MICROBIAL FUEL CELL ELECTRICITY GENERATION USING TWO TYPES OF WATER IN THE CITY OF CHOTA, PERU

GENERAREA DE ELECTRICITATE A CELULEI DE COMBUSTIBIL MICROBIAN CU DOUA TIPURI DE APĂ ÎN ORAȘUL CHOTA, PERU

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Abstract: *In this study, two sources of wastewater (municipal slaughterhouse and river) obtained in the city of Chota, Peru, were used to produce electricity by using microbial fuel cells (MFC). The type of wastewater and the storage time influenced the generation of energy with MFC. The slaughterhouse water, due to its high organic load, reached its maximum energy efficiency on day 30, producing 78.29 mV, while the river water generated 52.94 mV at most. This demonstrates the potential of wastewater as a sustainable source of energy,*

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offering a dual solution: waste management and development of renewable energy.

Keywords: river water, industrial wastewater, microbial community, MFC, energy.

Rezumat: *În acest studiu, două surse de apă uzată (abator municipal și râu) obținute în orașul Chota, Peru, au fost folosite pentru a produce energie electrică prin utilizarea celulelor de combustie microbiană (MFC). Tipul de apă uzată și timpul de stocare au influențat generarea de energie cu MFC. Apa abatorului, datorită încărcăturii sale organice ridicate, a atins eficiența energetică maximă în ziua 30, producând 78,29 mV, în timp ce apa râului a generat cel mult 52,94 mV. Acest lucru demonstrează potențialul apelor uzate ca sursă durabilă de energie, oferind o soluție dublă: managementul deșeurilor și dezvoltarea energiei regenerabile.*

Cuvinte cheie: apă de râu, ape uzate industriale, comunitate microbiană, MFC, energie.

1. Introduction

The electric power sector is critical to economic growth and global development. Demand for electricity continues to rise, driven by both developed and developing economies, underscoring its importance for the progress and sustainability of nations [1]. However, currently about 80% of the world's energy comes from non-renewable sources such as oil, gas, coal and nuclear power, posing major environmental challenges. In response, the adoption of renewable energy technologies has become an essential priority to move towards a more sustainable future and reduce environmental impact [2].

Among emerging renewable energy sources, microbial fuel cells (MFC) represent an innovative method for producing clean energy through the use of microorganisms, with the ability to transform wastewater into electricity and contribute to the degradation of organic compounds present in waste [3]. This process is carried out through electron transfer from the biofilm [4]; among the microorganisms studied, *Raoultella ornithinolytica* has been shown to produce a current density of up to 325.13 mA/m² and a power density of 87.78 mW/m² [3, 5]

MFC systems have evolved to improve their efficiency by using materials such as graphite in the proton exchange membrane and exploring different energy sources containing bacteria with energy potential. For example, Shirvani et al. [6] generated electricity from wastewater and ostrich leather tanning effluent, achieving a maximum power of 84.1 mW/m² and a current density of 320 mA/m². Likewise, Al-Ansari et al. [7] recorded that

wastewater containing *Bacillus subtilis* (EL06) in an open-loop system reached a maximum voltage of 1.28 ± 0.1 V within 60 hours of treatment.

Considering that in the city of Chota, Cajamarca region, Peru, there is a significant effluent of industrial wastewater such as that of the Municipal slaughterhouse of the Chota District, as well as the water of the Chotano river that has direct outlets from the drain of the city of Chota, MFC are presented as a promising technology for the generation of clean energy in the Cajamarca region. This research aimed to determine the energy efficiency of MFC using two types of water according to the place of origin (municipal slaughterhouse and Chotano river), which will allow to evaluate the viability of future energy projects based on this technology.

2. Materials and methods

2.1. Area of study

The wastewater samples were collected from the municipal slaughterhouse of Chota and the Chotano river, whose geographic coordinates are 6°32'50"S, 78°40'38"W, at an altitude of 2260 MASL; and 6°32'13"S, 78°41'35"W, at an altitude of 2220 MASL, respectively. Each sample was labeled and transferred to the Soil Mechanics and Hydraulics laboratory of the Professional School of Civil Engineering (Colpa Matara campus) for conditioning in the cell. The identification of the microorganisms was carried out in the Microbiology and Agroindustrial Biotechnology laboratory of the Professional School of Agroindustrial Engineering (Colpa Huacarís campus), of the National Autonomous University of Chota, district and province of Chota, Cajamarca region, Peru.

2.2. Microbiological analysis of wastewater

For the analysis of the samples, the methodology according to the "Manual of Methods for Microbiological Analysis of Food and Water" [8] was followed, using 25 ml of each sample, which were diluted in 225 ml of sterile peptone water at 0.1% (dilution factor 10^{-1}) and then the necessary successive dilutions were made.

Viable mesophilic aerobes were determined by using the Agar Plate Count and applying the depth seeding method. For this, a 1 ml aliquot of the dilutions was taken, which were seeded in duplicate and incubated at 35 °C/48 h. After the incubation, the colonies were counted.

The presence of coliforms was determined by the Most Probable Number (MPN) method, using 2% BRILA (Brilliant Green Bile Lactose) broth. Initially, a presumptive test was carried out using Lauryl Sulfate Tryptose broth. For this, a 1 ml aliquot of the dilutions was taken, which was inoculated in triplicate and incubated at 35 °C for 24 h. Samples that presented turbidity and gas formation were considered positive. From these positive samples, 20 µl were extracted, which were inoculated in tubes with 9 ml of Brilliant Green Bile broth and incubated at 35 °C for 24 h. At the end of the incubation, the positive tubes were recorded, and the results were interpreted using the MPN table.

Enterobacteria and *Escherichia coli* were determined by the plate counting method using double-layer violet red bile dextrose. For this, a 1 ml aliquot of the dilutions was taken, which were seeded in duplicate and incubated at 35 °C/48 h. After the incubation, the colonies were counted.

To determine the presence of lactic acid bacteria, MacConkey agar was used with the deep sowing method. A 1 ml aliquot of the dilutions was taken, which was inoculated in triplicate and incubated at 35 °C for 24 h.

2.3. Microbial fuel cells (MFC)

MFC based on the design proposed in the patent of [9] were used, adapted to the research. Figure 1 shows the design of the system, which consisted of six rectangular polyethylene containers (18 cm long, 10 cm wide, and 11 cm high) connected to a 6 L container by 0.8 mm hoses for the flow of wastewater. Each MFC had an anaerobic chamber (bottom) and an aerobic chamber (top) separated by a proton exchange membrane (electrode) (two graphite felts). The membrane was 10 mm thick, separated by a No. 6 electrowelded mesh, and each cell had an electrode of 11 cm wide x 17 cm long.

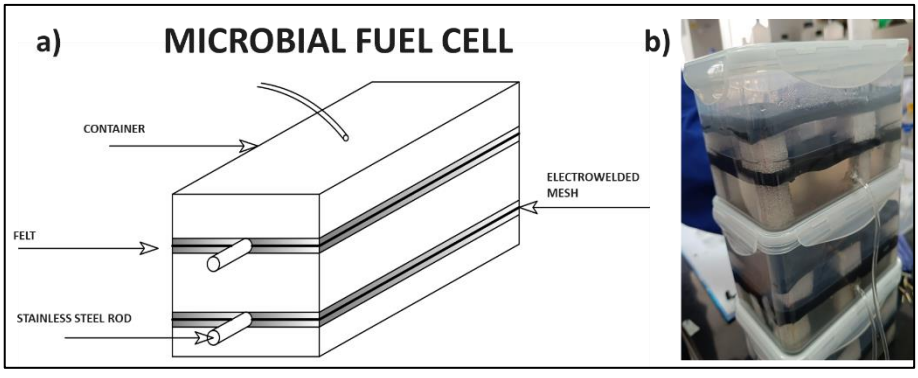

Figure 1. Microbial fuel cells. a) descriptive drawing of the cell; b) prototype of the cell

The external electrical circuit, according to [9] and [10] consisted of 2 small alligator clips with their respective copper cables of 0.02 mm diameter, and a kit of external resistors from 0 to 5.6 Ω to control the passage of electrons, all connected to a digital multimeter.

Each type of wastewater was processed separately in a 10-litre container, using Luria Bertani Broth, Miller (25 grams dissolved in 1000 ml) as the culture medium. The time interval between samples for testing was 30 days. The mixtures were then distributed in each experimental cell and left to incubate for 24 hours before proceeding to the corresponding measurements.

2.4. Electrical measurements

The electricity produced by the power cells was monitored with a digital multimeter (OWON B471+). Specific reading intervals were 7 hours, 13 hours, and 19 hours, over a continuous 30-day period for both wastewaters, replacing every 4 to 5 days to ensure consistency and stability. Measurements were reported in mV.

2.5. Data analysis

The results of the experiment were analyzed using Analysis of Variance (ANOVA) in a factorial scheme for a completely randomized design, verifying normality of residues with the Shapiro-Wilk test. The effects of the factors "type of water" and "evaluation time" were evaluated, as well as their interaction in the electricity production process. Tukey test was applied to identify differences between interactions. The analyses performed with AgroR in R used a significance level of 5%.

3. Results and discussion

Table 1 shows the results of the microbiological analyses performed on wastewater on days 0 and 10. Mesophilic microbiological agents, Enterobacteria, *E. coli*, lactic acid bacteria and total coliforms were identified. The results found are similar to research carried out by [11], who identified the presence of gram-negative bacteria such as inactive *Escherichia coli*, *Escherichia coli*, *Edwardsiella tarda*, *Salmonella parathypi*, *Shigella flexnery*, *Klebsiella pneumoniae*, *Pseudomona oryzihabitans* and gram-positive cocci such as *Staphylococcus aureus* in the wastewater samples from

the community of San Vicente de Lacas in the province of Chimborazo, Riobamba, Ecuador. On the other hand, in the research of [12], was observed a greater predominance of enteropathogenic bacteria such as *E. coli*, *Klebsiella* spp, *Shigella* spp, *Citrobacter* spp and *Salmonella* spp in the wastewater from different purification stages of the municipal slaughterhouse of the Huancavelica Province, Peru.

The microbial load from the municipal slaughterhouse wastewater was higher than that from the Chotano river, so differences in the production of electrical energy between both sources are expected.

Table 1. **Microbiological analysis carried out on wastewater samples from the city of Chota, Peru**

Microbiological Indicator	**Wastewater from the municipal slaughterhouse**		**Wastewater from the Chotano river**	
	Day 0 [CFU/ml]	**Day 10 [CFU/ml]**	**Day 0 [CFU/ml]**	**Day 10 [CFU/ml]**
Mesophilic aerobes	3.7×10^7	1.4×10^8	4.6×10^4	2.2×10^5
Enterobacteriaceae	3.1×10^6	5.1×10^6	1.3×10^3	8.3×10^4
Escherichia coli	2.8×10^6	2.4×10^5	1.6×10^2	5.8×10^3
Lactic Acid Bacteria	3.2×10^5	---------	3.4×10^2	3.1×10^3
Total coliforms	8.1×10^6	1.8×10^7	2.2×10^4	1.5×10^5

Figure 2 shows the electrical energy generated from the municipal slaughterhouse water and the Chotano river during 30 days of evaluation. There were significant differences between the treatment combinations, both between the types of water on specific days and between the days within each type of water. It is possible to observe that the slaughterhouse water generates more energy than the river water on most of the days evaluated. Throughout the period, the energy production increases, reaching maximums on day 30 for the slaughterhouse water with 78.29 mV and on day 25 for the Chotano river water, with 52.94 mV. The higher energy generation of slaughterhouse water can be attributed to its higher organic load, which favors the activity of microorganisms involved in electricity production. However, other factors may be involved. For example, [13] used a combination of graphene and nickel in the anode nanostructure as the electrode material. This configuration allowed the growth of bacteria in the pores of the electrode, achieving a notable improvement in

current density. Likewise, [14] worked with bacterial inoculum derived from the activated sludge of the municipal slaughterhouse of Huancavelica, Peru. The best trend was observed in the cell containing a mixture of 50% bacterial inoculum from the activated sludge and 50% water-based substrate from the slaughterhouse, reaching a measurement of 521.24 mV.

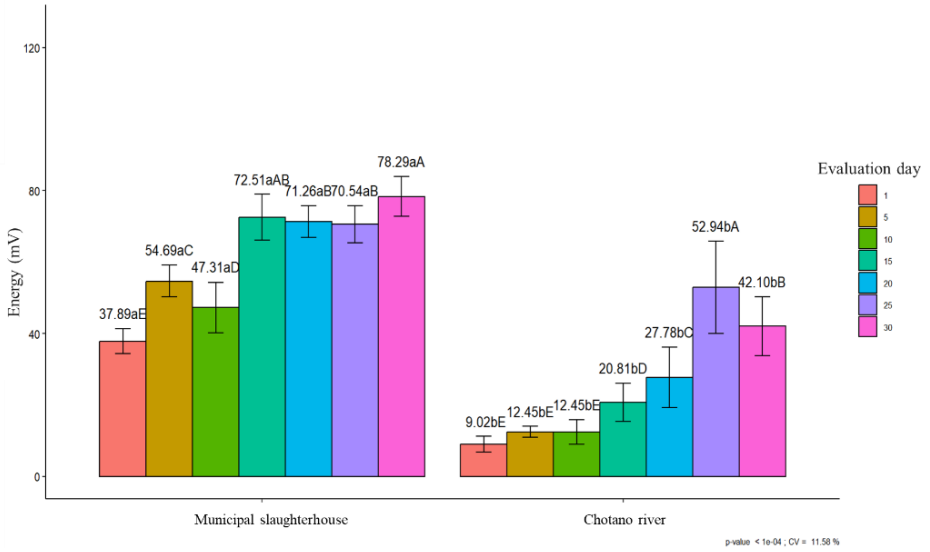

Figure 2. Electricity generated from the waters of the municipal slaughterhouse and the Chotano river for 30 days. According to Tukey test (significance level of 5%), different capital letters indicate significant differences in energy formation within the same water type, while different lowercase letters represent significant differences in energy formation between different water types, assessed by day.

In summary, the increase in energy generation as the evaluation time progresses suggests that storage increases the concentration of metabolites generated by microorganisms, improving the conditions for energy production. The interaction between the type of water and the evaluation time shows that the effect of storage is not the same for both waters, with slaughterhouse water being more favorable and constant for microbial growth, resulting in greater energy generation.

4. Conclusions

This study showed that both the type of wastewater and the storage time have a significant impact on energy generation using microbial fuel cells.

Slaughterhouse water was found to be more efficient than river water, especially due to its higher microbiological load, making it more suitable for the bioelectrogenesis process. Furthermore, energy production increases with storage time, peaking at day 30. These findings highlight the potential of wastewater as a sustainable source of energy for rural communities, offering a dual solution: waste management and renewable energy development. Future studies could focus on analyzing the specific components of these waters to optimize the substrates used and explore how different environmental conditions affect the efficiency of the process.

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