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Characterization of Voltage from Food Market Waste: Microbial Fuel Cells

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Abstract

Waste management and energy supply are among the most pressing problems facing the world today. In the current study, microbial fuel cells technology was employed to convert market waste to electricity using a two chamber fuel cell. Fruit wastes were collected, blended and minced before loading to the anodic chamber. Cow dung was used as bio catalysts. Distilled water was used in the cathodic chamber while salt bridges were made using 3% agarose in sodium chloride solution. The results obtained shows that voltage from fruits increase with time for the first 16 -18 days. The average voltage obtained was highest in avocado waste at 0.357V and lowest in water melon waste at 0.009V. The power and current density for all the fruits were in the range of 0.060856 to 22.53043µW/M2 and 0.751315 to 63.11044 mA/m2 respectively. In conclusion, microbial fuel cells technology employed to generate clean energy from market wastes can provide the Kenyan population with clean and relatively cheap electricity, and also address the problem of solid waste management especially in vegetable markets

Keywords: Fruit Waste, Muthurwa Market, Microbial Fuel Cells

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Introduction

Vegetable market wastes, domestic wastes and weeds contribute to environmental pollution. Most local markets have piles of vegetable wastes as well as other biodegradable matters. Figure 1.1 represents a real vegetable waste situation in Muthurwa market in Nairobi.

Most Kenyans depend on hydropower and petroleum products for their energy needs. Rural and some urban dwellers rely heavily on trees for firewood and charcoal. The use of fuel for both lighting and cooking has reduced the forest cover significantly, as a result of continued cutting down of trees for direct use as a source of fuel and charcoal burning. About 65.3% of energy consumed in Kenya is wood fuel and biomass while petroleum, electricity and other sources account for 32% (GTZ, 2007, PAC, 2010). According to official statistics, the number of Kenyans connected to national grid electricity has increased from 1, 041, 576, in 2014 to 3,300 467 at present which is a 46% increase (MOE, 2016). The number of primary schools connected has also increased from 8, 203 in 2013 to 22, 175 schools in 2016 (MOE, 2016). The launch of the last mile connectivity project by the Kenyan government and the reduction of electricity connection fee payable by consumers Kshs. 35000 to KShs. 15000 is aimed at ensuring the 70% of the households are connected by 2017. Liquefied petroleum gas (LPG) consumption in Kenya has increased by 59% in the year 2003-2008 from 40000 to 80000metric tons per year (GTZ, 2008) with the growth expected to increase until 2020 (Githiomi, 2012). In the current study, organic market waste is converted to green energy via microbial fuel cells technology by employing cow dung as bio-catalyst.

Figure 1.1: Photos of vegetable waste in Muthurwa market (20th February 2016)

Material and methods

Market waste was obtained from Muthurwa market in Nairobi County while cow dung was from freshian dairy cow. H-shaped double chamber microbial fuel cell were constructed using readily available material. They included 15.3cm to 16.3cm diameter and 7.4cm to 9.4cm long plastic containers, polyvinyl chloride (PVC) pipes, adhesive glue, scissors, wicks, driller, masking tape and pipes couplers. The anode was fed with different compositions of fat, carbohydrates and fat-containing substrates while the cathode was fed with distilled water. The amount of current and voltage generated was measured using a digital volt meter.

Microbial Fuel Cells Construction

Two 1.2l plastic containers were prepared as an anode chamber and a cathode chamber. Two small holes were made on the caps of the containers to pass a through. One end of the copper wire was attached to 5.7cm long and 0.7cm diameter graphite rod electrodes.

A salt bridge was prepared using 2.5 liter of 1M NaCl, 3% agarose solution and lamp wicks. The wicks were boiled in NaCl and 3% agarose solution for 10 minutes after which it was kept in the freezer at -4°C for solidification. The solidified salt bridge was passed through PVC pipes and attached to the chambers using araldite adhesive which makes them leak proof.

Circuit Assembly

The assembly of the H-shaped microbial fuel cell (MFC) was done as shown in figure 2.1. A digital voltmeter was attached to the copper wires from the cathodic and anodic chambers with voltage and current being monitored on daily basis.

Experimental Variations

To characterize voltage, current, power, current and power densities across different resistors, 750ml of fresh cow-dung in water was added to the anodic chamber while the cathodic chambers was fed with 750ml distilled water. The MFC was assembled as shown in figure 2.1. 1Ω, 1kΩ, 2 kΩ, 15 kΩ resistors were attached to the terminals from cathodic and anodic chamber. The amount of voltage and current from the cells were recorded daily for 16 days across the attached resistors using a digital voltameter.

Fruit Wastes with Cow Dung

A 500g sample consisting of water melon, avocado, banana, tomato and mango was chopped, minced using meat mincer and blended using a kitchen blender before being added to the anodic chamber of the H-shaped MFC. The cathodic chamber was fed with 500ml distilled water. A mixture of the fruits was made by mincing and blending 100g of water melon, avocado, banana, tomato, mango, spinach, cabbage and kales each together. 250ml cow dung in water was added to each cell to introduce the microbes. 750ml cow dung in water was used as the control experiment. The current and voltage emanating from the cells were recorded daily for 24 days using a digital voltmeter.

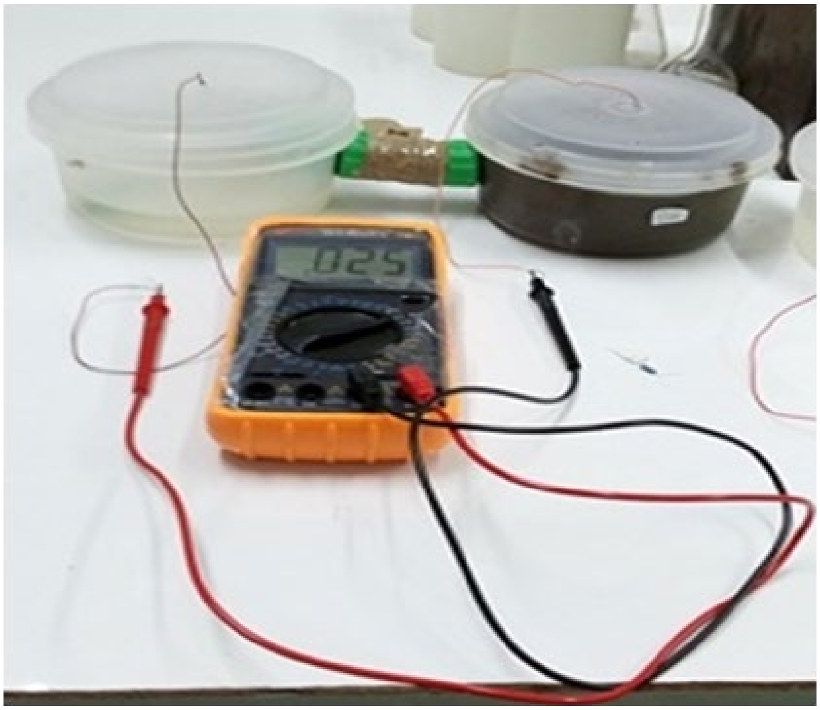

Figure 2.1: Set-up of H-shaped microbial fuel cells open circuit voltage

Results and discussion

On investigating the effect of external resistance on the voltage derived from the microbial fuel cells, the data in table 1 in the appendix was plot as shown in figure 3.1 were obtained. From the figure, it was observed that open circuit voltage was the highest. A resistor of 15kΩ gave the highest voltage compared to all the others. This had earlier been observed by Kamau et al., (2017). The results obtained are further in agreement with the Ohm's law which states that voltage is directly proportional to resistance.

The obtained voltage increases for the first 3 days then decreases hence forth. This is explained by the fact that microbes in the cowdung compete for the available substrates as food hence the upward trend. On depletion of fresh dung, the microbes start dying hence the downward trend of voltage.

Previous studies by Menicucci et al.,(2016) indicated that voltage reduces as external resistance decreases. This is explained by the limitations imposed on the electrode reaction kinetics, on mass transfer, and on charge-transfer processes at the current-limiting electrode. Other studies revealed that, cell voltage increased with an increase in external resistance from 0 to 4,000Ω; the maximum voltage of 358 mV was observed at an external resistance of 4,000Ω (Ghangrekar and Shinde.,2007) . Later on, Rismani-Yazdi et al. (2011) obtained similar cathode potentials at different external resistances. However, anode potential varied under different external resistance employed. MFCs with lower external resistances resulted in higher anode potentials. This was also observed in the study of Song et al. (2010) carried out using a sediment microbial fuel cell (SMFC).

DAYS	OCV	1Ω	1kΩ	2kΩ	15kΩ
1	140	10	20	35	76
2	197	1	27	43	108
3	203	2	19	51	103
4	130	3	4	8	34
5	110	4	4	8	41
6	166	4	17	29	88
7	169	7	16	27	85
8	166	7	12	23	73
9	166	7	12	19	75
10	160	5	9	17	63
11	135	5	14	22	74
12	140	3	17	29	93
13	103	1	11	17	56
14	69	3	7	14	39
15	72	2	6	12	37
16	68	1	7	12	35

Table 1: Voltage (mV) across different resistors

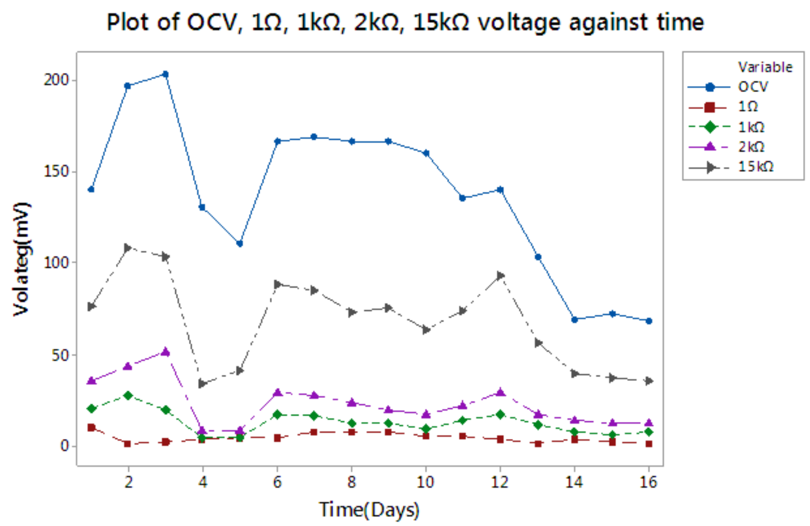

Figure 3.1: Plot of voltage against time across different resistors.

Figure 3.2: was obtained for daily voltage when cow dung was used as bio-catalyst in conversion of fruits wastes to electricity. The obtained voltage is shown in table 2 in the appendix. The recorded voltage was lowest in banana wastes at 0.021V to 0.23V on day 5 and 12 respectively. Cowdung contains methanogenic bacteria which break down organic substrates (Mwaniki et al., 2016). Avocado voltage was in the range of 0.03 to 0.357V obtained in day 6 to 16 respectively. The energy released in breaking down high fat content in avocado explains the high voltage observed.

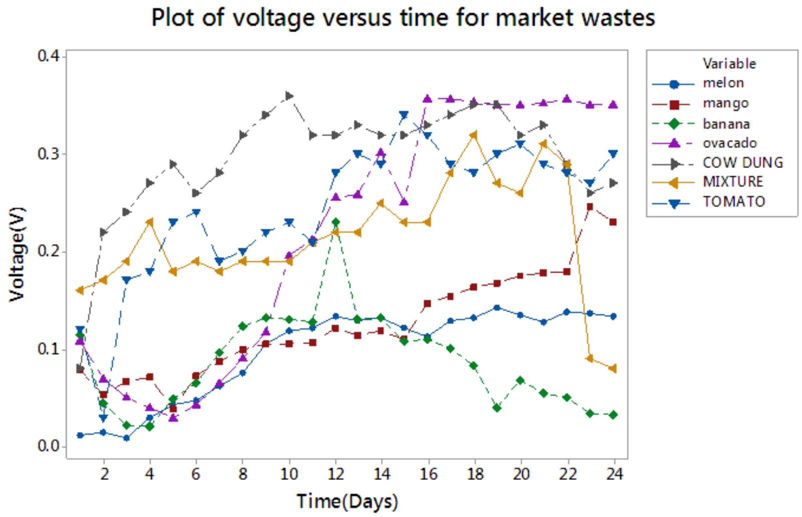

Figure 3.2: Plot of voltage against time for different fruit wastes.

DAYS	MELON	MANGO	BANANA	OVACADO	COW DUNG	MIXTURE	TOMATO
1	0.012	0.079	0.115	0.109	0.08	0.16	0.12
2	0.014	0.053	0.045	0.07	0.22	0.17	0.03
3	0.009	0.067	0.022	0.05	0.24	0.19	0.17
4	0.029	0.071	0.021	0.04	0.27	0.23	0.18
5	0.043	0.039	0.049	0.03	0.29	0.18	0.23
6	0.047	0.073	0.065	0.043	0.26	0.19	0.24
7	0.062	0.087	0.096	0.065	0.28	0.18	0.19
8	0.076	0.1	0.123	0.091	0.32	0.19	0.2
9	0.105	0.106	0.132	0.117	0.34	0.19	0.22
10	0.118	0.105	0.13	0.196	0.36	0.19	0.23
11	0.122	0.107	0.127	0.212	0.32	0.21	0.21
12	0.134	0.121	0.23	0.255	0.32	0.22	0.28
13	0.129	0.115	0.131	0.259	0.33	0.22	0.3
14	0.132	0.119	0.132	0.301	0.32	0.25	0.29
15	0.121	0.11	0.108	0.251	0.32	0.23	0.34
16	0.113	0.147	0.11	0.357	0.33	0.23	0.32
17	0.129	0.154	0.101	0.356	0.34	0.28	0.29
18	0.132	0.164	0.083	0.354	0.35	0.32	0.28
19	0.142	0.168	0.04	0.351	0.35	0.27	0.3
20	0.135	0.175	0.068	0.351	0.32	0.26	0.31
21	0.127	0.178	0.055	0.352	0.33	0.31	0.29
22	0.138	0.179	0.05	0.356	0.29	0.29	0.28
23	0.136	0.247	0.034	0.351	0.26	0.09	0.27
24	0.134	0.23	0.032	0.351	0.27	0.08	0.3

Table 2: Voltage from different fruit wastes

The voltage obtained from fresh cow dung was highest in the first 10 days. This is because the dung is smooth with the microbes already living in it. The trend decreases when the microbe's nutrients in the dung depletes.

Power was calculated by multiplying current by voltage. The obtained power was lowest in banana and highest in the avocado as shown in figure 3.3.

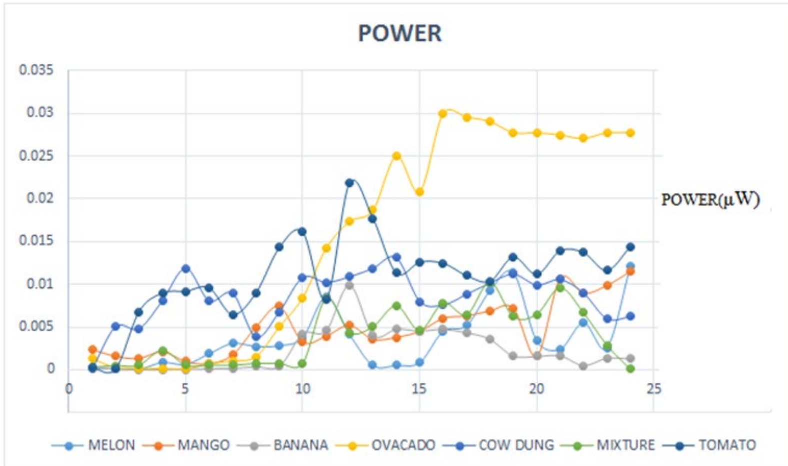

Figure 3.3: Plot of power against time generated by different fruits wastes.

MFC efficiency is evaluated through power output and coloumbic efficiency (Bruce et al., 2006). The obtained power was in the range of 0.000081 to 0.01206mW for water melon and 0.00008 to 0.01024 mW for the fruits mixture. For the avocado, the power increased from 0.00002 to 0.029988mW from day 3 to day 16 with a constant decline thereafter.

In order to compare power output for different systems, power is normally characterized per reactor parameters e.g. electrode surface area. Biological conversion of wastes to electricity takes place at the anode (Rabaey et al., 2004, Park and Zeikus., 2003, Liu et al., 2004, Park et al., 1999). Power output per anodic surface area gives power density.

The current density and the power density were calculated using equation 1 and 2. Where I is current and A is electrode surface area.

$$Current\ Density = \frac{I}{A_{area}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Power\ Density = \frac{Power}{A_{area}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The observed current density was highest in avocado at 63.11044 mA/m2 and lowest in banana at 1.50263 mA/m2 in day 7 as shown in figure 3.4.

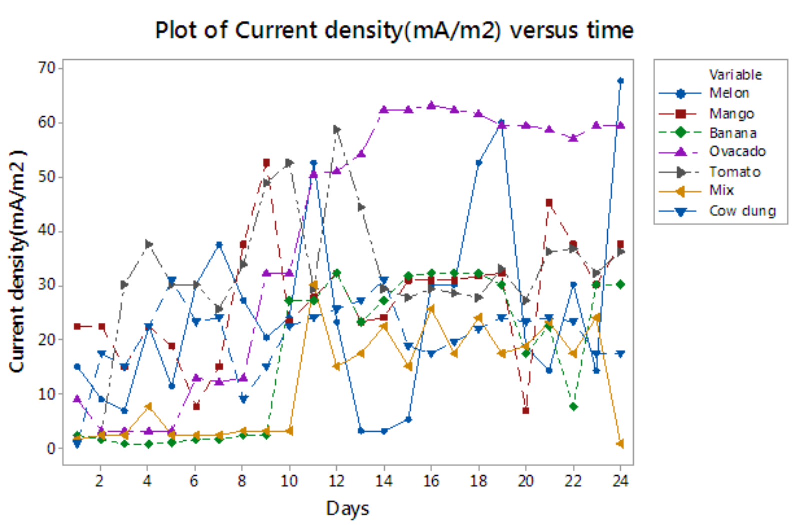

Figure 3.4: Plot of current density against time.

The power density plot is shown in figure 3.5. The plots shows that avocado had the highest power density followed by tomato. Banana and the fruit mixture were observed to have the lowest power density in this study.

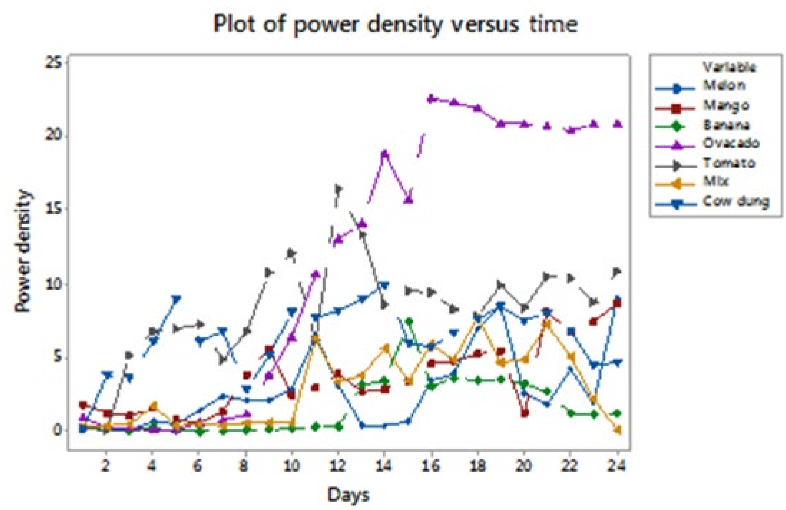

Figure 3.5: Plot of power density against time.

A plot of power density versus current density is shown in figure 3.6. In this power curve, power increases with current to a maximum point of 22.53mW for avocado and then decreases due to increasing ohmic losses and electrode over-potentials. This applies to all the fruits investigated in this study.

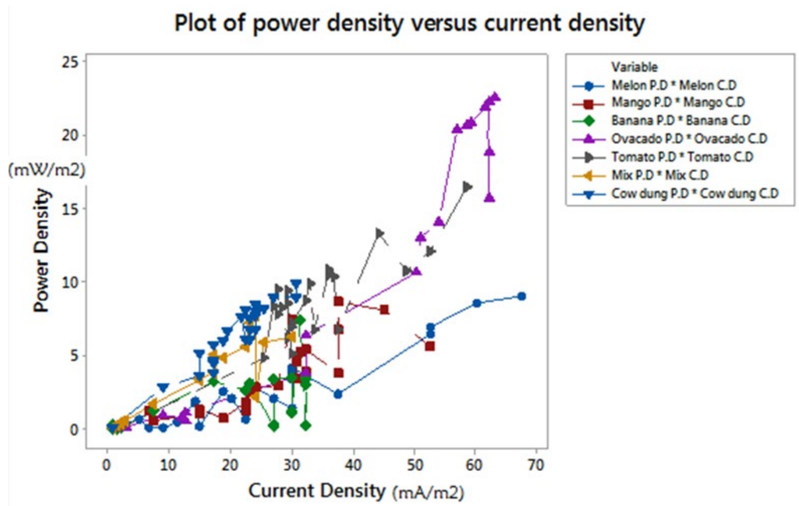

Figure 3.6: Plot of power density versus current density

Conclusion

In conclusion, the results obtained from the current work indicates that, microbial fuel cells are ohmic since voltage increases with increase in resistance. Avocado had the highest voltage and power due to high energy required to breakdown long fat bonds. The power curve increases steadily with current for the first 16 days.

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