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The Effect of Different Soil Feed Stock for the Development of a Soil Based Microbial Fuel Cell

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Abstract: The effect of different soil feedstock for Microbial Fuel Cell development is presented. Four different soil samples namely; the soil from gutter (drainage), soil from refuse dump, soil mixed with cow dung and soil from sewage deposits were examined for a period of 49 days. This was done to determine the most suitable soil for the microbial fuel cell technology. Two different experimental step-ups were utilized; the first set-up was prepared with four different soil samples of equal quantities and the same electrode type for the first 5 weeks. The second set up used the soil with the best yield from the first set-up to further prepare four more cells during the start of the 6th week. This was done to increase the overall power output because that of the first set-up was low. The entire set-ups were connected in parallel. The results obtained from the first set up showed that the soil sample from gutter gave the highest output voltage compared to other soil samples with the value of 1.49 volts; while the maximum voltages of the soil samples obtained from refuse dump, mixture of soil and cow dung and sewage deposits were 0.90, 1.40 and 1.21 volts respectively.

Keywords: Microbial Fuel Cell, Soil Samples, Sample Electrode

1. Introduction

Globally, there is a considerably high demand of energy due to expansion in population, urbanization and industrialization. This has led to an increase in energy costs. The global population is expected to increase by 30% in the next 25 years, where 80-90% of the increase is expected to be from the developing countries [1]. Power generating units are mega projects which require not only huge capital investment but also various natural resources like fossil fuel and water, thus creating immeasurable and extensive impacts on the environment which generates tremendous stress on the local ecosystem [2]. The increasing fuel costs and diminishing petroleum supplies as well as environmental problems associated with the use of conventional energy sources are forcing governments and industries to increase the power efficiency of engines [3] and encourage researches on alternative energy sources.

Basically, to establish a sustainable global development with growth in population and living standard, it is necessary to develop renewable and cleaner energy sources; improved energy efficiency and mechanisms for utilization of new and robust technology. Various forms of alternative energy sources have been discovered among which are the use of wind turbine, solar energy, tidal energy, fuel cells, etc. These alternative energy sources do not solve the problem of energy consumers as a result of high cost of energy generation. In developing nation like Nigeria, poor masses can hardly afford to pay for energy consumed. Consequently, the need for an alternative energy source which is environmentally friendly with little or no cost of energy generation, since raw materials are sourced from waste. This research is focused on energy generation from different waste materials. This area of research is becoming trendy especially in developing nation where waste are carelessly disposed since they are considered inapt for any good use. Some research work on alternative energy with focus on waste conversion to biogas are presented by [4-9]

Microbial fuel cell system technology is one of the new areas of focus for alternative source of energy generation. The system utilizes the activities of some special types of bacteria in generating electrical energy (bio-electricity generation). It uses electrochemically active bacteria to transfer electrons to electrodes. Among the electrochemically active bacteria are shewanella, putrefaciens, aeromonas hydrophila. Some of these bacteria are able to transfer their electron production through the pilus on their external membrane. In a MFC, micro-organisms oxidize organic matters to produce electrons that travel through a series of respiratory enzymes in the cell and produce electrical energy in the cell. The electrons are then released to a terminal electron acceptor which accepts the electron and becomes reduced. The present study focuses on the production of electrical energy using the above mentioned process. If properly harnessed, it will provide a sustainable source of energy to power street lights especially in developing nations like Nigeria.

According to [10], a microbial fuel cell (MFC) is a device that converts chemical energy to electrical energy by the action of microorganisms. It is a bio electrochemical system that generates current from the activity of microbes as they digest sugar in decaying wastes in the soil to release energy. Microbial Fuel Cells are very clean and efficient method of energy production [11]. MFCs are low temperature power generating devices unlike conventional fuel cells such as molten carbonate and alkaline fuel cells which require high temperatures of about 500-750°C to operate. The MFC and all its variants produce energy at low temperatures ranging from 18 – 35°C [12-14]. MFCs are renewable as they tap into already existing sources of feedstock including waste water which represents an environmental concern [15, 16].

MFCs can be of different types such as soil based microbial fuel cell, waste water microbial fuel cell, etc. This work is focused on the soil based type (Figure 1) which adheres to the basic MFC principles. Thus, the authors sought to evaluate different soil types especially within the municipal council in the developing nations that has high energy yielding potentials. The energy when harnessed can power street lights and provide an alternative source of energy. This paper further sought to investigate the rate of the release of electrons from different soil types for use in Microbial Fuel Cell development, viz, soil samples from gutter (A), refuse dump (B), soil mixed with cow dung (C) and soil obtained from sewage deposits (D), respectively using similar electrodes.

2. Materials and Methods

The materials used for this present study include plastic containers, soil samples from different sources, Copper electrodes. The copper electrodes were used for both anode and cathode on the different soil samples. For the cathode, a copper electrode of length 150mm and diameter 2.5mm was used. For the anode, a copper electrode of length 300 mm and 2.5mm diameter was used. Eight (8) different containers of equal sizes were used as containment for the soil samples. Each of these containers has a capacity of about 5 litres. The containers were labeled A-H to specify the soil sample for easier identification. Tiny holes were drilled at the top of the containers which is just wide enough to allow for the passage of the electrodes. Also, the top of each container was cut out providing a large opening for the cathode electrode to receive sufficient oxygen.

During the course of the experiment, different soil samples were collected to determine and ascertain the most favorable for power generation (i.e. the soil that gives the highest output). About four different soil samples were used, thus, soil gotten from refuse dump, soil gotten from sewage deposits, soil from the gutter and soil mixed with cow dung. The same quantities of each soil were collected so as to ascertain the most efficient at the given volume. The different soil samples were sun-dried for some time before being transferred to the sample container. This is to reduce the moisture content of the soil to enable the bacteria to start the anaerobic respiration process in earnest and thereby releasing the energy required for power generation.

From this it was observed that the source of soil collection is very important in the performance of the soil. A preliminary observation showed that the soil sample from the gutter gave a more favorable result. Consequently, a *prima facie* was established for the gutter sample as the most suitable for bioelectricity production in the present study. Thus the high rate of power generation from the gutter sample may be attributed to the fact that the soil from the gutter is basically a mixture of sewage drain, animal waste and other bacteria filled mixtures. Four more containers were introduced but this time with the sample soil sample (soil from gutter). This was done to improve the overall power output of the cell. The anode is placed at a particular depth within the soil, while the cathode rests on top of the soil and is exposed to air. Soils naturally teem with diverse microbes, including electro genic bacteria needed for MFCs, and are full of complex sugars and other nutrients that have accumulated from plant and animal material decay. Moreover, the aerobic (oxygen consuming) microbes present in the soil act as an oxygen filter which cause the redox potential of the soil to decrease with greater depth. The top, end and oblique views of the MFC are shown in Figures 1 and 2.

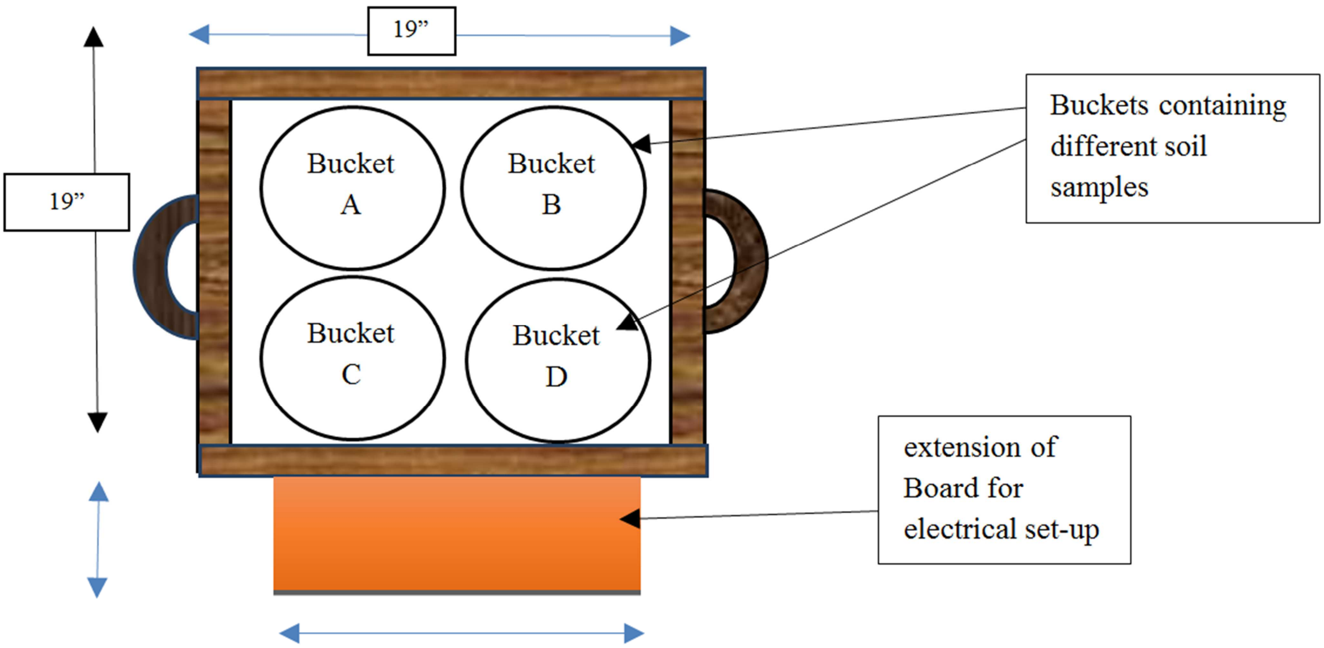

Figure 1. *Top View of the MFC setup.*

The top, end and oblique views of the MFC are shown in fures 1 and 2.

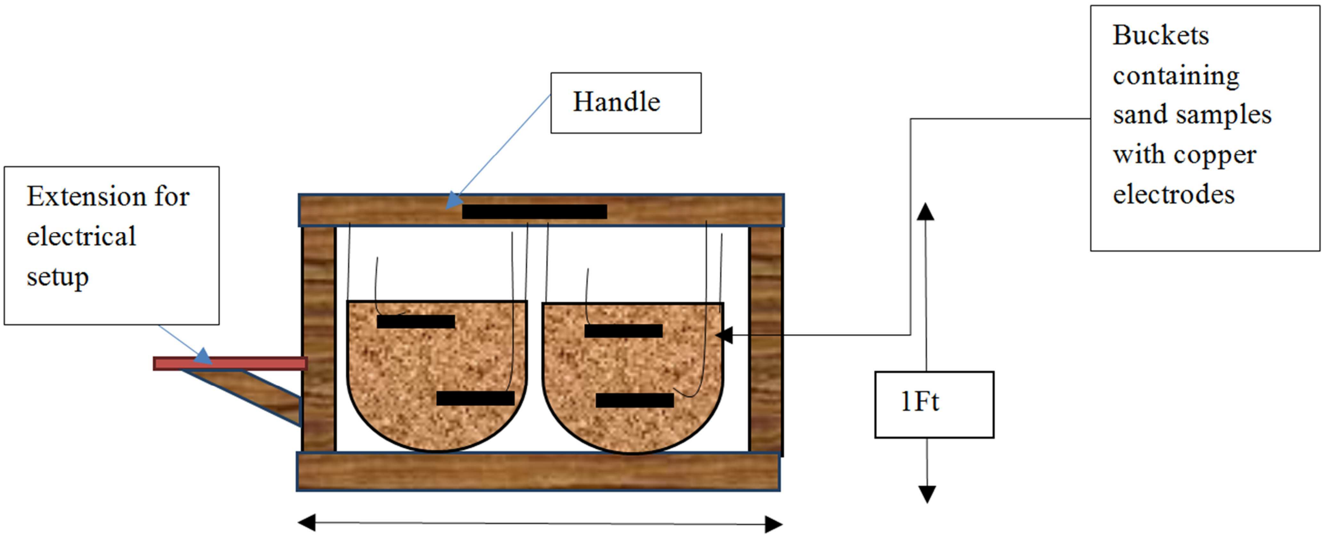

Figure 2. *End view of the MFC setup.*

3. Experimental Set up

Two different set-ups were prepared; each set-up being made up of four cells making a total of eight cells as seen in figure 3. This set-up was connected in parallel. The first and the second set-up were connected in series.

The first set-up (Figure 2) was prepared with the four different soil samples of similar quantities and the same type of electrodes. This is to ensure that a fair comparative study of the samples is achieved in order to easily identify the cell with the best power output. This was monitored for about four weeks before the next set-up was done. This setup was connected in series. And finally, the first and the second set-ups were connected in series consequently to boost the overall power generation. It is expected that the more samples that are connected in this manner, the more the energy yield from the system. Further application will consider having several samples connected in series to produce enough energy to power an appliance.

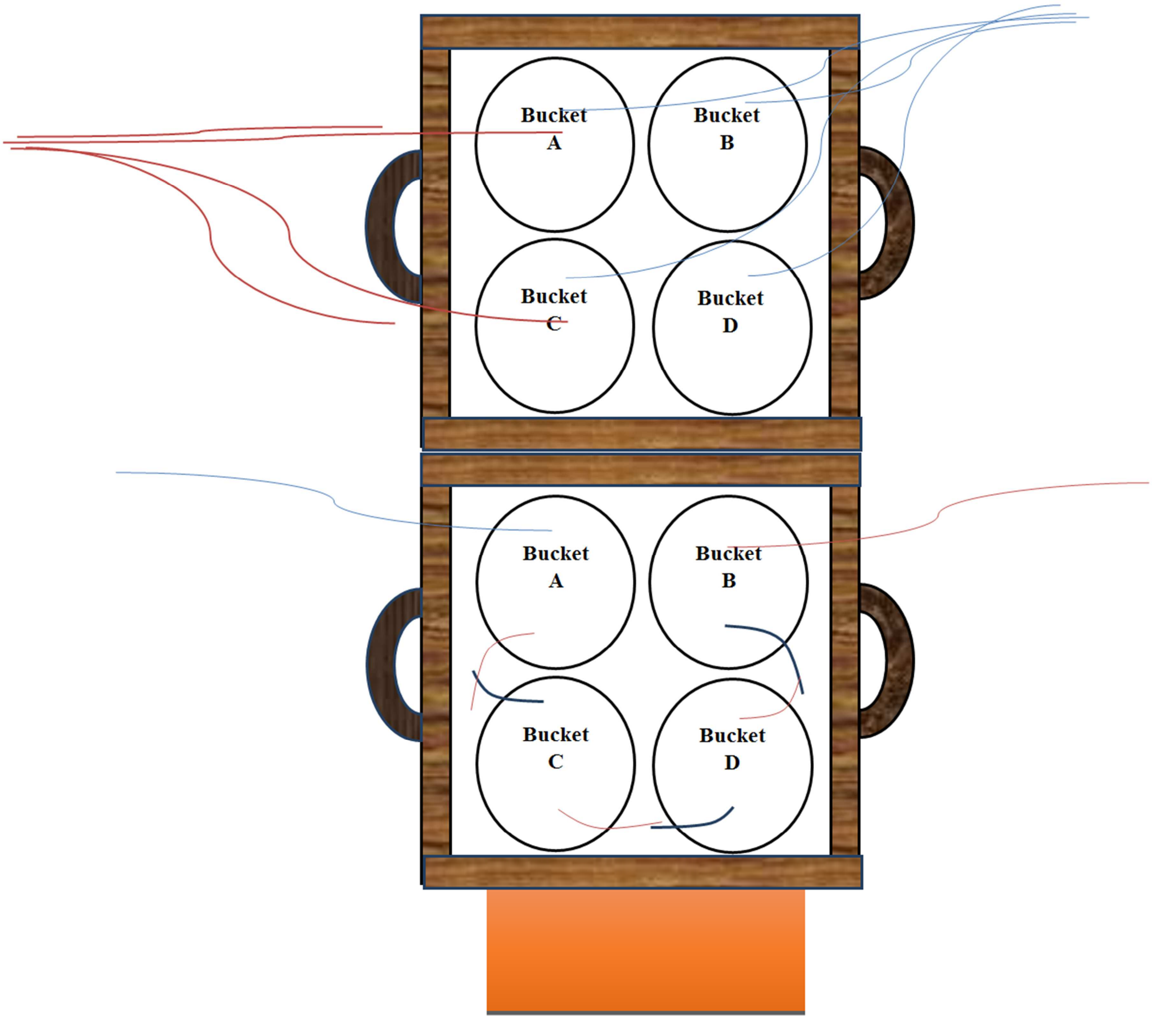

Figure 3. *First Experimental Set-Up.*

Figure 4. *Second Experimental Setup.*

The soil sample with the best power output from the first set-up, that is the sample gotten from gutter was further used to prepare four more cells. This was done to increase the overall power output because the sample from the first set-up was low. The first and the second set-up were connected in series.

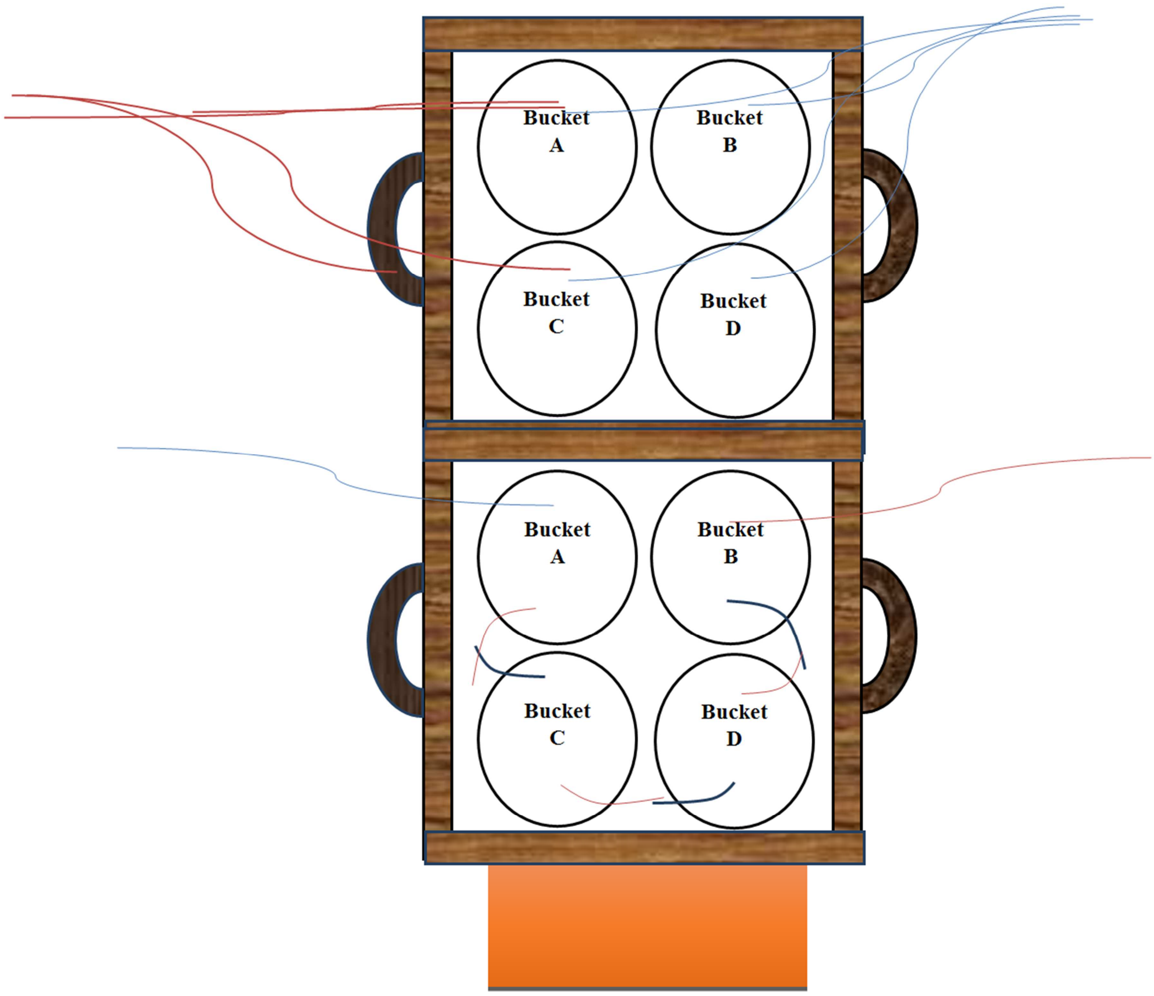

Figure 5. *Connection of Experimental Set-up.*

Experimental Observation

After several weeks of observation, it was discovered that the soil sample gotten from gutter was more productive than those from other samples. From this it became obvious that the source of soil collection is very important in the performance of the MFC. However, four more containers ranging from E to H were introduced but this time containing only the sample soil from gutter. This was done to improve the overall power output of the cell, thus bringing the total set-up to eight cells. When the four cells were connected together in series, the voltage measured was about 4 volts with a current approximately 1 mA giving power output of 0.004Watts. It was noticed that the power component of the cell was significantly low and could not power any substantial electronic device. This problem led to the preparation of the second setup. The second setup shown in Figure 5 is made up of four cells with the same soil sample gotten from the gutter; it was observed that the four cells responded like that of cell C in the first setup. However, when the two setups were connected together in series, a total output of 8.23volts and 1mA were achieved giving a power output of 0.008Watts

Considering the first setup, cell A initially produced a voltage of 610 mV but increased gradually to a value of about 1490 mV within the fifth week and then decreased to a relative value of about 1070 mV. For cell B, the voltage initially was 520 mV but increased gradually to a value of 910 mV after the fourth week and eventually decreased to a value of about 790 mV. For cell C, the average voltage was 710 mV initially but increased gradually to a value of about 1400 mV after about 4weeks and then decreased a little to a relative value of about 900 mV. For cell D, the recorded voltage 710 mV initially but increased gradually to a value of about 1210 mV after about 4weeks and then decreased to a value of about 880mV.

4. Results and Discussion

The results obtained from the experiment are shown in Figures 6 to Figure 8. After the setup, the cells were monitored weekly for seven weeks. Voltage readings were taken (morning and evening) weekly. The data generated was tabulated and plotted accordingly. The records obtained from the seven weeks stipulated periods are given below in table 1. From table 1, it could be observed that in some samples there were negative fluctuations in voltage produced during the process this may be attributed to some environmental factors. Some bacteria may respire more at cool temperatures or at any weather most favorable to them. So, the performance of the fuel cell vis-à-vis the soil samples used depends on the prevailing environmental conditions. It is evident from this table that after the fourth week, the voltage improved appreciably in cells A and C respectively.

The second setup was prepared from cell A that achieved the highest average power output from the first set up. These additional four cells were labeled from letters E to H, respectively.

Table 1. *The voltage readings of different soil samples measured for a period of 7 weeks.*

Period of observation	First Setup	Voltage of Soil Samples (volts)			
		Sample A Voltage (V)	**Sample B Voltage (V)**	**Sample C Voltage (V)**	**Sample D Voltage (V)**
Week 1	Morning	0.61	0.52	0.71	0.68
15th September	Evening	0.39	0.38	0.56	0.58
Week 2	Morning	0.64	0.53	0.41	0.38
22nd September	Evening	0.65	0.47	0.28	0.56
Week 3	Morning	0.65	0.69	0.49	0.49
29th September	Evening	0.68	0.75	0.50	0.48
Week 4	Morning	0.81	0.78	0.90	1.10
5th October	Evening	0.75	0.62	1.30	1.21
Week 5	Morning	1.49	0.71	1.40	0.90
12th October	Evening	0.82	0.65	0.90	0.88
Week 6	Morning	1.27	0.86	1.09	1.04
17th October	Evening	1.05	0.68	1.01	0.98
Week 7	Morning	1.25	0.91	1.07	1.04
24th October	Evening	1.07	0.79	1.05	1.02
Second Setup		Sample E Voltage (V)	Sample F Voltage (V)	Sample G Voltage (V)	Sample H Voltage (V)
Week 6	Morning	0.69	0.63	0.59	0.60
17th October	Evening	0.62	0.65	0.58	0.56
Week 7	Morning	0.89	0.90	0.91	0.88
24th October	Evening	0.88	0.88	0.86	0.90

It is also obvious in the second setup during week 7 that energy generation became quite stable showing very little variation in the morning and evening periods in the four cells. The voltage is also impressive, generating an average of 0.89 volts in just a period of one week. However, the average voltages generated by both setups are summarized in the table 2 and the figure 6 that follows shows the overall progress on the different soil samples. From the first week to about the sixth week of the study, the following average output voltages were recorded.

Table 2. *Average Voltage per Week for Each Sample.*

Period of observation (days)	Sample A(v)	Sample B(v)	Sample C(v)	Sample D(v)	Sample E(v)	Sample F(v)	Sample G(v)	Sample H(v)
Week 1 7	0.50	0.45	0.64	0.63	-	-	-	-
Week 2 14	0.66	0.47	0.69	0.35	-	-	-	-
Week 3 21	0.67	0.41	0.49	0.49	-	-	-	-
Week 4 28	0.78	0.70	1.10	1.16	-	-	-	-
Week 5 35	1.16	0.68	1.15	0.89	-	-	-	-
Week 6 42	1.16	0.77	1.05	1.01	0.66	0.64	0.59	0.58
Week 7 49	1.18	0.85	1.06	1.03	0.89	0.89	0.88	0.89

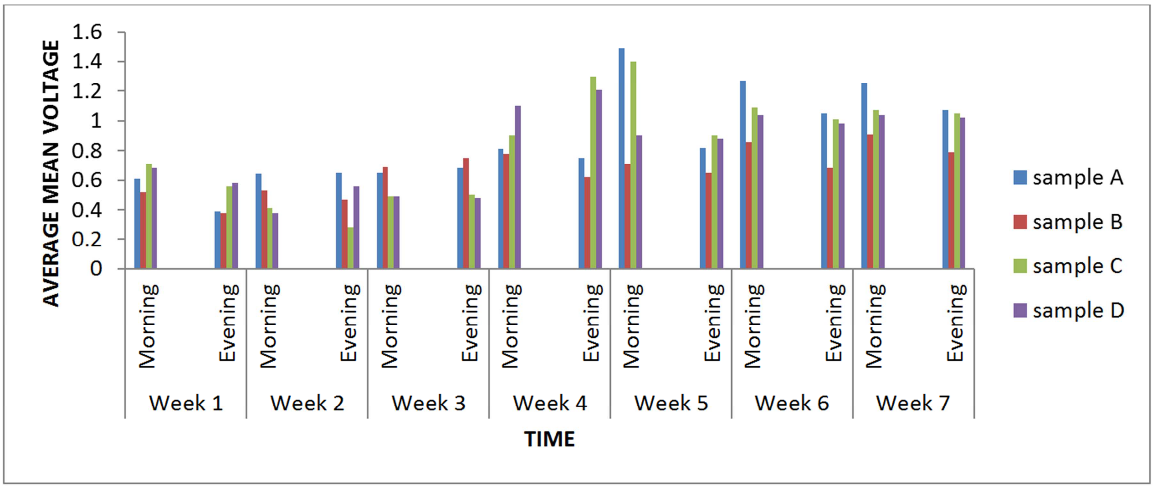

Figure 6. *Average Voltage vs Soil Samples.*

Figure 6 gave the average voltage for the different soil samples for the first seven weeks. From cell A, which contains the sample (sample A) from gutter soil, the average voltage was 0.6V initially but increased gradually to a value of about 1.49V after about 5 weeks and then decreased a little to a relative value of about 1.3 V as shown in Figure 6. The second cell which contains the sample (sample B) made of soil from refuse dump site, the average voltage was 0.52 V initially but increased gradually to a value of about 0.78 V after about 4weeks and once again, decreased a little to a relative value of about 0.71V. In the same vein, the third cell which has the sample made from mixture of soil and cow dung, the average voltage was as low as 0.71V initially but gradually increased gradually to a value of about 0.9 V after about 4weeks and then decreased to a value of about 0.8V. The fourth cell which has the sample made from sewage soil, the average voltage was 0.68V initially but increased gradually to a value of about 1.45V after about 4weeks and then decreased a little to a relatively value of about 1.2V.

Similarly, Figure 7 shows the result of the sample gotten from the gutter which has the highest voltage value during the first seven weeks. This figure indicates that the production of electricity from the soil microbial fuel cell progresses with time.

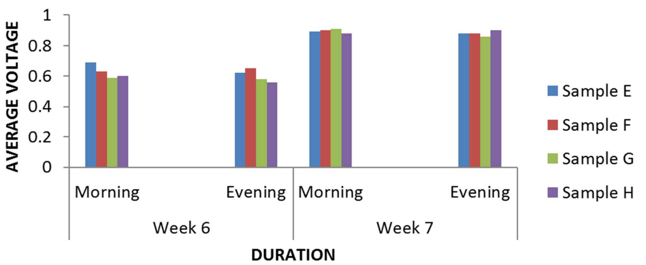

Figure 7. *Result of the Second Experimental Set Up.*

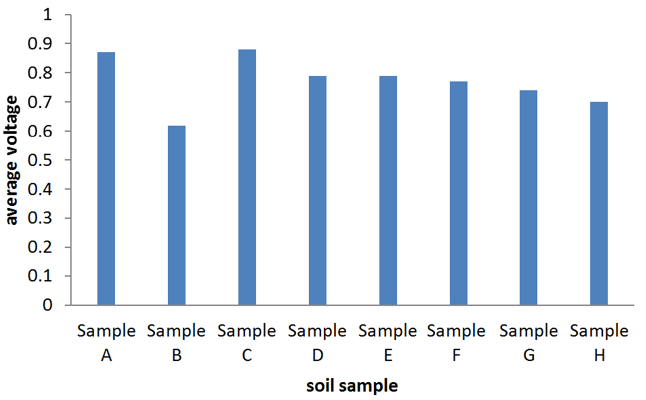

Figure 8. *Mean average voltage value for each of the sample for the entire period.*

It could be observed from the Figure 8 that there was a progressive increase in the voltage produced by the soil samples used in the microbial fuel cell in the second set up. It should be noted that the variation in the produced voltages are small compared to the results obtained in the figure 7. Figure 8 shows the mean values of the average voltage readings obtained for each of the fuel cells throughout the experiment. This figure illustrates the average voltage generated from the soil samples against various samples this is to compare the relevant progress made by each cell and then the entire system throughout the duration of the experiment.

5. Conclusion

It is obvious that the need for energy and its related services to satisfy human, social and economic development is increasing as a result of appreciable increase in population, urbanization and industrialization. It is evident from literature that resorting to alternative energy sources as means of power generation will help significantly in ameliorating environmental problems associated with burning of fossil fuels. However, the challenges faced are that of producing renewable energy to a sustainable level so as to meet the energy demand of the world's population. This study investigates the electric power producing potentials of four different soil samples in a fuel cell. Basically, although a microbial fuel cell has its limitations (such as low power output) it still possesses a whole lot of potentials as it is part of the remedies to the world's energy crisis and environmental disasters as it is pollution-free. The results were measured in the evening and very early in the morning at periods when the fuel cells gave better readings. The reason behind this is that the electro genic bacteria cannot operate properly at high temperature conditions and the favorable temperature range is between 18°C and 35°C. The results obtained from the first set up showed that the soil sample from gutter (city drainage) gave the highest output voltage compared to other soil samples with the value of 1.49 volts; while the maximum voltages of the soil samples obtained from refuse dump, mixture of soil and cow dung and sewage deposits were 0.90, 1.40 and 1.21 volts respectively. The first setup was connected in series producing an output voltage of 4 volts and 1mA with power output of 0.004Watts. While when the two setups were connected together in series, a total output of 8.23volts and 1mA were achieved giving a power output of 0.008Watts. The results achieved suggest that the type of soil used as anodic media affects the output. The micro-organisms can be genetically modified to form high reducing recombinant strains producing more available electrons at anode. Basically, the development and utilization of MFC's is still in infancy. Hence, there is a wide scope for their development as the power output is too low for use in industries. Conclusively, the performance of the soil microbial fuel cell is dependent on the environmental condition.

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