INVESTIGATION AND V-I CHARACTERISTICS OF SUBSTRATE FOR MFC: CASE STUDY OF RAW HONEY

INVESTIGACIÓN Y CARACTERÍSTICAS V-I DE SUSTRATO PARA MFC: ESTUDIO DE CASO DE LA MIEL CRUDA

Matilda Kpeli*, **Michael K. E. Donkor, Francis K. Ampong, Reuben Y. Tamakoloe**

Department of Physics - College of Science, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana.

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Abstract

The world is gradually shifting from the over-reliance on fossil fuel energy to the discoveries, development, and use of various forms of renewable energy. One advancement is towards the use of Microbial Fuel Cells (MFCs). This is a bioreactor that makes use of microbial activity present in the organic substance in an electrochemical system to generate electricity. In this research, raw honey was utilized as the fuel source for fabricating a double-chambered MFC device using clay partitions. Six dilutions of the raw honey were made into Cell 1 (2 %), Cell 2 (5 %), Cell 3 (20 %), Cell 4 (40 %), Cell 5 (60 %), and Cell 6 (80 %). After fourteen days with two experiments carried out, the maximum current densities obtained were 270.2 mA/m^2, 583.7 mA/m^2, 654.0 mA/m^2, 351.3 mA/m^2, 140.5 mA/m^2, 64.8 mA/m^2, with the corresponding maximum power densities of 99.2 W/m^2, 215 W/m^2, 247.0 W/m^2, 123.1 W/m^2, 49.8 W/m^2, 22.5 W/m^2 for Cell 1, Cell 2, Cell 3, Cell 4, Cell 5, and Cell 6, respectively. It was determined that raw honey that has been diluted can be used as a fuel source to create MFC.

Keywords: raw honey, bioreactor, clay partition, unmediated honey.

* matildabestill@gmail.com
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Resumen

El mundo está abandonando gradualmente la dependencia excesiva de la energía procedente de combustibles fósiles en favor del descubrimiento, el desarrollo y la utilización de diversas formas de energía renovable. Uno de los avances es el uso de celdas de combustible microbianas (MFC). Se trata de un biorreactor que aprovecha la actividad microbiana presente en la sustancia orgánica de un sistema electroquímico para generar electricidad. En este estudio, se utiliza miel cruda como fuente de combustible para fabricar un dispositivo de MFC de doble cámara utilizando tabiques de arcilla. Se realizaron seis diluciones de miel cruda en la celda 1 (2 %), la celda 2 (5 %), la celda 3 (20 %), la celda 4 (40 %), la celda 5 (60 %) y la celda 6 (80 %). Tras catorce días en los que se realizaron dos experimentos, las densidades de corriente máximas obtenidas fueron de 270,2 mA/m^2, 583,7 mA/m^2, 654,0 mA/m^2, 351,3 mA/m^2, 140,5 mA/m^2, 64,8 mA/m^2, con las correspondientes densidades de potencia máximas de 99,2 W/m^2, 215 W/m^2, 247,0 W/m^2, 123,1 W/m^2, 49,8 W/m^2, 22,5 W/m^2 para la celda 1, la celda 2, la celda 3, la celda 4, la celda 5 y la celda 6, respectivamente. Se determinó que la miel cruda diluida puede utilizarse como fuente de combustible para crear una MFC.

Palabras clave: miel cruda, biorreactor, tabique de arcilla, miel no mediada.

Introduction

The world's scarce source of fossil fuels and the influence of fossil fuels on climate change necessitate us to develop alternative energy sources. Among the next generation of energy sources is microbial fuel cell which is attracting extensive consideration due to their proposed use in recovering energy in the form of electricity [1]. By definition, a microbial fuel cell (MFC) is a bio-electrochemical system [2] that drives an electric current by using bacteria and a high-energy oxidant. Microbial fuel cells are self-sustaining devices without the requirement for any power supply and it is an environmentally friendly technology for electricity harvesting from a variety of substrates [3]. MFCs have been employed to convert wastewater to electricity by electrogenic bacteria [4]. First, the power needed for the MFC to function is obtained from the anodic substrate itself. The second requirement depends on the oxidizing agent of the cathode.

Any excellent scientist aspires to be able to improve people's lives and make them easier. Therefore, the primary goal of this project is to investigate and develop methods to enhance fundamental infrastructure, such as power, at a lower cost and within everyone's reach. The commercialization of MFC will offer several benefits, including the ability to: 1) use organic substrates and also utilize microorganisms to convert the chemical energy within the substrate into electricity in a simple process; 2) produce electricity using raw honey at a low cost; and 3) produce electricity all year round as raw honey is easily obtainable in our region of the world.

However, MFC performance is affected largely by the reactor architecture and its components [5]. Designing and developing anode substrates appropriate for use in MFCs need to meet the standards of high electrical conductivity, high surface area, and bio-compatibility that would permit efficient electrochemical links of living bacterial cells [6]. Major parameters that affect the performance of MFCs include: 1) oxidation of substrates in the anode chamber; 2) electron transport from the anode chamber to the anode surface; 3) permeability of proton exchange partition, and 4) supply and utilization of oxygen in cathode chamber [7]. Also, columbic efficiency in MFCs is affected by several features, including internal and external resistances, substrate concentration, the presence of electron acceptors, bacterial presence, and the electrode and receptacle chamber design [8].

In this laboratory, varying concentration of raw honey was made to develop MFC suitable for systemic durability and robustness. The elements of the family basket consist of a variety of things that vary geographically. In order to avoid being labeled as "poor", a family must have at least the amount of food, consumer goods, and services represented by the family basket. However, honey is not on the list, which might not stop it from being used as a substrate in MFCs.

For honey production, honeybees ingest nectar and turn this with help of enzymes. Raw honey is an organic source and is rich with microbes, making it very suitable for electricity generation. Raw or natural honey is a sticky and viscous solution with a content of 80–85 % carbohydrate, mainly glucose and fructose, 15–17 % water, 0.1–0.4 % protein, 0.2 % ash, and minor quantities of amino acids, enzymes, and vitamins, as well as other substances, like phenolic antioxidants.

Beyond the enzyme genus, bacteria such as *Actinomyces, Bacteroides, Clostridium, Enterobacter, Enterococcus, Escherichia, Klebsiella, Lactobacillus, Proteus, Pseudomonas, Staphylococcus, and Streptococcus* incorporate some symbiont microorganisms associated with the gastrointestinal tract that can bring benefit to human health [9]. O. Anjos et al. (2015) studied 63 raw honey samples using HPAEC-PAD and concluded that fructose comprises about 36 %, and glucose about 26 % of the sugars in honey, respectively. The 1st Der spectra with MSC or SLS in the wavenumber range from 1500 to 750 cm^{-1} for both fructose and glucose [10, 11]. Other sugars found were trehalose, sucrose, turanose, maltose, and melezitose. They confirmed the 3 types of honey: raw honey, adulterated/processed honey, and artificial honey.

The objective of the present study is to produce bioelectricity from various concentrations of honey as substrate in MFC. To enable electron transfer in the anode chamber and enhance the oxidation-reduction reaction in the cathode chamber, hydrogen peroxide (H_2O_2: 6 % w/v) is an oxidation agent between 75 % to 90 % dilution. The amount of open-circuit-voltage (OCV) and power production were investigated respectively. The second objective of this study was to verify the effect of dilution on the FTIR-ATR pattern of the raw honey and also to monitor the stability of MFC for the long-time process. Christwardana et al., in 2018 researched on Optimization of glucose concentration and glucose/yeast ratio in yeast MFC, the OCV extracted from yeast-MFC in the absence of methylene blue was from 0.455 to 0.711 V, while in the presence of methylene blue, the OCV range was from 0.429 to 0.584 V [12–14].

Methodology

The honey that was used was pure and had not been altered or inoculated. This was bought from a farmer in Saltpond in the Central Region of Ghana, and was very thick and sluggish between -10 °C and 26 °C. The experimental setup using this raw form did not provide any significant Open-Circuit Voltage (OCV). This could be a result of the high viscosity creating a high impedance to ion flow, so that called for the dilution to reduce the viscosity and enhance microbial flow.

For this further study, the honey was diluted using distilled water at different concentrations: 2 %, 5 %, 20 %, 40 %, 60 %, and 80 %, all at a volume of 10 ml each, as shown in Table 1. This is to help obtain the relation between diluted raw honey and the maximum power density produced.

Cells	**Dilution Percentages (%)**	**Total Dissolved Solids (TDS) (mg/L)**	**pH**	**Conductivity (µS/m)**
Cell 1	2	73.7	3.68	147.4
Cell 2	5	129.3	4.10	259.0
Cell 3	20	258.0	3.30	517.0
Cell 4	40	157.1	4.70	314.0
Cell 5	60	75.6	4.20	151.1
Cell 6	80	16.3	4.15	32.0

TABLE 1. *Properties of Natural/Raw Honey measured per their diluted percentages*

However, these experiments continually use zinc plates (1pc High Purity 99.9 % Pure Zinc Sheet Zn Plate for Science Lab Accessories 100 mm x 100 mm x 0.2 mm from aliexpress.com store) and copper plates (1pc 0.2 mm x 100 mm x 1000 mm 99.9 % High Purity Pure Copper Cu Metal Sheet Foil Plate from aliexpress.com store), as electrodes, for good results [15]. In the present work, zinc plates with a surface area of 18.5 cm^2 each were placed in the honey. Copper plate of the same surface area was placed in the H_2O_2 respectively. The combined pots form a cell.

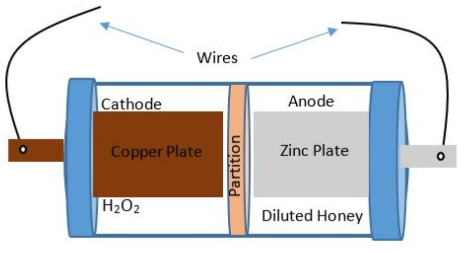

FIGURA 1. *Schematic representation of honey MFC setup*

The cells were made of a non-conducting tube of a suitable inner volume of 10 ml and were partitioned with a Mfensi-clay slab (Mfensi/Kaolin/Bentonite; all mixed in appropriate percentage shown in Table 2) and suitable thickness of 6.31 mm. This is robust and served as the ion exchange system. Filling and emptying the chambers are done by opening the screw covers one at a time at both ends. External conduction is via wires through which electrons flow to complete the circuit. Consequently, this setup has an unmediated anode chamber. The type of H_2O_2 used in this study as catholyte was bought from a nearby chemical store in 200 mL bottles (Over counter H_2O_2 used as mouthwash: density of 1.45 g/cm^3, the melting point of -0.43 °C and boiling point of 150.2 °C - ECL'S, Solution of Hydrogen Peroxide B.P. 20 Volumes, contains 6 % w/v of H_2O_2 with a stabilizer, made in Ghana by Ernest Chemists Ltd.). It was diluted with distilled water at 80 % concentration [12]. Between 75 % to <90 % concentration, this H_2O_2 decomposes to two OH and becomes a more powerful oxidizing agent and safe to be used in MFCs. For 90 - 100 %, it is more reactive with the electrode.

Element	%	Element	%
Na_2O	6.15	K_2O	1.66
MgO	1.28	CaO	0.54
Al_2O_3	13.82	TiO_2	0.04
SiO_2	65.26	MnO	0.07
P_2O_5	0.23	Fe_2O_3	0.83
SO_3	0.10	LOI	10.00
Cl	0.02	**Total**	**100**

TABLE 2. *Mfensi Clay: Geological Survey Department X-Ray Fluorescence Laboratory Results [16]*

Results and Discussion

FTIR-ATR Characteristics of diluted raw honey

Fourier transform infrared spectroscopic spectrum with attenuated total reflectance (FTIR-ATR) for different absorption phases studied on different concentrations; 2 %, 5 %, 20 %, 40 %, 60 %, and 80 % are shown in the stack plot in Figure 2. This shows the variation of FTIR-ATR spectrum of all the diluted kinds of honey in this study.

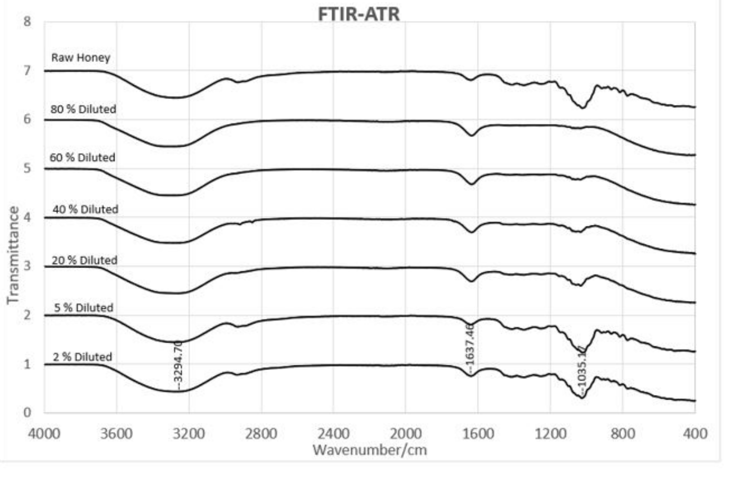

FIGURA 2. *FTIR-ATR for raw and diluted honey samples*

This study used raw honey; therefore, the FTIR curves were observed to be similar to the raw undiluted honey as represented in Figure 2. Three major and similar peaks were observed in the charts at 3294.70, 1637.46, and 1035.17 wavenumbers. The characteristic peaks represent areas of the spectrum where specific bond vibrations occur relating to the preserved properties of honey. Water has a very strong absorptivity only in the MID-IR region and does not affect the absorption peaks of fructose and glucose. Since the dilution percentages of FTIR-ATR data did not provide a noticeable trend, the effect is only visible in the output of OCVs depicted in Figures 3 to 5.

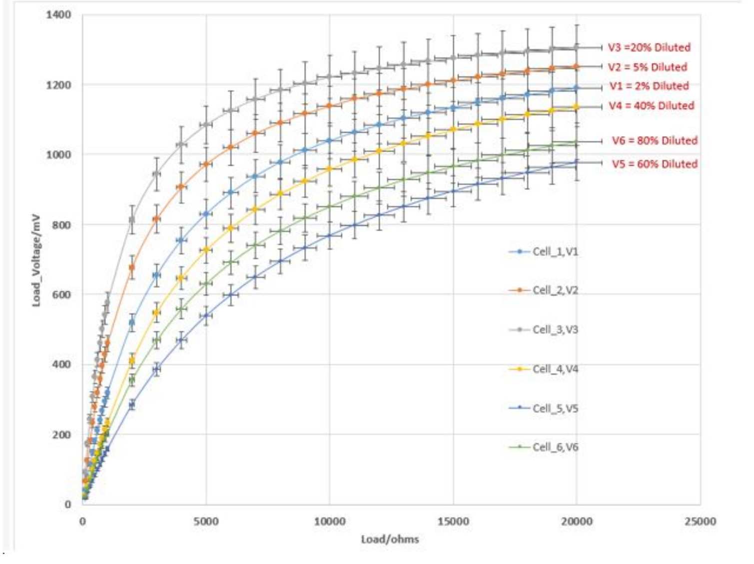

FIGURA 3. *Variation of a potential drop with external load*

The V-I characteristics

The V-I characterization experiment was conducted for all six diluted raw honey substrates. The anode and cathode wires were connected to a variable resistor board with resistance loads ranging from 100 Ω to 20,000 Ω, and their corresponding voltages were recorded using a 2010DMM digital multimeter. Individual currents were then calculated using $I = \frac{V}{R}$. The open circuit voltage (OCV) against the dilution of raw honey is shown in Table 3. The load vs. potential drop trend in Figure 3 makes it very evident that the relationship between dilution and OCV was not linear. It was predicted to have a linear inclination toward increasing honey concentration. That is, 2 %, 4 %, and 20 % followed the trend of growing polarization. Meaning that at a 20 % dilution, greater microbial activity and more potent ions may be released, ranging from 100 Ω to 15 KΩ to determine the polarization.

Cell	Raw honey Dilution	OCV/mV	ASR/Ωcm^2
Cell 1	2 %	1363	61122
Cell 2	5 %	1376	36381
Cell 3	20 %	1399	26227
Cell 4	40 %	1213	95580
Cell 5	60 %	1270	136708
Cell 6	80 %	1377	102061

TABLE 3. *Voltages measured and area-specific resistance (ASR) for all 6 diluted raw honey cells*

As observed, 20 % diluted performed above all others, showing that the appropriateness of dilution and suitable flow of ions was achieved.

The electrode separation, related to the thickness of the clay partition that could increase the ionic conductivity, may be the cause of the major ohmic losses illustrated by the plots in Figure 4.

Activation losses are insignificant in these experiments as there were ready active enzymes in the raw honey. The area-specific resistance (ASR) function shown on the diagram relates to the cell design, material choice, fabrication technique, and temperature (26 °C) under which the study was done. This shows the corresponding magnitude in Table 3.

Figures 4 and 5 are required to examine the extent to which the cells could be used to power the required devices. All cells were normalized by their anode operational surface area.

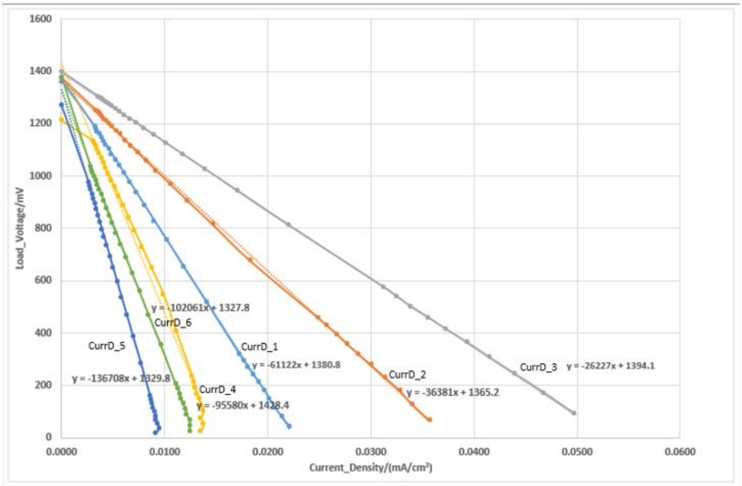

FIGURA 4. *Variation in the load voltage as a function of current density*

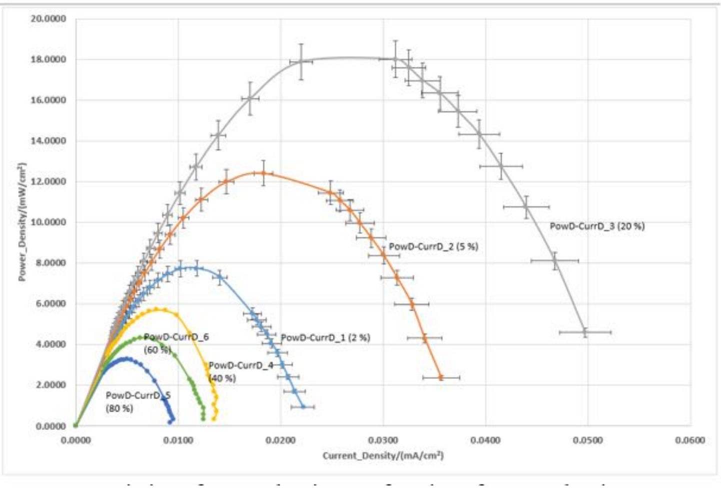

FIGURA 5. *Variation of power density as a function of current density*

Conclusions

In this project, power generated via double chamber MFC using various dilutions of raw honey was studied. Because raw honey is an essential substrate in this experiment, its use has an immense impact on how well the systems work. The results suggested, to a moderate extent, that the power density is dependent on the microbial activity of the anodic substrate. The OCVs, which are represented in Figures 3, 4, and 5, compared favorably. After fourteen days with two experiments carried out, the maximum current densities obtained as shown in Figure 5 were 270.2 mA/m^2, 583.7 mA/m^2, 654.0 mA/m^2, 351.3 mA/m^2, 140.5 mA/m^2, 64.8 mA/m^2 with the maximum power densities also of 99.2 W/m^2, 215 W/m^2, 247.0 W/m^2, 123.1 W/m^2, 49.8 W/m^2, 22.5 W/m^2 for Cell 1, Cell 2, Cell 3, Cell 4, Cell 5, and Cell 6, respectively.

The OCV may be comparable, but the current is only dependent on the population of functioning electric charges in the system. Additionally, it is reliant on bio-electrochemical reactions, which is probably the case. Other parameters such as dissolved solids, pH, conductivity, and Mfensi clay properties have played some significant roles in the study. The performance of honey substrate was compared with wastewater substrate in an earlier study [17]. Nevertheless, the focus in this study is on the power generation and sustainability.

In conclusion, FTIR-ATR spectroscopy was used to determine if there were any similarities among the samples, as well as the impact of dilution on the absorption properties of the raw honey used in this investigation. The unadulterated, raw honey's peaks are the most noticeable (3261.89 cm^{-1} and 1024.31 cm^{-1}). These results are only taken into account by characteristic band ranges that establish the quality of the honey exploited, following the references [18–20]. It was determined that raw honey that has been diluted can be used as a fuel source to produce MFC.

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