EXPLORING THE USE OF RAW HONEY AS A FUEL SOURCE FOR MICROBIAL FUEL CELLS

ANÁLISIS DEL USO DE LA MIEL CRUDA COMO FUENTE DE COMBUSTIBLE PARA LAS CELDAS DE COMBUSTIBLE MICROBIANAS

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Abstract

Microbial fuel cell (MFC) technologies are making headway in developing and expanding renewable energy through the conversion of organic matter to electricity. Various substrates can be used in the MFCs technology to enable energy generation, either pure substances or complex mixtures of organic materials. This study aims to consider the feasibility of raw honey as a fuel for mediator-less double-chamber MFC. The cell voltage was monitored in mediator-less double-chamber H_2O_2 cathode microbial fuel cell. The Mfensi clay partition and the raw honey were analyzed using FTIR-ATR. The results show the highest open-circuit voltage of 1414 mV with a maximum current density of 0.6540 A/m^2 and a maximum power density of 247.0 W/m^2. These results demonstrate that raw honey can be used for power generation in MFCs and for practical applications.

Keywords: electrochemical activity, FTIR-ATR, microbial activity, microbial fuel cell, raw honey.

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Resumen

Las celdas de combustible microbianas (CCM) como tecnología se están abriendo paso en el desarrollo y expansión de las energías renovables mediante la conversión de materia orgánica en electricidad. En la tecnología de las CCM pueden utilizarse diversos sustratos que permiten generar energía, ya sean sustancias puras o mezclas complejas de materiales orgánicos. Este estudio tiene como objetivo considerar la viabilidad de la miel cruda como combustible para las CCM de doble cámara sin mediador. Se monitorizó el voltaje de la celda en la CCM de doble cámara sin mediador y con cátodo de H_2O_2. La partición de arcilla Mfensi y la miel cruda se analizaron mediante FTIR-ATR. Los resultados muestran una tensión de circuito abierto máxima de 1414 mV con una densidad de corriente máxima de 0,6540 A/m^2 y una densidad de potencia máxima de 247,0 W/m^2. Estos resultados demuestran que la miel cruda puede utilizarse para la generación de energía en las CCM y para aplicaciones prácticas.

Palabras clave: actividad electroquímica, FTIR-ATR, actividad microbiana, celda de combustible microbiana, miel cruda.

Introduction

The impact of global carbon emissions on the environment, alongside the degradation of the ecosystem and natural resources, has become a pressing reality as economic growth is constantly pursued worldwide. Environmentally sustainable energy options are constantly being investigated to arrive at sustainable solutions that can help mitigate the problems associated with the use of conventional sources of energy. Solar, wind, and biomass are renewable energies that have been utilized to the point of providing a solution to this energy dilemma [1]. These non-conventional sources of energy have played a key role in the decarbonization agenda towards a sustainable environment.

Microbial fuel cells (MFCs), which are bio-electrochemical cells, are emerging as an eco-friendly renewable energy technology. MFCs multidimensional application makes the technology very versatile. The technology depends on exoelectrogens which are electroactive bacteria to concurrently produce electricity and treat waste fluid [1]. MFCs generate electricity through an environmentally sustainable process. In MFCs' operation, bacteria replicate continuously, which leads to the generation of electricity as long as the conditions that favor bacterial growth continue to exist. [2]. MFC technology shows great potential as an efficient alternative technology for the conversion of chemical energy into electricity [3] and is proving to be a viable addition to renewable energy solutions to sustainably decarbonize the environment.

One vital feature of MFC is the substrate microbes feed on which eventually led to the generation of electricity [4]. Various substrates can be utilized in the MFC technology to enhance energy generation. These can either be pure substances or complex mixtures that constitute the organic materials. Microbes are of high value for microbial fuel cells to work. Crude honey is one organic material that contains microbes [5]. According to Buba et al., (2013) 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 [6]. The major ingredients of honey are almost the same in all honey samples as indicated by Anjos et al., (2015), using FTIR-ATR to analyze 63 samples [7]. Honey contains some microorganisms and acts as a reservoir for useful bacteria. Moisture influences the growth of microorganisms in honey. Hence, diluting honey with water favours the growth of microorganism present within honey.

When water was added to crude honey, it was observed that honey supports the growth of non-pathogenic bacterial strains. Bacteria can survive longer in solutions with less than 50 % honey by volume of water. Crude honey has very limited microbial growth and development potential [8]. Several different assays may be used in regular microbiological analysis of honey; however, this study is not concerned with actual microbes responsible for power production, hygienic quality, heat treatment, source handling, or microbe control. Notwithstanding, one or more of the following could be responsible for power generation in MFC; *Bacillus, Achromobater, Bacteridium, Citrobacter, Brevibacterium, Escherichia coli, Flavobacterium and Enterobacter* [9].

Materials and methods

Fabrication of the Local Clay as an Ion-Exchange Partition

Mfensi clay and alumina were used in the fabrication of the partition (Figure 1). The ratio 2:1 of Mfensi clay and alumina moulded and fired at a maximum temperature of 982 °C in a gas kiln. The slab was then left to cool down in the kiln for 48 hours. The apparent porosity was measured to be 19 %. The slab is then shaped to fit into the cell.

FIGURE 1. *Fabricated and shaped Mfensi clay slab partition.*

In this study, a pair of plastic containers, for both the anode and cathode chambers of the MFC, was used, as shown in Figure 2. The cell was made up of two 10 ml containers, a Mfensi clay partition with a thickness of 6.31 mm (Table 1), zinc and copper plates with a surface area of 18.5 cm^2, and two wires. The bottom ends of the two containers were cut open and the clay partition was placed in between them. The zinc and copper plates were inserted through the screw covers of the containers with a wire attached to each plate

Raw honey was used as a fuel source in this study. A 20 % diluted honey was made with a pH of 3.30, total dissolved solids (TDS) of 258.0 mg/L, and conductivity of 517.0 μS/m. The honey used was pure and not treated or inoculated with any vaccine.

Hydrogen peroxide (H_2O_2) was used at the cathode as an oxidizer

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 1. *Mfensi Clay: Geological Survey Department X-Ray Fluorescence Laboratory Results.*

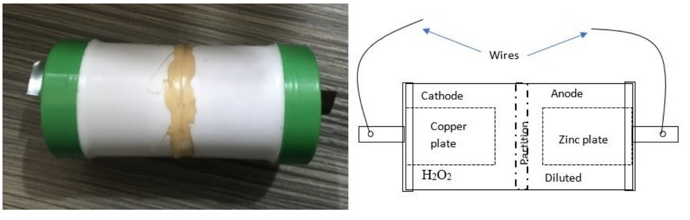

FIGURE 2. *A built MFC device using plastic containers c) Block diagram.*

(over-the-counter H_2O_2 use as mouthwash: density of 1.45 g/cm^3, a 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 into an 80 % concentration [10]. Between 70 % to <90 % concentration, this H_2O_2 decomposes to two OH and becomes the most powerful oxidizing agent and is safe to be used in MFCs. For 90-100 % it is more reactive with the electrode.

In this study, 10 ml of the diluted raw honey was filled into one part of the plastic container as the fuel source or anode. A zinc electrode ("1pc High Purity 99.9 % Pure Zinc Sheet Zn Plate for Science Lab Accessories 100mmx100mmx0.2mm" from aliexpress.com store) was placed in the diluted raw honey and closed tightly with its cover. Also, a volume of 10 ml of diluted hydrogen peroxide was also filled into the opposite part of the cathode. The copper electrode ("1pc 0.2mm*100mm*1000mm 99.9 % High Purity

Pure Copper Cu Metal Sheet Foil Plate" from aliexpress.com store) was placed into the cathode and also closed tightly with its cover to enhance anaerobic activity.

A digital multimeter was used to measure the load voltages across resistors from 100 Ω to 20,000 Ω as load. The open-circuit voltage (OCV) was also read. The cell was then left to operate for fourteen days, and measurements were re-taken.

The resistances and corresponding voltages were plotted with Microsoft Excel and graphs were generated for their corresponding current readings into a curve. Current density and power density curves were also plotted as normalized with the surface area of the anode electrode.

Fourier Infrared Spectroscopy - Attenuated Total Reflectance Spectroscopy (FTIR- ATR)

Sample of the clay partition grounded to a fine powder and diluted raw honey was sent to the General KNUST Laboratory for analysis and the results were obtained.

FTIR transmittance measurements were carried out between 4000 and 400 cm^{-1} on a Bruker Platinum ATR tensor II spectrometer with a resolution of 4 cm^{-1}. This type of partition consists of 50 % Mfensi clay mixed with 30 % of Kaolin and 20 % of Bentonite fired at 850 °C, molded and shaped into a circular partition [11]. The system employs the UATR technology, hence the sample is scanned in the same state and it was submitted to the lab.

Results and discussion

(FTIR- ATR) Spectroscopy of raw honey

The FTIR analysis was carried out in the spectral range (4000 to 400) cm^{-1} by a Bruker Platinum ATR tensor II spectrometer with a resolution of 4 cm^{-1}. In comparison to the study of O. Anjos et al. (2015), [11] performed on all honey samples, the fingerprint in

Figure 3 compares favorably with the peaks observed at almost the same wavenumbers.

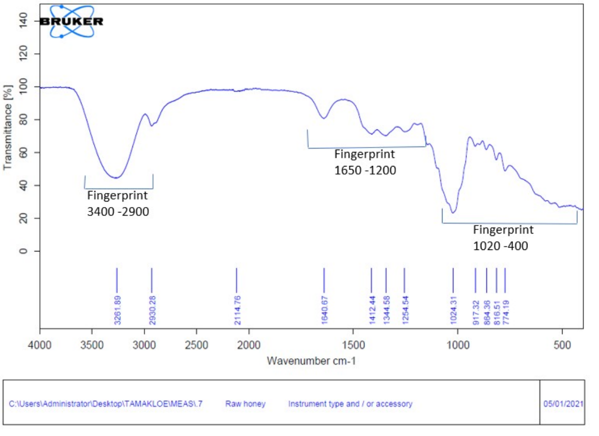

FIGURE 3. *FTIR-ATR graph of undiluted raw honey result from the KNUST Central Lab.*

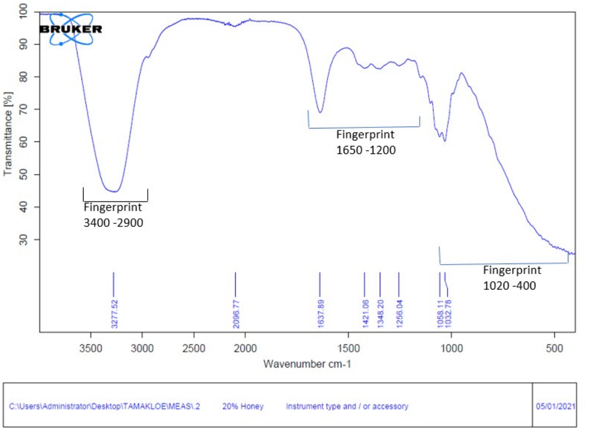

FIGURE 4. *FTIR-ATR graph for 20 % diluted honey result from the KNUST Central Lab.*

In Figure 4, the fingerprints were in correlation with the undiluted honey. The dilution has very little effect on the wavenumber/transmittance peaks at 3277.52 cm^{-1}, 1637.89 cm^{-1}, and 1032.78 cm^{-1}, except for the peak at 1637.89 cm^{-1}, which dropped down from 80 % to 70 %. This may be due to the water

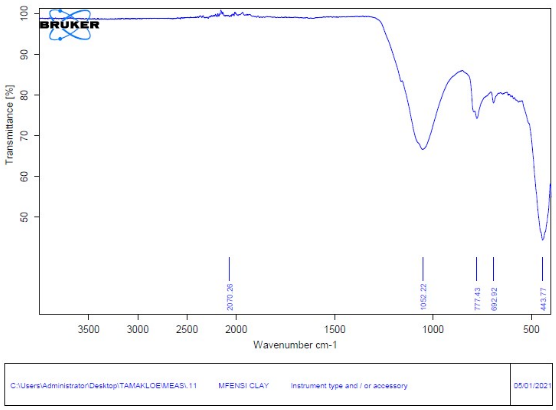

FIGURE 5. *FTIR-ATR graph for clay partition result from the KNUST Central Lab.*

content but did not show any observable change in the fingerprint.

M. Bayazit et al. (2013) analysis shows that clay materials fired between 800 – 900 °C have their transmittance peaks located 1050 cm^{-1} to 440 cm^{-1}. Figure 5 exhibited similar nature.

I-V curve characteristics of the fuel cell

As observed in Figure 6, the two curves indicate the voltages produced for the ranges of resistors in increasing order. The second experiment, carried out after 14 days (Table 2), showed an increase in voltages compared to the first experiment carried out. This may be due to the increase in microbial activity in the fuel over time. As microbial activity increases, the electrochemical process also increases, thereby increasing power generation in the cell. Also, the adaptation of the microbes to the fuel feed may be the reason for the increasing voltage in the cells. A percentage increase in voltages between both experiments was found to be 31.52 %.

From Figure 7, the current density and power density curves were plotted as observed. The current density versus the potential drop curve gave a straight line. Ohmic polarisation has dominated the system in such a manner that activation and concentration polarisations were not significant. No areas of loss of activation or concentration were indicated. This may be due to the fact that

Cell (20 % Diluted)	OCV/mV
Initial day – Cell_int	1376
After 14 days – Cell_fin	1414

TABLE 2. *Initial voltage measured after 14 days of operation.*

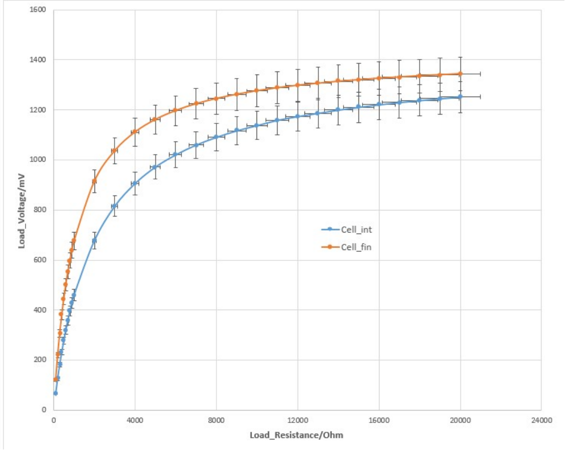

FIGURE 6. *I-V curve characteristics for the 20 % diluted honey.*

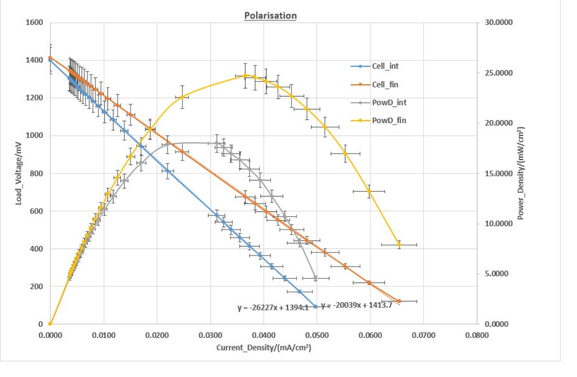

FIGURE 7. *Polarization curve for the fuel cell.*

the measurements in 14 days were short and the cell could work for a longer period. The ohmic loss zone is caused by the internal resistance to the flow of electrons. Internal resistances before and after 14 days were 1417.68 and 1083.19 respectively, as calculated from the current density vs load voltage slop.

Conclusions

In this research, raw honey was investigated as a fuel source for MFC, and it was observed that diluted raw honey can be used in fuel cells, thus eliminating the perception of contracting some strange diseases that may be associated with wastewater collection. This is a perception because in the earlier studies [1, 6, 8], physics only observed the production of power using various substrates collected from the gutter, wastewater from Guinness Ghana Limited, and some animal dungs. Precautions were taken, in high order, not to get into contact with substrates of any kind. Biological and toxic make-ups of such substrates were not in the scope of those studies. The present system produced the highest open-circuit voltage of 1414 mV, with a maximum current density of 0.6540 A/m^2 and a maximum power density of 247.0 W/m^2. This was observed to be achieved due to lower loss of power caused by microbial activity in the fuel.

FTIR-ATR showed to be the methodology to confirm the viability of raw honey as a source of fuel for MFCs and can easily be adapted by the MFC community.

Acknowledgments

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