, 25 and 64 cm^2, showed pH values of 6.43, 6.49 and 6.54, respectively, from the initial pH of 7.39. Likewise, Ru et al (2022) mentions that when there are low pH conditions, the aluminum metal ion (Al^{3+}) has a high conductivity [26]; this explains why our 64 cm^2 cell, having a lower pH during the days evaluated, had a higher electrical conductivity. The final pH obtained from the 9 MFCs showed an average value of 6.49 (Figure 4 (b)), which remains in an adequate range, according to previous investigations suggests that an appropriate pH range for the development of microorganisms is between 6- 9 [27,28].

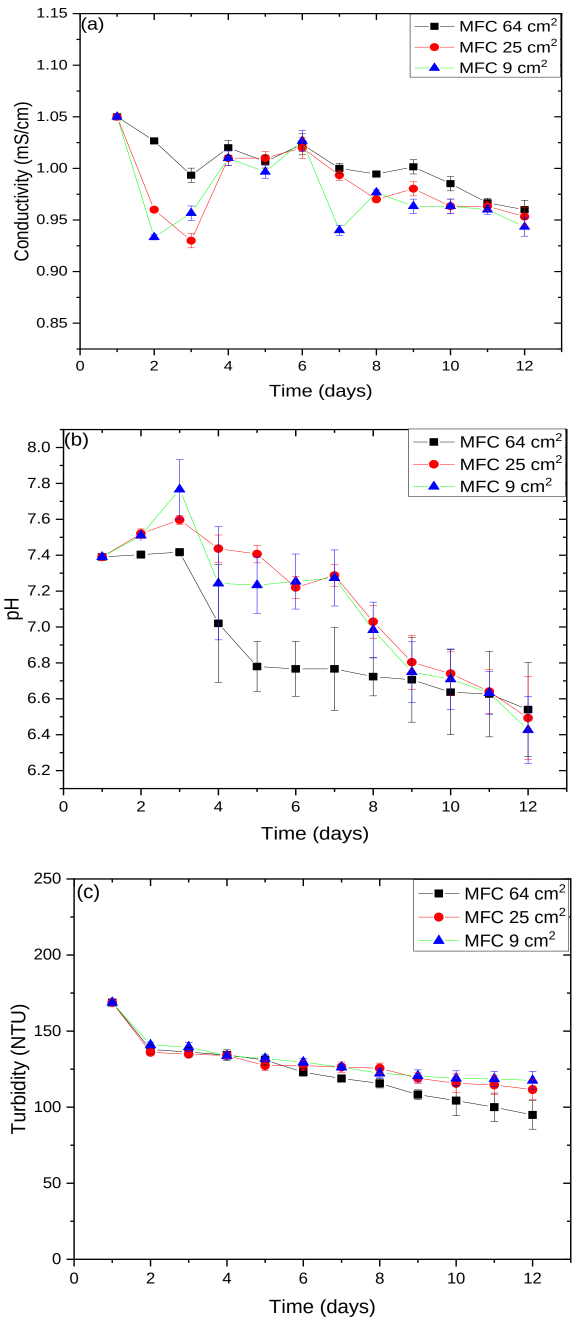

Fig. 4. Variation of the (a) conductivity, (b) pH and (c) turbidity of the MFCs during the 12 days of monitoring.

The pH and conductivity values within our microbial fuel cells vary slightly, but are not significant. According to Kavya et al. (2021) they obtained an average of 7.05 ± 0.5 between their initial and final pH values of their microbial electrolysis cell (MEC), a result that the authors consider to be non-significant [29]. In turn, they state that having a stable pH and conductivity improve the performance of microbial fuel cells. Said performance had an effect on the removal of COD and thermo-tolerant coliforms thanks to microbial action [30].

The turbidity values of the residual water samples incorporated into each MFCs during the 12 days of monitoring are shown in Figure 4 (c), it can be seen that in the microbial fuel cell with 64 cm^2 electrodes, a decrease in turbidity was observed. turbidity from 168 to 94.9 NTU, in the 12 days evaluated, turning out to be the most effective of the three prototypes used in the trial. Regarding the cells with the electrode size of 9 and 25 cm^2, they showed turbidity reduction values of 117 and 111.5 NTU, respectively. When wastewater is used, the bacteria present degrade organic matter, resulting in cleaner water [31]. Likewise, in MFCs, oxidation and reduction processes take place while COD is eliminated and electricity is generated [32]. That is, there is aerobic degradation on the surface, eliminating COD, and anaerobic degradation at the bottom, eliminating COD and generating electricity [33].

Table 1. Concentration of the parameters evaluated in the treatment of wastewater before after passing through the MFCs.

PARAMETERS	*BEFORE*	*AFTER*	*REDUCTION (%)*
Chemical Oxygen Demand (Mg O_2/L)	416	124	70
Thermotolerant Coliforms (UFC/100ml)	20 x 10^2	5.4 x 10^2	73
Turbidity (NTU)	168.8	107.99	36

Table 1 shows the concentration of the parameters evaluated in the treatment of the wastewater samples before and after passing through the microbial fuel cells, as well as their removal percentage. A favorable decrease of 70% of the Chemical Oxygen Demand (COD) of the wastewater samples incorporated into the MFCs is clearly observed. According to Wang et al. (2022), in their results obtained an initial value of COD in their MFC was 42.843 ± 118 mg/L [30]. which later, in its final result, a decrease to 16.209 ± 21 mg/L was observed. On the other hand, in terms of efficiency, the reported COD removal was 57% for wastewater. Likewise, Rossi et al. (2022) mentions that, in order to achieve a good removal efficiency of pollutants from wastewater, firstly, it must be adapted to the environment and stabilized to obtain better results [34]. This refers to the reason for the cross section that was made in our cells so that they can adapt to the environment and obtain favorable results. Furthermore, Yaqoob et al. (2020), mentions that the electrode material is very important, therefore, carbon-based materials such as: PVC and graphite, turn out to be important in the removal of COD, due to their high affinity for microorganisms [35]. In relation to all of the above, this explains why favorable results were obtained with an initial value of 416 mg/L and later 124 mg/L. On the other hand, a notable reduction in the concentration of thermotolerant coliforms present in the wastewater samples of each MFC is also observed, with a removal of 73%. This high removal is mainly due to the graphite electrode, which has adsorption properties. Rosero et al, (2019) obtained removal efficiencies of 99.99% of coliforms in their biofilters based on corn cobs/sawdust which were coupled to microbial fuel cells with graphite and steel electrodes [36]. While Rossi et al (2022) in their microbial fuel cells with carbon fiber electrodes achieved a removal of the concentration of fecal coliforms of 99.1% [34].

IV. Conclusion

Low-cost microbial fuel with graphite and aluminum electrodes, and as a substrate, a wastewater sample. MFCs with 64 cm^2 electrodes generated higher voltage, electric current, and conductivity throughout the monitoring period, with peak values of 0.22 V, 0.08 mA, and 1.05 mS/cm, respectively. The pH of the substrate of each MFC remained slightly stable, with values from 7.39 to 6.49 during all the days evaluated. Likewise, efficiency was achieved in the removal of the concentration of Chemical Oxygen Demand (COD) by 70%, Thermotolerant Coliforms by 73% and Turbidity by 36%, from the wastewater sample incorporated into each MFC. With this research, it is determined that MFCs are a promising approach for a sustainable future in which energy can be generated through the use of household wastewater, and simultaneously, these effluents can be treated.

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