

ELECTRICITY GENERATION BY SINGLE- AND DOUBLE CHAMBER MEMBRANE-LESS MICROBIAL FUEL CELLS (MLMFCS)

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ABSTRACT

Waste biomass is a cheap and relatively abundant source of microbes capable of producing electrical current. Rapidly developing microbial electrochemical technologies, such as microbial fuel cells, are part of a diverse platform of future sustainable energy. Application of Microbial Fuel Cells (MFCs) may represent a completely new approach in production of sustainable clean energy. Microbial fuel cells (MFCs) are not yet commercialized but they show great promise as a method of power production. The power produced by these cells is currently limited, primarily due to high internal (ohmic) resistance. There are two main components of the fuel cell; cathode and anode compartments along with a cation specific membrane. In the anode compartment, microorganism oxidizes substrates which generate electrons and protons. Electrons are then transferred to the cathode compartment via an external electric circuit. Protons are transferred to the cathode compartment through the cation specific membrane like Proton Exchange Membrane (PEM) which is very expensive. In this study, a successful attempt has been made to fabricate single and double chamber Membrane-Less-Microbial-Fuel-Cells (MLMFCS) which are capable to give COD reduction greater than 93 percent, with maximum power production 6 W/m^2 .

INTRODUCTION

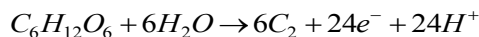
The 21st century has seen a lot of research attention being given to renewable energy. It has become clear that non-renewable sources of energy cannot indefinitely sustain a global economy (Logan 2008). There is therefore urgent need to find lasting alternatives to these non-renewable energies so as to forestall a global energy crisis. The main alternatives suggested are wind, solar and hydropower. However, these sources also have inherent shortcomings. This is where wastewater comes in as a viable energy alternative. Microbial Fuel cells, aside their ability to produce electricity, can remove a good deal of

chemical oxygen demand (COD) from the wastewater, making them ideal for waste treatment. This is particularly important in developing countries where waste treatment has not been given much attention, owing to the high cost involved. Microbial fuel cells promise to reduce the cost of wastewater treatment by reducing the electrical cost involved. This has the capacity of reducing the total waste treatment cost appreciably.

The usefulness of microbial fuel cells transcend their ability to generate power and treat wastewater. With little modifications the MFC may be used to produce hydrogen gas and methane or

remove impurities such as sulphur. Although a microbial fuel cell may not produce as much power as other types of fuel cells, its multiple advantages, in terms of power production, waste treatment and pollutant removal makes it unique among other fuel cells and, for that matter, an attractive field of research.

A microbial fuel cell may be viewed as a bio-electrochemical system that exploits the catabolic activities of microbes towards energy production (Benneto, 1993, in Liu, 2004, Cheng and Logan 2011, in Zielke 2006). The fuel for the cell is usually domestic or industrial wastewater which typically contains microorganisms and organic compounds. The cell itself may comprise two chambers which are separated by a cation-specific membrane. The wastewater is put into one of the chambers, called the anode chamber. In this anode chamber, microbes feed and respire on the organic compounds in wastewater. This respiration generates electrons which are picked up by the anode, in the absence of a more electronegative element. The reaction for the catabolic activity of the microbes may be summarized as follows:



The protons travel through the proton-exchange membrane into the cathode chamber. The electrons also travel along an external load into the cathode chamber where they recombine with the protons, in the presence of oxygen, to produce water (Bond et al 2002).

Though the first microbial cell was developed about 1911 (Potter, 1911), modern MFCs emerged in 1999 with the discovery of anodophilic bacteria (Logan 2008). Despite these advancements, MFCs still lag behind other fuel cells as viable energy alternatives. This is because of their characteristic low power outputs, coupled with their high cost of production. Electrodes such as Platinum-doped carbon cloth cost around \$2000 / m² while Nafion membranes that are used as PEMs cost around \$ 2500 / m² (Patra 2008). If MFCs are to become a preferred choice

for power production, therefore, it is essential to increase power output with a concomitant decrease in their cost of production. If MFCs are to become a commercially viable energy source, then it is imperative to increase their power density and simultaneously decrease their manufacturing cost. It is also vital to formulate architectures that can withstand high hydraulic pressure from huge volumes of wastewater. As in dissertation by Kwan (2013) proton transport measurement showed that zeolite micromembrane exhibited comparable proton flux as the commercial Nafion 117 membrane, such that the cost per watt may be reduced.

The research into MFC technology, thus, has been an attempt to decrease cost of production with a concomitant increase in energy production. Various researchers have tried to use cheaper materials and various architectures for the electrode and membranes. Tamakloe et al., (2014) discovered that the use of hydrogen peroxide (H₂O₂) at the cathode of double-chambered MFC (DC-MFC) yielded a coulombic efficiency of 9.20% as against 1.88% shown by an equivalent SC-MFC. Though cheaper alternatives have been used for membranes in most researches, the use of rigid cation exchange materials such as clay have not been given much attention.

MATERIALS AND METHODS

Zeolite Cells

20% Zeolite was added to Koalin (80%) and molded to a slab of 8 cm x 8cm x 1cm. This was then fired at the temperature of 3000°C. Part of the slab was covered with epoxy leaving 4 cm x 4 cm operating surface area (Fig. 1). The corners were then drilled and securely sandwiched (Fig. 3), with bolts and nuts between two plastic chambers with same 4 cm x 4 cm holes. The slab thus formed ion exchange source for the anode and cathode chambers. The single-chamber cell has the slab secured on 4 cm x 4 cm hole at one side of the plastic container (Fig. 2) and Carbon-paper doped with Platinum serves as the catalyst and cathode with a copper plate as a conductor. This design is similar to the set up used by

Opoku-Donkor et al., (2013), except the chamber being smaller and thus the slab replaced the PEM. Since the slab can pass water, the epoxy makes the outer portion of the slab water-tight, as in Fig. 1.



Fig. 1: Zeolite slab



Fig. 2: Single Chambered MFC



Fig. 3: Double chambered MFC

The two MFCs were designed and operated together under the same condition of temperature and pressure. They were each filled with wastewater (Balance of COD 7700 mg/L) from GGBL. The second chamber of the DC-MFC was filled with 60 % diluted H_2O_2 as the oxidation substrate. However, the SC-MFC gets its oxygen from the surrounding. The two cells used graphite as anodic electrodes.

Porous Pot

Two hollow cylindrical porous pots were used to fabricate SC- as well as DC-MFCs. For DC-MFC, one of the porous pots was placed in a copper can as shown in Fig. 5. The other pot had a copper wire wrapped round it with patches of Platinum doped carbon paper on the surface which were in contact with the porous pot. Platinum doped carbon paper serves as catalyst and also as a conductor (Fig 4).



Fig. 4: SC-MFC using Porous Pot

Both MFCs used zinc rods as anodic electrodes immersed into the wastewater (Balance) as microbial source substrate.



Fig. 5: DC-MFC using Porous Pot

RESULTS AND DISCUSSION

All the cells were connected to a Datalogger (CR10X) and were observed for 30 days. The open circuit voltage (OCV) for zeolite cells was recorded every minute and stored. Data were then collected via computer interface. Table 1 shows sample data as collected in excel format.

It was found that the OCVs generated by the porous pots were high as compared with the zeolite cells. Loads of 1000 Ω were then connected across the terminals of the pot cells. The recorded voltages now become the potential drop for both SC and DC porous pot cells. The results as plotted are shown in Figs 6 and 7. The readings per minutes were averaged to hours of reading so as to reduce volume of data that can be handled.

Table 1: Sample Data as stored by the Datalogger

ID	Yr	Prog Reg	Time 24hr	Single OCV/mV	Double with H ₂ O ₂ OCV/mV	Single Porous OCV/mV	Double Porous with H ₂ O ₂ OCV/mV
101	2014	41	835	449.8	325.6	745.0	1317.0
101	2014	41	836	449.8	325.6	744.0	1313.0
101	2014	41	837	449.8	325.6	746.0	1307.0
101	2014	41	838	449.8	326.9	744.0	1306.0
101	2014	41	839	449.8	326.9	746.0	1305.0
101	2014	41	840	449.8	326.9	747.0	1304.0
101	2014	41	841	449.8	327.6	746.0	1302.0
101	2014	41	842	449.8	326.9	746.0	1301.0
101	2014	41	843	449.8	334.9	746.0	1301.0
101	2014	41	844	449.8	350.3	746.0	1300.0
101	2014	41	845	449.8	351.3	749.0	1299.0
101	2014	41	846	449.8	350.3	751.0	1298.0
101	2014	41	847	449.8	323.6	752.0	1297.0
101	2014	41	848	449.8	321.6	754.0	1296.0
101	2014	41	849	449.8	321.9	756.0	1296.0
101	2014	41	850	449.8	322.3	758.0	1295.0
101	2014	41	851	449.8	322.3	758.0	1294.0
101	2014	41	852	449.8	322.3	759.0	1293.0
101	2014	41	853	449.8	322.3	759.0	1293.0
101	2014	41	854	449.8	322.3	759.0	1292.0
101	2014	41	855	449.8	321.6	759.0	1291.0
101	2014	41	856	449.8	321.6	756.0	1291.0
101	2014	41	857	449.8	321.6	755.0	1290.0
101	2014	41	858	449.8	320.9	752.0	1289.0

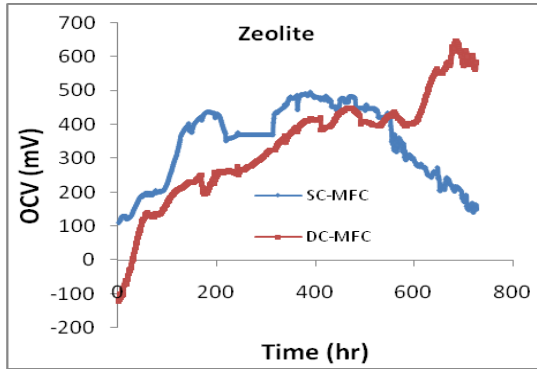


Fig. 6: Zeolite cells OCV-time variation

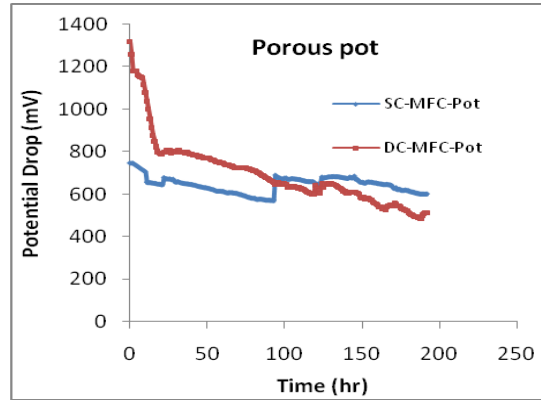


Fig. 7: Porous pots Potential drop-time variation

Table 2: Porous pot reading as normalized by anodic electrode area (38.8 cm²)

Resistance Ω	Single-Pot				Double-Pot			
	I/mA	Pd/mV	Cur-Den/A/ m ²	Pow-Den W/m ²	I/mA	Pd/mV	Cur-Den/ A/m ²	Pow-Den W/ m ²
0	0	0			0	0		
100	3.250	325	0.838	0.272	3.780	378	0.974	3.683
200	2.400	480	0.619	0.297	2.770	554	0.714	3.955
300	1.780	534	0.459	0.245	2.097	629	0.540	3.399
400	1.433	573	0.369	0.212	1.703	681	0.439	2.988
500	1.190	595	0.307	0.182	1.424	712	0.367	2.613
600	1.023	614	0.264	0.162	1.225	735	0.316	2.321
700	0.929	650	0.239	0.156	1.100	770	0.284	2.183
800	0.815	652	0.210	0.137	0.969	775	0.250	1.935
900	0.728	655	0.188	0.123	0.874	787	0.225	1.774
1000	0.662	662	0.171	0.113	0.797	797	0.205	1.637
2000	0.370	739	0.095	0.070	0.428	856	0.110	0.944
3000	0.255	766	0.066	0.050	0.292	876	0.075	0.659
4000	0.198	791	0.051	0.040	0.222	888	0.057	0.508
5000	0.163	816	0.042	0.034	0.180	898	0.046	0.416
6000	0.139	836	0.036	0.030	0.151	904	0.039	0.351
7000	0.125	874	0.032	0.028	0.130	909	0.033	0.304
8000	0.110	880	0.028	0.025	0.114	912	0.029	0.268
9000	0.099	894	0.026	0.023	0.102	915	0.026	0.240
10000	0.090	903	0.023	0.021	0.092	917	0.024	0.217

Table 3: Zeolite cells reading as normalized by slab operating surface area (16.0 cm²)

Resistance Ω	Current mA	Single			Double			
		Cur. Den A/m ²	PD mV	Pow Den mW/m ²	Current mA	Cur. Den A/m ²	PD mV	Pow Den mW/m ²
0								
100	0.353	0.221	35.3	7.788	0.470	0.294	47.0	13.806
200	0.281	0.176	56.2	9.870	0.402	0.251	80.3	20.150
300	0.238	0.149	71.3	10.591	0.353	0.221	106.0	23.408
400	0.213	0.133	85.3	11.369	0.324	0.203	129.7	26.285
500	0.188	0.118	94.2	11.092	0.289	0.181	144.7	26.173
600	0.171	0.107	102.5	10.944	0.265	0.165	158.8	26.268
700	0.157	0.098	109.8	10.764	0.250	0.156	175.2	27.406
800	0.147	0.092	117.5	10.786	0.233	0.146	186.5	27.174
900	0.138	0.086	124.3	10.730	0.218	0.136	196.1	26.705
1000	0.129	0.081	129.4	10.465	0.200	0.125	200.0	25.000
2000	0.086	0.053	171.1	9.149	0.128	0.080	255.0	20.320
3000	0.066	0.041	197.8	8.151	0.093	0.058	278.0	16.101
4000	0.054	0.034	216.0	7.290	0.074	0.046	294.0	13.506
5000	0.047	0.029	233.0	6.786	0.061	0.038	306.0	11.705
6000	0.041	0.026	245.0	6.253	0.052	0.033	313.0	10.205
7000	0.037	0.023	256.0	5.851	0.045	0.028	318.0	9.029
8000	0.033	0.021	265.0	5.486	0.040	0.025	322.0	8.100
9000	0.031	0.019	275.0	5.252	0.036	0.023	327.0	7.426
10000	0.028	0.018	280.0	4.900	0.033	0.021	331.0	6.848

Graphs of polarization characteristic are shown in Figs. 8 and 9. The potential drops against current densities followed the usual characteristics of a fuel cell, i. e., the normal linear load portion and the substrate concentration points. Power

variations with current densities were also shown. The peak powers occurred at the points where the internal resistances were equal to the external resistances.

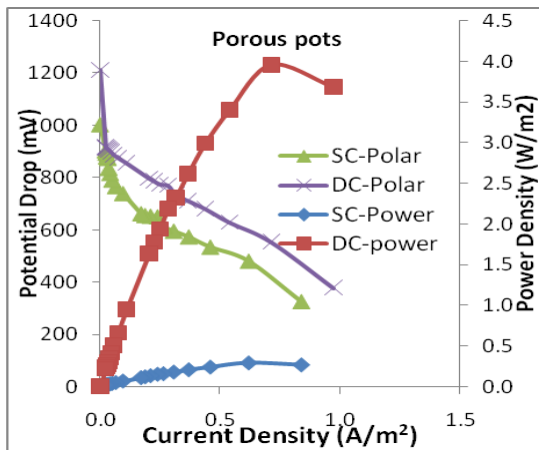


Fig. 8: Polarization curves for porous pots

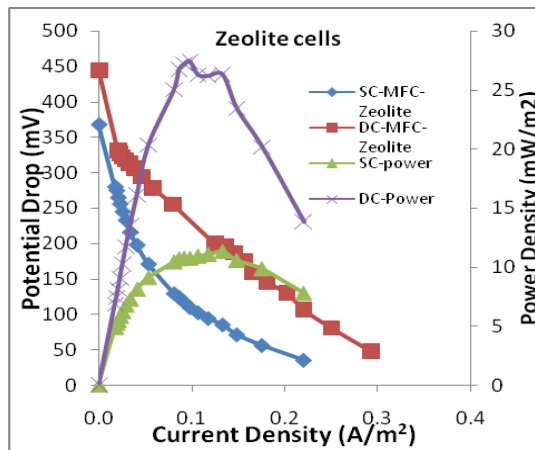


Fig. 9: Polarization curves for Zeolite cells

The three stacked cells produced as much voltage to light a LED as shown in Fig. 10.

CONCLUSION

Both, single and double chamber Membrane-Less-Microbial-Fuel-Cells (MLMFCs) were found to give COD reduction greater than 93 percent (Table 4), with maximum power produc-

tion 6 W/m^2 . It was expected to generate enough power to light a LED through only one cell so as to be able to power low voltage circuits or devices. However, efforts are being made to improve the structures of MFCs for better performance.

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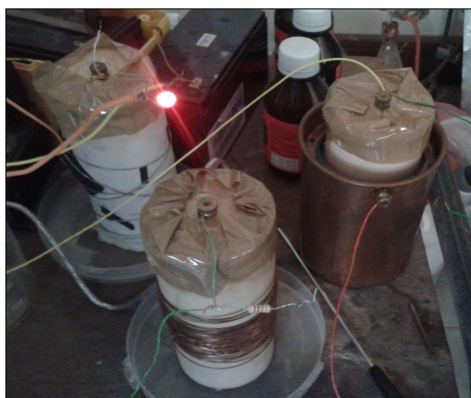


Fig. 10: Series connection of MFCs.

	Initial	Final	Δ COD	
pH	5.9	6.9		
Temp. °C	26	28		
COD (mg/L)	7700	509	7192	93.4 % COD Removal

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