Impact of soil type on electricity generation from a Microbial Fuel Cell

Elvis Fosso-Kankeu, Sanette Marx, FransWaanders, and Visagie Jacobs

***Abstract*-** In this study, three different soil types were used in soil microbial fuel cells (SMFCs) to investigate and compare the different performances of electricity generation. These soils included sand, silt and clay. One hundred percent organic compost was used as source of electrogenic bacteria. The compost was mixed into the different soils and the SMFCs were left to run for two weeks. Three runs at different compost to soil ratios were investigated. Voltage readings over a 1000 Ω external resistance were taken every 24 hours.Experimental results indicated that clay is the best soil to use for electricity generating purposes, delivering a peak voltage of 644 mV compared to 348 mV from silt and 336 mV from sand at a ratio of 1 to 1, compost to soil.Clay soil produced the highest peak voltages at all three ratios and is therefore the best soil to use for electricity generating purposes in a SMFC.

***Keywords*---**Microbial Fuel Cell, Soil type, Electricity generation, Electrogenic-bacteria, Biodegradation

I. Introduction

MICROBIAL fuel cells (MFCs) bring forth an unique method of recovering green energy. This is achieved through the direct conversion of organic material into electricity by means of electrogenic bacteria. Virtually any biodegradable material can be used[1; 2].

The usual MFC consists of two compartments - the anodic and cathodic half-cells - which are separated by a selectively permeable, cation-specific membrane or a salt-bridge. The anodic chamber consists of microbes suspended under anaerobic conditions in the anolyte. The microbes will then attach themselves to the anode, forming a bio-layer. These anaerobic conditions would normally slow down the growth of these microbes. This is because oxygen normally acts as an electron acceptor. What happens in the metabolism of the substratefrom the waste stream, is that electrons in sugars, fats, proteins, or other biodegradable molecules are taken by the bacteria and transferred through a bacterial metabolic pathway in such a way that the electrons can be used by the cells for energy [3].

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The electrode acts as an alternative electron acceptor and thus stimulates the anaerobic degradation of organic contaminants. Thus electrodes provide a pathway for electrons to be passed from the anode to the oxygen in the cathode, in a cheap and easy way.These electrons travel through a set of respiratory enzymes, found in the cell, in order to produce energy for the cell. This energy is presented in the form of ATP. Next the electrons are sent to a terminal electron acceptor (TEA) which reduces upon receiving these electrons [4].

It has been observed that *Deltaproteobacteria* are the dominant microbe in most SMFC systems. This is thought to be as a result of the complete anaerobic conditions under which MFCs operate. According to studies done by Bond et al. [5], Holmes et al. [6] and another study done in Tuckeron, New Jersey, the bacteria most involved in most cases is *Deltaproteobacteria*(average 75%), with about 60% in the *Geobacteraceae family.* All three cases also had a very high percentage (in the range of 95%) I6S rRNA sequence identity to *Desulfuromonasacetoxidans.* The bacteria in the soil were more diverse than those which adhere to the anode. The bacteria adhering to the anode were mainly *Escherichia coli, Deltaproteobacteria*and *Geobacter*[4].

The limitation of power generation mainly lies in the slow oxygen reduction rate of the cathode. The power generation can however be increased by using high activity electrode materials, having a sufficiently large anode area and by operating at optimal temperatures[7].

Using soil in a microbial fuel cell (MFC) is a good way to generate green and renewable electricity while simultaneously cleaning up contaminated soil. Different types of soils may however have different electricity generating abilities. It is therefore likely that the performance of the MFC will depend on the type of soil used in the anodic compartment and mixture ratio thereof. Other uses of the MFC include being used as a remote energy source or being used for bioremediation. SMFCs have shown that power can be generated and maintained using only the organic matter available in the sediment [4]. This study will therefore consider different types of soils at the anode compartment in order to improve the transport of electron to the cathode and improve the power generation.

II. Methodology

A. Materials

For the reactor structure of the MFC see-through PVC (polyvinylchloride) was used. PVC is a cheap, strong and safe material. PVC is not inhibitory towards the microbes in the MFC. From Figure 1 it can be seen that two cylindrical tubes, one smaller than the other were needed. The smaller cylinder was 30 mm in diameter and the larger one was 90 mm in diameter. Both these cylinders were 150 mm long and 3 mm thick.

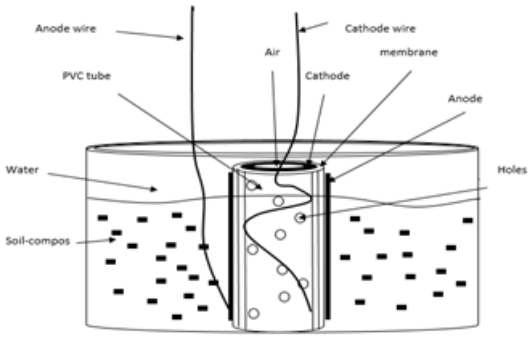


Fig.1 SMFC – setup [8]

In the single chamber MFC, the cathode electrode is wrapped around the centre PVC cylinder. The cathode electrode is then wrapped with the membrane to seal it off from the anode and the sediment and also to ensure that only the cathode chamber is in contact with oxygen as the anode compartment must be operated under anaerobic conditions. The membrane used is thus only charge permeable. A CMI-7000 cation exchange membrane was used.

The electrodes refer to the cathode, which is the positive electrode and the anode, which is the negative electrode. As seen in Figure 1, the cathode is wrapped around the centre cylinder, followed by a membrane wrapping and finishing with the anode wrapping. Because the electrodes are submerged in water, the electrodes should be corrosionresistant. The electrodes should also be resistant to fouling. For instance if the electrodes are covered in algae, their conductive properties will be negatively influenced. Carbon is also a highly conductive and non-inhibitive [4]. Carbon in the form of weaved fibres were used. The cathode sheets were 50 mm wide and 110 mm long and when wrapped around the inner PVC cylinder overlapped about 10 mm.

The soil included sand, silt and clay, which were used in mixture with 100 % organic compost.

B. Preparation of soils

The soils were ground with a mortar and pestle to obtain a size <300μm that could be used for mixing and could be made into a slurry. The soils were then autoclaved in order to sterilize the soils. This was to ensure that only the compost served as source of microorganisms and therefore consistency in the number and nature of microorganisms during the experiments were obtained.

C. Mixing and ratios

The sterilized soils were mixed with the 100 % organic compost in 3 different ratios. Ratios of 1:2, 1:1 and 2:1, soil: compost were used. The ratios were done on a volumetric scale in a 500 ml beaker. The total volume of mixture was kept constant at the 500 ml mark. After volumetrically mixing the soil and compost according to the desired ratio, distilled water was used to mix the soils and compost into a slurry, with 10 mm overlaying water, which could be poured into the SMFC's.

D. Anaerobic operation nitrogen purge

After the SMFC's were filled with the 550 ml slurry, nitrogen gas at room temperature (22°C) was used to purge the anodic chamber of oxygen before sealing the SMFC's. Marine silicon was used to seal the membrane and the hole in the lid through which the anode wire was fed. This ensured that anaerobic operation in the anodic chamber was achieved.

E. Water-bath

The SMFC's were incubated in a water-bath at 35 °C to help with microbial growth and productivity. The effects of temperature on the SMFCs were also investigated in previous tests. Three temperatures were tested (10, 20 and 35°C)[9]. The maximum current densities were achieved at higher temperature. It is thus known, through previous experiments, that metabolic activities of electrogenic bacteria are temperature dependant and that the decomposition rate of organic matter is increased at temperatures above 30°C[7].

F. Characterization of soils

The soils were characterized by using a X-ray diffracometer (XRD) and a X-ray fluorometer (XRF). The XRD determines the mineralogical composition and the XRF determines elemental composition.

G. Voltage and power

When evaluating MFC performance, the current and power produced was determined. The most commonly reported measure of MFC performance is known as the power density.

The voltage over the load (the resistor) was measured. The relationship between voltage, current and resistance is known as Ohm's law [8].

$$E = I R_{ext}$$

From the measured voltage, the current was calculated from the above equation. E is the cell potential, I is the current and $R_{ex}$is the external resistance (in ohms).

When calculating the power, the following relationship was used:

$$P = I E_{MFC}$$

Where P is the power (in Watts), and E_{MFC} is the measured voltage across the external load.

Power alone does not sufficiently describe the overall performance, therefore a measure is employed by normalising the power by surface area to give a parameter known as the power density. This measure allows us to compare different MFC configurations more directly by removing the effect of anode surface area [3]. The power density can be described by the following equation:

$$P_{An} = \frac{E_{MFC}^2}{A_{An} R_{ext}}$$

Where P_{An} denotes the power density (based on the anode) and A_{An} the anode surface area.

III. Results and Discussion

A. Mineralogical and elemental composition of soils

The XRD was operated at 40 kV and 30 mA. The scan speed was 2 degrees/minute with a step width of 0.01 degrees and a scan range of 3 – 90 degrees. The scan axis was at 2 theta. The results (Tables 1, 2 and 3) show that quartz was present in all the soils; it was dominant in the silt and sand soils while the clay soil was dominated by muscovite.

TABLE I
XRD RESULTS ON CLAY

Phase name	Content (%)
Muscovite-2M1	53.94
Quartz low HP	43.11
Goethite	2.95

TABLE II
XRD RESULTS ON SILT

Phase name	Content (%)
Quartz low hp	97.09
Anorthite	0.68
Wollastonite-2M	2.23

TABLE III
XRD RESULTS ON SAND

Phase name	Content (%)
Quartz	99.69
Sillimanite	0.31

The main components present in the clay include SiO_2, Al_2O_3 and Fe_2O_3 as can be seen in Table 4, below.

The silt consisted out of the same main components as the clay, but the SiO_2 was in more excess and the Al_2O_3 and Fe_2O_3 were present to less extent. The silt and clay also showed small amounts of CaO and TiO_2 with trace amounts of other components also present. Tables 4 and 5 can be consulted to examine these other components.

TABLE IV
XRF RESULTS ON CLAY

Component	Result (Mass %)
Na_2O	0.9615
MgO	2.1746
Al_2O_3	18.4537
SiO_2	62.7444
P_2O_5	0.1051
SO_3	0.4283
Cl	0.0263
K_2O	2.521
CaO	1.5674
TiO_2	1.1092
V_2O_5	0.0464
Cr_2O_3	0.037
MnO	0.1574
Fe_2O_3	9.3955
Co_2O_3	0.0106
NiO	0.016
CuO	0.0169
ZnO	0.0152
Rb_2O	0.0191
SrO	0.0229
Y_2O_3	0.0143
ZrO_2	0.0406
BaO	0.1165

The sand exhibited the same main components as the silt and clay, with only even more SiO_2present and almost no Al_2O_3 and Fe_2O_3, as can be seen in Table 6.

TABLE V
XRF RESULTS ON SILT

Component	Result (Mass %)
Na_2O	0.419
MgO	0.6362
Al_2O_3	15.9485
SiO_2	67.1348
P_2O_5	0.2164
SO_3	0.4017
Cl	0.0627
K_2O	5.051
CaO	1.6036
TiO_2	1.029
Cr_2O_3	0.0891
MnO	0.1279
Fe_2O_3	6.932
Co_2O_3	0.0187
NiO	0.0175
Rb_2O	0.0402
SrO	0.0253
ZrO_2	0.0507
BaO	0.1957

TABLE VI
XRF RESULTS ON SAND

Component	Result (Mass %)
Na_2O	0.067
MgO	0.0898
Al_2O_3	2.9159
SiO_2	94.7854
P_2O_5	0.0374
SO_3	0.1498
K_2O	0.5467
CaO	0.0957
TiO_2	0.1577
Fe_2O_3	1.1253
SrO	0.0041
ZrO_2	0.0252

B. Voltages

The SMFC's were operated for 14 days at each of the three ratios. Voltage measurements over a 1000Ω resistor were taken every 24 hours for the total experimental period.

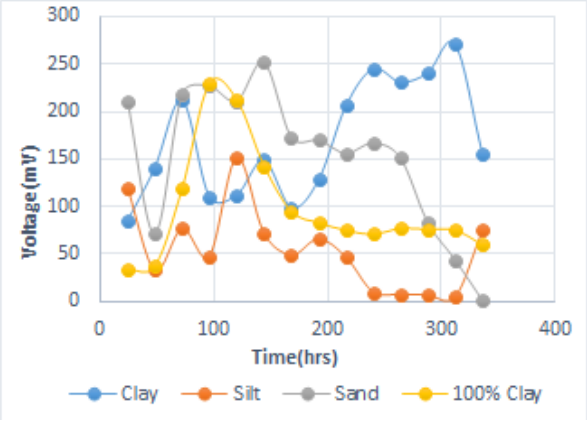


Fig. 2 Voltages at 1:2 ratio (soil: compost)

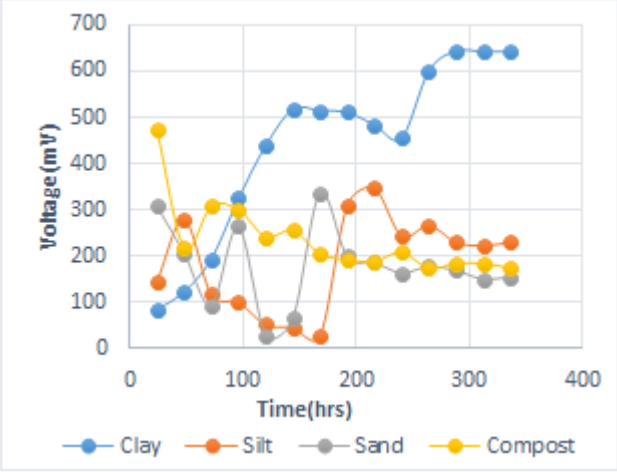


Fig. 3 Voltages at 1:1 ratio (soil: compost)

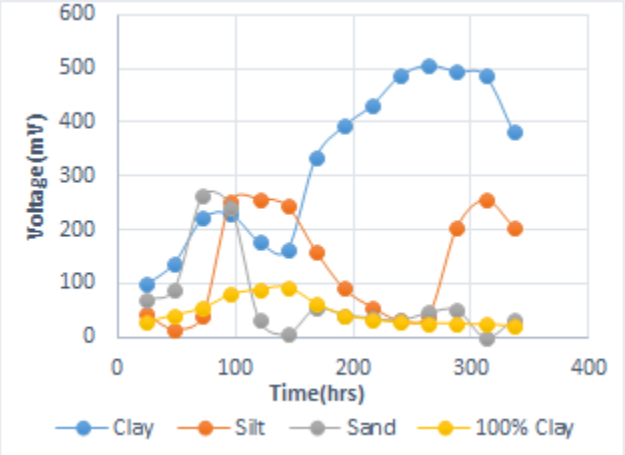


Fig. 4 Voltages at 2:1 ratio (soil: compost)

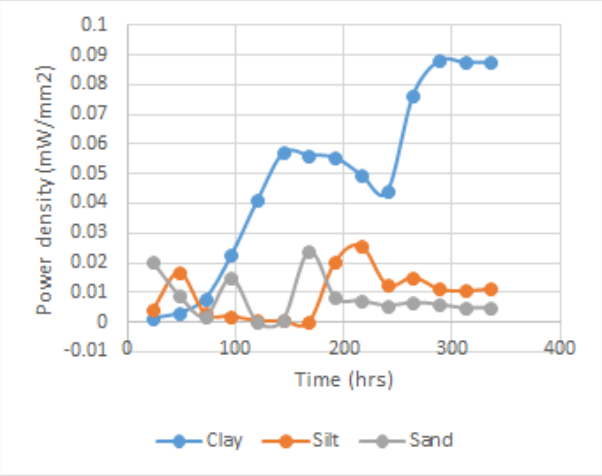


Fig. 5 Power density of soils at 1:1 soil to compost ratio

As can be seen from Figures 2 to 4, the clay produces the best results in a SMFC. The sand and the silt produced comparable results, with silt marginally outperforming sand. The clay has a higher peak voltage and also a higher average voltage compared to the sand and the silt at all three soil to compost ratios.

When inspecting the ratios, it is also clear that more soil has a better impact in a SMFC.

When comparing the clay peak and average voltages at the different ratios, it can be seen that the 1:1 soil to compost ratio is more optimal for generating electricity in a SMFC than the 1:2 and the 2:1 ratios. Inspections of Figures 2 and 4 denote that the 2:1 soil to compost ratio has a more desirable impact for generating electricity in a SMFC than the 1:2 ratio.

A pure compost configuration was tested together with the 1:1, soil to compost ratio, as a control. The pure compost did generate electricity, but not as much as the SMFC's with a soil-compost mixture. A pure clay configuration was tested to confirm that the power generated was in fact from microbial biodegradation activity and not just from ionization reactionsbetween the elements and minerals in theelectrical conductivity generated by the minerals in the soils. From

Figure 4 it can be seen from the low voltages generated by the pure clay configuration that the power generated is mainly from microbial activity, although it is slightly enhanced by the soil.

IV. Conclusion

Soil has a positive impact on the electricity generation in a microbial fuel cell. From the three soils tested (sand, silt, clay) the clay was most promising, with a peak voltage of 644 mV and a peak power density of 0.0885(mW/mm2) as is seen in Figure 5.

The one to one, soil to compost ratio configuration worked the best for electricity generation. The pure compost MFC did generate electricity, but the SMFC's which had a soil-compost ratio outperformed the pure compost configuration. Further investigation is required to better understand the mechanisms by which the soil type affects the electricity generation in the SMFC.

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