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Comparative study of double-chamber microbial fuel cells (DC-MFCs) using Mfensi clay as ion-exchange-partition: Effect of electrodes

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An alternative answer to the vital issues of electricity production and wastewater treatment leads to the application of microbial fuel cells. This study has developed a low-cost double-chambered microbial fuel cell (MFC) for electricity generation, which can also be used for simultaneous wastewater treatment. These fuel cells were constructed using cheap Mfensi clay as an ion-exchange-partition and compared two types of electrode combination that work at temperatures between 25 ^{o}C and 27 ^{o}C. The performance of the cell assemblage was affected by the type of electrodes used. Experimental results showed maximum power densities of 118 mW/m^2 and 79 mW/m^2 respectively for the pot-zinc/copper pair of electrodes and pot-graphite/graphite pair of electrodes.

Keywords: Microbial fuel cell, anode, cathode, Mfensi clay, pot-zinc/copper pair, pot-graphite/graphite pair

JEL classification: O30, O31, O55

Introduction

Currently, research activity in fuel cell technology has greatly increased. Great efforts are directed at fuel cells because of the exhaustion of fossil fuel resources. Microbial fuel cells (MFCs) present a viable potential technology for sustainable production of alternative energy and thus provide a technique of adding wastewater to the catalog of renewable energy sources.

MFCs in general consist of an anode, a cathode, an electrolyte/catalyst and an electrical circuit to complete the system. It draws on the metabolic activity of microorganisms or microbes living in the wastewater. The anode compartment of the MFC houses the wastewater in which the microbes dwell. These microorganisms convert organic and/or inorganic contents of the wastewater through their metabolism. These metabolic activities generate electrons at the anode which travel via an external circuit to the cathode. This situation simultaneously results in the transfer of complementary numbers of cations and anions between anode and cathode. The presence of electrons on the anode gives it a lower potential than that of the cathode creating a potential difference. The flow of electrons through the external load constitutes current. Likewise the protons that are generated diffuse through a proton (cation) exchange partition.

MFCs are attracting worldwide attention, motivated by the assurance of clean and renewable energy from various wastes products including wastewater. Until 2009, MFCs could only produce low power outputs (< 6 W/ m^2; ≤ 500 W/m^2) due to many factors related to the anode, the cathode, the chemical species present in the electrolyte, the ion-exchange or filtration membrane, the microbial species present and their metabolisms, fuel cell configuration, and operational conditions, which include reduction and oxidation for the system to work..

In order to get better performance, a broad range of techniques have been used (Zhao et al. 2009), which include 'doping' of the anode, varying the electrodes and the use of various types of cathode substrate. This work has made successful attempts at improving the power outputs of an MFC by employing an ion-exchange partition made of clay as well as varying the MFC's electrode properties.

Materials and methods

The materials used for this study include Mfensi clay from the Atwima Nwabiagya District in the Ashanti Region of Ghana, The clay is known to have negative charges.

Two cylindrical chambers (Figure 1) of the capacities of 1.7 L and 1 L and thickness of 1 cm were fabricated from the clay and fired at a temperature of 1050 ºC by the Department of Ceramics – College of Arts and Social Sciences, KNUST.

The apparent porosity of the cylinders as measured was 14.3%. These parameters of the cylinder passed it for an ion exchange partition. Figure 2 shows our MFC assembly consisting of an improvised cathode which was an aluminum cooking utensil housing the cylindrical clay pot. The ion-exchange partition houses the anodic substrate. The two cells used in our investigation were fed with 1.40 L and 0.80 L wastewater respectively from Guinness Ghana Breweries Ltd (GGBL) Kumasi, Ghana, which had an initial chemical oxygen demand (COD) of 4 385 mg/L. This wastewater was fed into the anode chambers

Figure 1: Pots 1 and 2

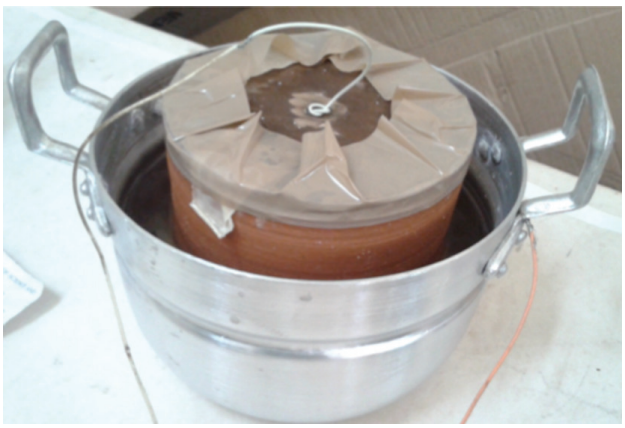

Figure 2: MFC assembly

surrounded by 40% hydrogen peroxide (H2O2) with the fabricated Mfensi clay ion-exchange partition cylinder serving as the separation.

Results and Discussion

This experiment sought to compare pot-electrode combinations, that is: 1) a pot-graphite combination and 2) a pot-zinc/copper combination. The two MFCs used in this study were connected to a Campbell Data logger CR10X to measure and store initial open circuit voltages (OCV) as well as potential drops across a 1 000Ω resistor for 30 days. The logged data was then collected via a computer interface with the logger and evaluated.

Clay pot

Earlier work by Opoku-Donkor (2013) and Tamakloe (2014) yielded positive OCVs based on theoretical calculations from Logan (2008) and Zielke (2006). Logan showed that the total cell potential, which is the difference in the anode and cathode potentials, may yield a positive value as in the equation $E_{emf} = E_{Cat} - E_{An}$.

The pot-graphite/graphite pair yielded contrary results although same substrates were used. The results obtained for this electrode pair (the lower curve of the plot in Figure 3) show a gradual rise of the initial OCV of −300 mV to almost 0 V after which a gradual fall was observed over the time period.

Table 1: Selected characteristics of MFCs in this work

	Pot-Zn/Cu	Pot–C/C
Initial COD	4385 mg/L	4385 mg/L
Final COD	571 mg/L	522 mg/L
% COD Removal	86.98	88.10
Apparent Porosity	14.3%	14.3%
OCV (mV)	800	−250
$R_{int}(\Omega)$	200	556
I_{max} (mA/m^2)	403	19
P_{max} (mW/m^2)	118	78
Initial pH (H_2O_2)	6.8	6.8
Final pH (H_2O_2)	7.9	8.4

The addition of 1 000 ohms load had no significant effect on the potential drop. The observation relating to the equation above is that the anode potential EAn is less than the cathode potential E_{Cat} (Rabaey et al., 2005). The implication here may be that there are fewer microbial activities in the anodic chamber. In both curves; the decay in cell voltage with time may be due to depletion and cross-over seepage of the cathode reagent in addition to consumption of the microbial COD content.

The pot-zinc/copper pair also yielded positive voltage in accordance with studies carried out by other researchers, as can be seen in the upper curve of Figure 3. The starting OCV was 700 mV for the pot-zinc/copper pair. When a 1 000 ohms resistor was connected, the voltage began to drop till stability was somehow attained after 400 hours.

The negative result of the pot-graphite/graphite pair was thought to be the effect of negatively charged Mfensi clay that tended to neutralise the incoming positively charged ions from the anode.

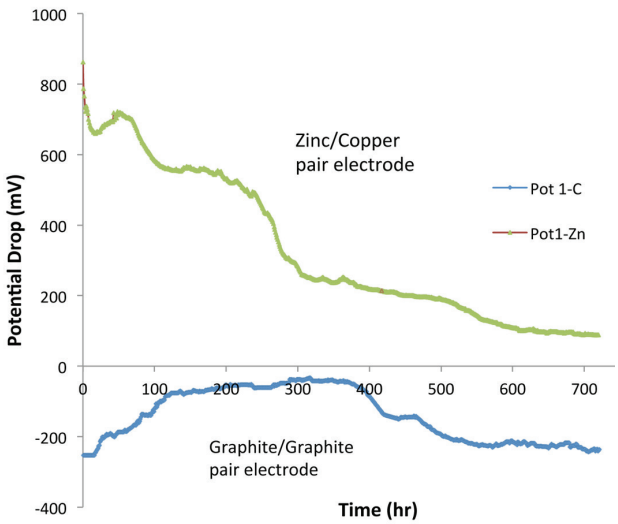

Figure 3: Variation in potential drop (OCV) with time

The chemistry of the clay and graphite pair is beyond this paper. Other studies are on-going to delve into the chemistry of wastewater content/clay pair and electrode/clay pair reactive.

From Figures 4 and 5 it was seen that the pot-zinc/copper pair produced higher values in relation to the applied external loads, ranging from 0 to 15 000Ω. As shown in Figure 5 the polarisation curves depicted the activation region and the ohmic region (actual performance region), but the concentration regions were not that clear.

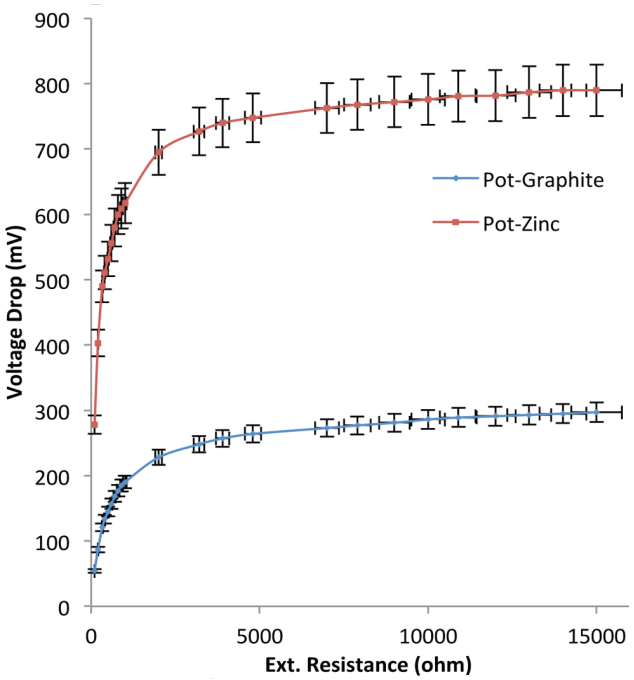

Figure 4: Variation of potential drop with external load relating to pot-graphite/graphite pair and pot-zinc/copper pair

The pot-zinc/copper pair yielded a higher peak, which occurred at118 mW/m^2 while 79 mW/m^2 was observed for the pot-graphite/graphite pair. Unfortunately, the pot-graphite did not reach a turning point with the highest load used for this paper, as shown in Figure 6.

Elementary zinc does not react with water molecules. The ions form a protective water insoluble zinc hydroxide ($Zn(OH)_2$) layer with dissolved hydroxide ions, according to the following reaction mechanism: $Zn_2^+ + 2OH^- \rightarrow Zn(OH)_2(s)$ (Lenntech BV, 2014). Copper also does not react with water because the oxygen in water is locked into a compound with one part oxygen and two parts hydrogen (Inmatrade, 2014).

Determination of internal resistance of the cells

The internal resistance is one of the major characteristics of a MFC, in accordance with the theorem of maximum power delivered by an electromotive force. An MFC connected with an external resistance equal to its internal resistance will give a maximum power output (Logan 2008, Halliday 2010). From Figure 6 the peaks occurred at 118 mW/m^2 and 79 mW/m^2 for the zinc/copper and graphite/graphite systems respectively. The alternative to finding internal resistance was calculated from the slope of Figure 5. The peak value corresponds to 200Ω internal resistance for the zinc/copper system and 556Ω for the graphite/graphite. The internal resistance, however, seems to be high for the graphite/graphite system, as can be predicted using the polarisation curve method.

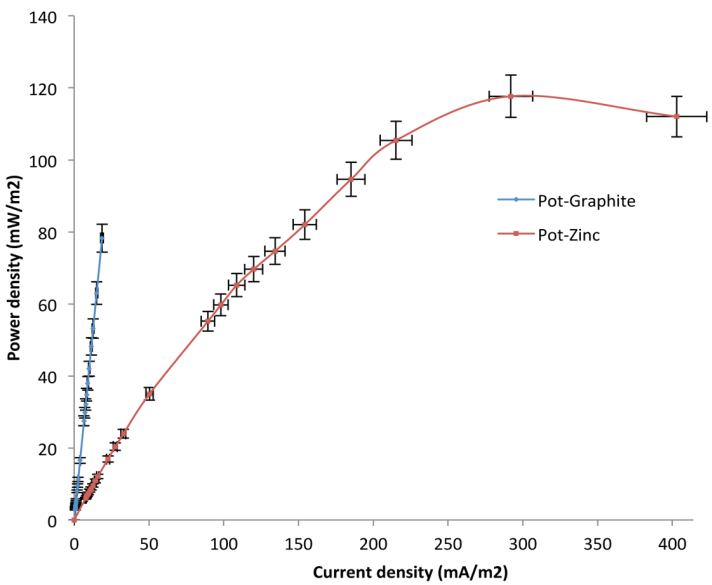

Figure 5: Variation of potential drop with current density relating to pot-graphite/graphite pair and pot-zinc/copper pair

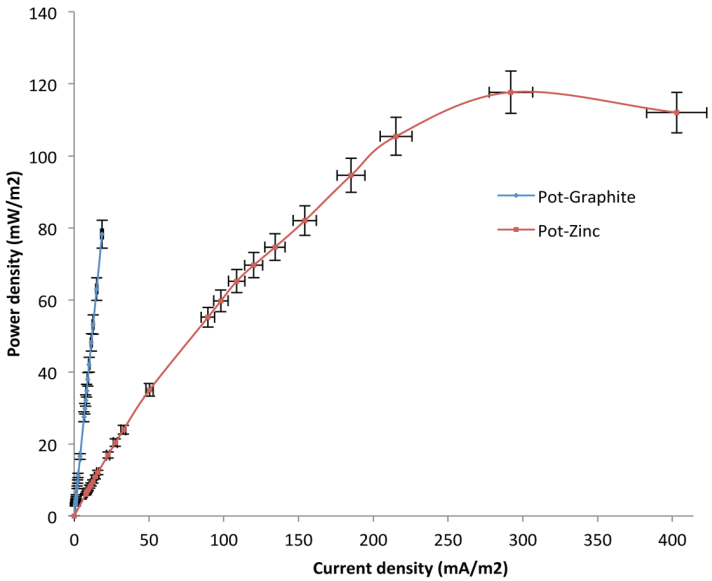

Figure 6: Variation of power density versus current density as normalised with the anode electrodes relating to the pot-graphite/graphite pair and pot-zinc/copper pair

Conclusions

This paper was aimed at designing and improving the performance of MFCs using a combination of a clay partition as an ion-exchange as well as electrode pairs with varying characteristics. The effect of the electrode characteristics on the cathode and anode potentials have been investigated. The polarisation curves as well as plots of power densities versus current densities for cells loaded with incremental loads of 100Ω to 1500Ω are depicted in Figures 4, 5 and 6. Comparably, the pot-zinc/copper pair performed more creditably than the graphite/graphite system. The rate of enzyme consumption occurring in the cells similarly resulted in the final COD being almost equal. The unconventional inexpensive Mfensi clay ion-exchange medium used for the study has forecast a viable alternative to the conventional expensive proton exchange membrane or polymer electrolyte membrane (PEM). It was observed, however, that a porosity of 14.3% may facilitate the flow of liquid in both directions. We believe it holds the future for improvements in MFC performance. These MFC systems might be useful in applications of MFC type at a very low cost. This approach represents a potential solution for simultaneous electricity production and removal of COD and thus offers a technological tool both for sustainable energy generation and for economic feasibility.

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