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Electricity Generation from Scrap Metal Wastes obtained from Dump Sites

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Abstract

Most of our urban waste dumps are filled with scrap metals that contribute significantly to environmental degradation. The reuse and recycling of scrap metals helps in protecting the environment and reducing greenhouse gas emissions.This study investigates the use of scrap metals through the principle of reuse and recycling for electrical energy generation. A prototype fuel cell was built consisting of the anode and cathode separated by a proton exchange membrane. The anodic chamber consisted of scrap metals, salt bridge, water, and graphite electrode while the cathodic chamber consisted of graphite electrode and graphite granules.The prototype fuel cell was analyzed and the performance assessed based on current density, power density, internal resistance and power generated.The results of the study showed that when connected in series the current density is 1.8mA/m^3 with internal resistance of 2.7Ω and maximum power density of 11.3mW/m^3 which was higher than that for single connection. The study further revealed that utilization of scrap metals in fuel cell system when stacked in series will provide higher voltage of electricity than when placed individually. Given its inherent environmental friendliness, fuel cell should become an important part of the renewable energy development.

Keywords: Anodic chamber, cathodic chamber, microbial fuel cell, proton exchange membrane, internal resistance

1.0 Introduction

Management of solid waste has become a major challenge in many cities in developing countries and the problem associated with indiscriminate dumping of solid waste (scrap metal) and the management of this waste is the sole concern of an Environmental Engineer. If solid waste is properly used, it can be a valuable resource, but if not effectively managed, it can result in adverse impacts on the environment and public health. Once this waste material is exposed to air and water, rusting occurs and in so doing leaching of toxic material into the environment leads to high amount of hazardous content into the soil, polluting surface water, ground water and agricultural produce. Since the problem of proper integrated sustainable solid waste management scheme still persists in Nigeria, an alternative way of minimizing the effect of scrap metal through the principles of reuse and recycle of this environmental nuisance into energy generation was considered. Microbial fuel cells (MFCs) are devices which convert organic matter to energy (electricity or hydrogen) using microorganisms as catalysts. Generally, bacteria are used in MFCs to generate electricity while accomplishing the biodegradation of organic matters or wastes.

Microbial fuel cell (MFC) technology is gaining more attention as companies push for sustainability, and represents a new form of renewable energy by generating electricity from what would otherwise be considered waste [1,2]. Earlier development of microbial fuel cell (MFC) emphasized harvesting the electricity for power generation. Recent advances in microbial fuel cell (MFC) technology expanded the basic concept to the production of fuel and chemicals such as hydrogen, methane, ethanol, as well as using a MFC for desalination.

In a microbial fuel cell operation, the anode is the terminal electron acceptor recognized by bacteria in the anodic chamber [3].Therefore, the microbial activity is strongly dependent on the redox potential of the anode. Recent researches indicated that a Michelis-Menten curve was obtained between the anodic potential and the power output of acetate driven microbial fuel cell. A critical anodic potential seems to exist at which a maximum power output of a microbial fuel is achieved [4]. However, there are many challenges to scaling these. Most designs have been tested only in the laboratory, and many tests are conducted in fed batch mode with synthetic wastewater. The viability of scaling up MFCs could open up new ways of generating renewable energy while treating wastewater, contributing to a more sustainable society [5]. Microbial fuel cells use inorganic mediators to tap into the electron transport chain of cells and channel electrons produced. The mediator crosses the outer cell lipid membranes and bacterial outer membrane; then, it begins to liberate electrons from the electron transport chain that normally would be taken up by oxygen or other intermediates [5]. This electrode becomes the electro-generic anode (negatively charged electrode). The release of the electrons means that the mediator returns to its original oxidized state ready to repeat the process.

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Metal Air Batteries/Air Fuels Cells technologies represent new form of emerging renewable energy technology used for the generation of electricity directly from waste materials and will one day contribute to a large portion of world global energy productions and usage. The energy generated from this waste materials and other renewable is becoming increasingly important and interesting owing to its climatic friendliness and enormous reserves [6]. The fuel cell batteries supply electrical energy from the chemical reactants stored within them; when these reactants are consumed, the battery is "dead". An alternative approach would be to feed the reactants into the cell as they are required, so as to permit the cell to operate continuously. In this case, the reactants can be thought of as "fuel" to drive the cell, hence the term fuel cell [7].

One reason for the interest in fuel cells is that they offer a far more efficient way of utilizing chemical energy than conventional thermal conversion. Although this technology seems promising, Metal/Air fuel cells are not deficient in their own challenges, having a high power density and can vary its output quickly [8]. The internal resistance can be minimized by increasing the anode, cathode and the proton/ion exchange membrane (PEM), in addition to the surface area and the ionic strength of the electrolyte [9]. In a bid to improve power density of microbial fuel cells (MAFCs), the use of electron acceptor apart from oxygen has been extensively explored [9,10]. Further amplification of density remains one of the greatest challenges for realizing the practical application of microbial fuel cells technology especially in the case of proton/ion exchange membrane fuel cells (PEMFCs).

In this research work, a comparative analysis will be carried out using cement and water sealed proton exchange membrane in microbial fuel cells, in addition to a performance evaluation of the microbial fuel cell to Air battery System.

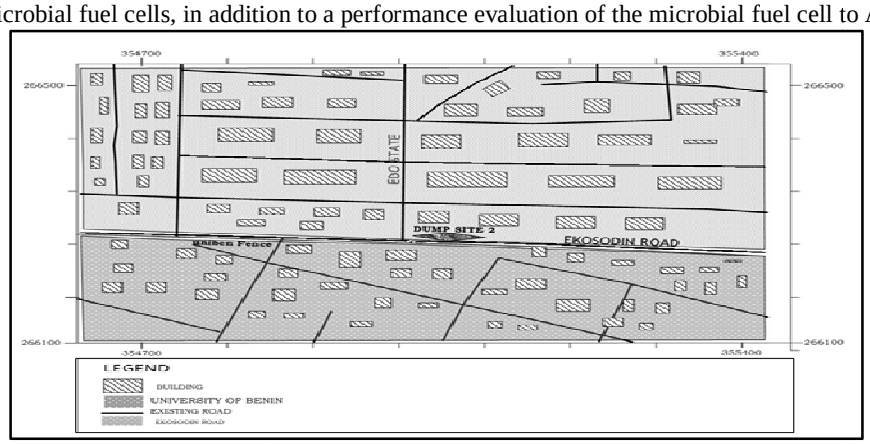

Fig. 1a: Layout Plan Showing Location of Dumpsite at Ekosodin

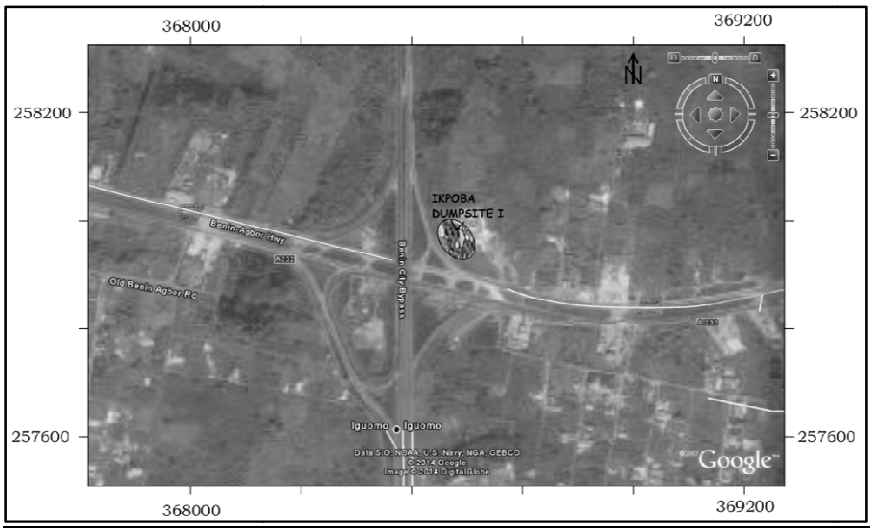

Fig.1b: Satellite Imagery showing Ikpoba Dumpsite`

2.0 Materials and Method

The methodology employed in the study included, waste collection, preparation of the proton exchange membrane, construction of metal (iron) -Air fuel batteries, construction of the anode chamber, preparation of scrap iron and fuel cell operation.

The scrap iron sponge prototypes were collected from various dump sites located within and outside the University of Benin, at Ekosodin Village; and market places at Ikpoba Hill (see Fig. 1a and Fig. 1b respectively).The materials assembled for the studies includedresistor box,copper wires (red and black), multimeter, transparent container, plaster of paris (POP), Silicon PCV gum,razor blade, soldering iron: 2.5 volt batteries, electronic, weighing balance, pliers, lead, scrap iron, cement, crestal water seal and hand gloves. The experiment set up consisted of the following:

1) Construction of Metal (Iron) – Air Fuel Batteries:

A cylindrical container with depth of 11cm was obtained.Graphite rods were removed from 2.5volt big batteries (6 pieces of graphite rods).The graphite rods were heated in a Bunsen burner and fixed at 90^{o} to the container at a height of 4cm from the bottom of the container, and at equal distance from each other around the container.PVC gum was used to aid a firm attachment of the graphite rods around the container and the wire was extended downward for circuit connection.Flexible red copper wire was used to interconnect the 18 graphite rods around the container and the wire extended downward for circuit connection.From the 4cm height to a height of 3cm on the container, holes of 5mm diameter were bored at the entire circumference of the down base to maintain a height of 7cm.Also holes of 3mm diameter were bored at the bottom of the container.The graphite rods were removed from the 2.5volt batteries and crushed to granular particles, then use to load the container to a height of 11cm from the 4cm height on the container.From the 4cm height on the container to the bottom of the container constitute the cathode region (cathode compartment).

2) Construction of the anode chamber:

In the construction of the anode chamber, graphite rods were removed from 2.5volt batteries (6 pieces of graphite rods).The graphite rods were heated in a Bunsen burner, and were used to bore six holes on the top cover of the Anode Chamber.PVC gum was used to aid a firm attachment of the six graphite rods on the anode cover, and the six rods were connected with black copper wire and extended outward for circuit connection.

3) Preparationof the proton exchange membrane

In the preparation of the proton exchange membrane, 1400g of Plaster of Paris (POP) was measured with the aid of a weighing balance.1kg of cement was mixed with water sealed.2650ml of water was measured with a measuring cylinder.The plaster of Paris (POP) was properly mixed with the water until a homogeneous solution was attained.The solution was poured uniformly on top of the graphite granular particles to a height of 7cm from the 11cm height on the container. The proton exchange membrane was therefore 3cm high.The plaster of Paris (POP) and the water sealed were allowed to solidify properly for 24 hours.From the proton exchange membrane to the top cover of the anode region constitutes the anode compartment.

4) Preparation of the scrap iron

In the preparation of the scrap iron, the following steps were taken: 500g of the scrap iron was measured with the aid of a weighing balance.The scrap iron was then poured on the anode chamber.After this process, the cell was ready to be used.The setup is shown in Fig.2.

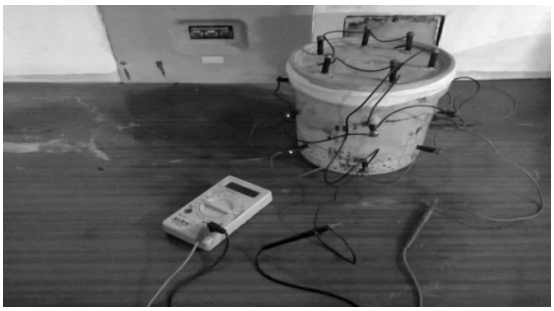

Fig 2: Laboratory setup of Fuel cell

2.1 Fuel cell Assembly and Measurement of Voltage

The fuel cell setup and operation consisted of the following: 250ml of salt was added to the anode chamber of each of the cells and sealed tightly to prevent entrance to air. The Open Circuit Voltage (OCV) was measured across the five cells assembled. A 100ohm resistor was connected across the five cells and the respective voltage in each cell measured. Thereafter, the current across the five cells were measured with the load disconnected. Polarization test was conducted on the cells both individually and in series connection when steady and maximum voltage was reached. This was necessary in order to determine the internal resistance producing maximum amount of power. The voltmeter was used in the measurement and recording of voltage.

The power output produced from the scrap metal waste was calculated using the measured voltage, V_{emf} across the load and the current. The equation is given as:

$$P = IV_{emf} \quad (1)$$

The current produced by laboratory scale Proton Exchange Membrane Fuel Cell (PEMFC) was calculated by measuring the potential across the load and using the equation

$$I = \frac{V_{emf}}{R_{ext}} \quad (2)$$

From where power output is given by

$$P = \frac{V_{emf}^2}{R_{ext}} \quad (3)$$

In order to maximize the total system power in metal/air fuel cell using scrap waste as fuel, the most important factor is the power production in the basin of the total reactor volume [3,12]. In this case, power output normalized by volume is calculated as

$$P_v = \frac{V_{emf}^2}{V_{ext}} \quad (4)$$

Where;

P_v = Volumetric power (W/m^3)
R_{ext} = External resistance (Ω)
V_{emf} = Voltage (V)

The power output of the EMF is given as

$$P_\varepsilon = \frac{\varepsilon^2}{r+R} \quad (5)$$

Where r is internal resistance which is computed from the equation

$$r = \frac{E-IR}{I} \quad (6)$$

In this study, linear regression equation was used to study the correlation between the dependent and independent variables consisting of current against voltage, current against time and power generated against time. The coefficient of determination, R^2 was used to determine the goodness of fit.

3.0 Results and Discussions

The prototype fuel cell designed was analyzed, and the performance of the fuel cell was assessed based on the current generated, the voltage, current density, power density, internal resistance and power generated with details of the cell behavioral pattern after three months of repeated measurements.

After four weeks of study, the experimental setup of the microbial fuel cell showed an initial open circuit voltage of 0.6volts which was too small, so the scrap metals were removed and cut into smaller bits and all the graphite rods at the cylindrical container were pushed inside with more than half their full length inserted into the cylindrical container. The reading was taken after 24hrs and it read 1.2 volts of an initial open circuit voltage. However, voltage dropped with the service hour probably due to factors associated with proton transfer atthe proton exchange membrane. The energy density per gram of the cell shows a continuous discharge with time for the period as shown in Fig. 3 below.

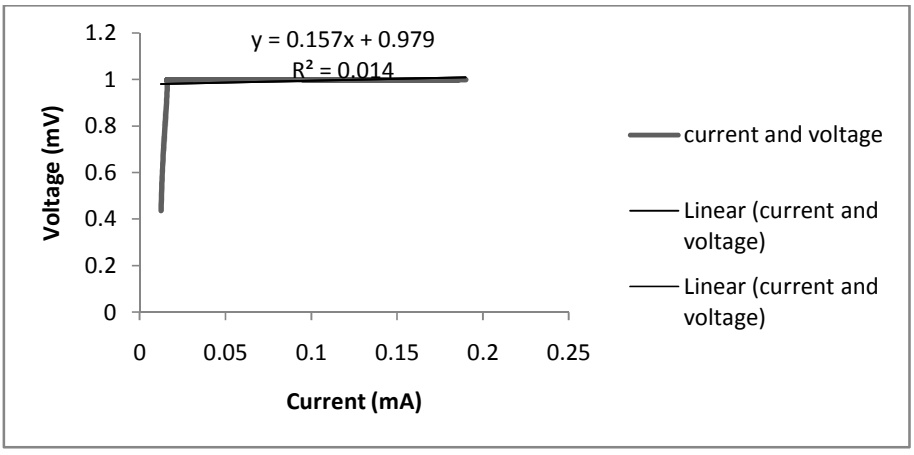

Fig.3: voltage (mV) against Current (mA)

From Fig.3, it can be seen that the voltage is continuous with current. The current is due to free electrons moving along the metal, i.e., the rate of flow of charge. The cell produced a continuous voltage with current.

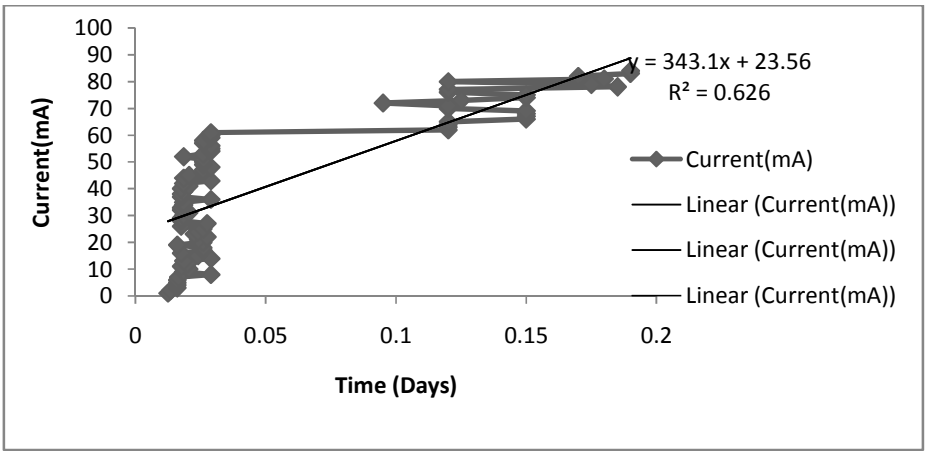

Fig. 4: Current(mA) against Time (Days)

Fig. 4 consist of two sections, the first section which is almost horizontal indicates when the microorganisms are still breaking down the cells while the second shows the increased flow of current. It indicates the definition of microbial fuel cell which generates electricity while accomplishing biodegradation of organic matter or waste. These two sections are joined by a step increase.

These two sections are presented separately as two separate graphs and the R^2 for each is given separately as in Fig.4 and Fig.5. It is observed that the R^2 for the entire graph has increased indicating the improved relationship of Current versus time for each section see Fig. 6.

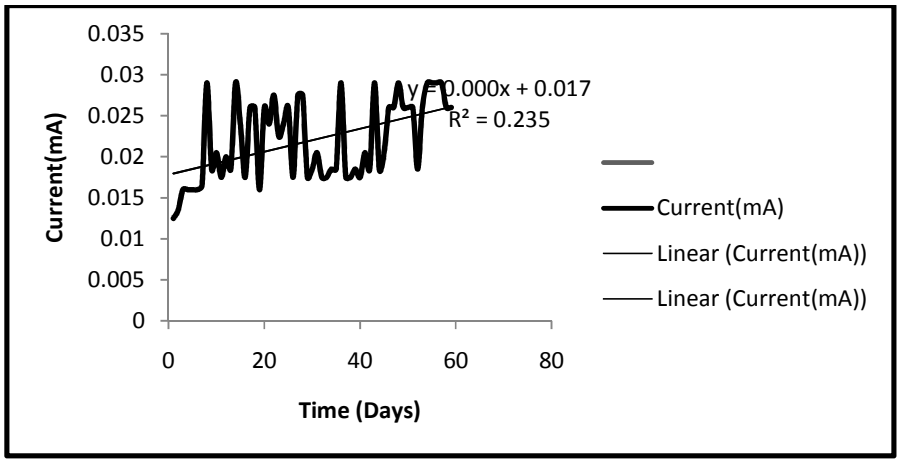

Fig 5: Current (mA) Against Time (Days)

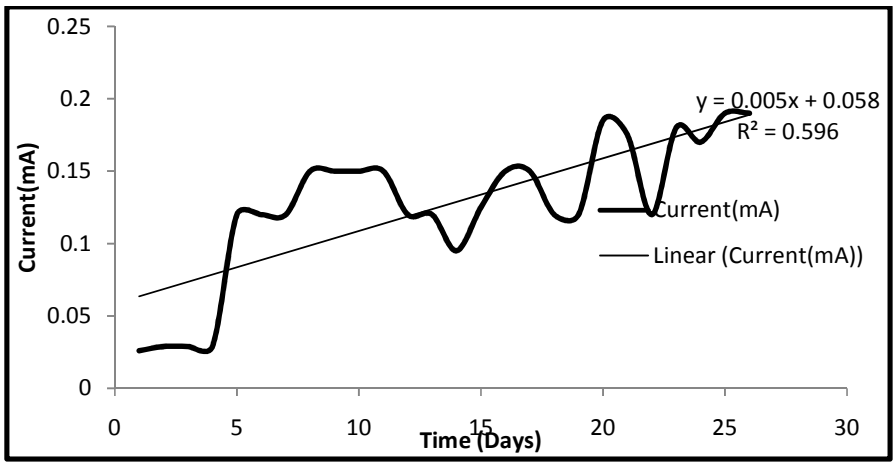

Fig 6: Current (mA) Against Time (Days)

3.1 The Determination of Internal Resistance and Maximum Power of the Single Cell System.

After weeks of assessment, a steady maximum voltage of 0.70V was recorded for the single cell system. When the peak voltage was reached, polarization test was conducted in order to obtain the internal resistance and maximum power of the cell system as shown in Fig.7.

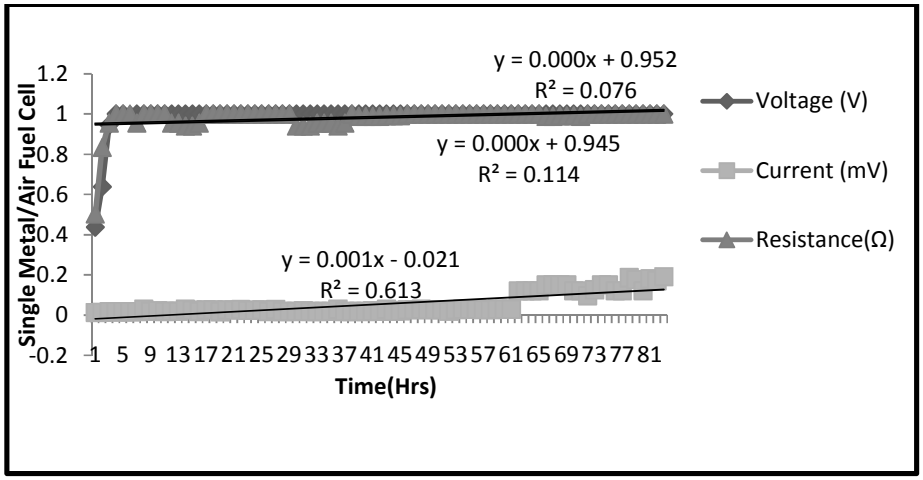

Fig. 7: Single Metal/Air Fuel Cell Against Time (hrs)

Fig. 7 above shows the behavior of a single metal/Air fuel Cell against time. The graph shows that a single fuel cell will produce less than one volt of electrical potential. To produce higher voltages, fuel cells were stacked on top of each other and connected in series as shown in Fig. 8. It means that microbial fuel cell performs better when connected in series or parallel.

3.2 The Determination of Time and Maximum Power Density of Single Metal/Air Fuel Cells

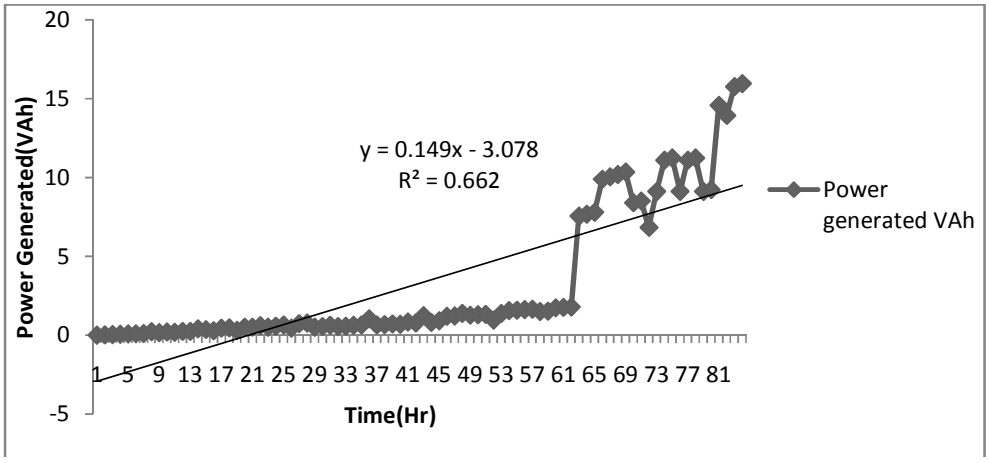

Fig. 8: Power Generated (W/hr) Against Time (hrs)

From Fig. 8, it is observed that the power generated increases with time. It indicates the definition of microbial fuel cell which generates electricity while accomplishing biodegradation of organic matter or waste. The graph shows that from the 1st week, the waste was still trying to decompose, but with time when it might have undergone some decomposition, the power increased. This means that Power generated increases with time due to decomposition of organic matter or waste that is taking place with time so, the longer the days or months the more power it generates.

3.3 Application of the Metal/Air Fuel Cell System

The assessment of the potential of waste to energy technology was used to power a 4 volts bulb as shown in the Fig. 9.

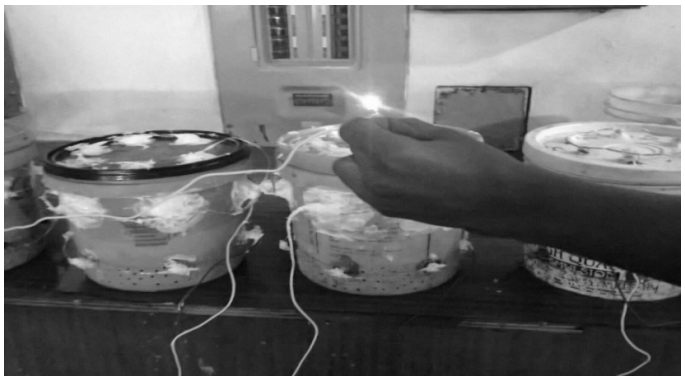

Fig. 9:Five (5) Metal/Air Fuel Cells used to Power a 4V Bulb

It was observed that each fuel cell produced about 0.7V to 0.8V. To produce higher voltage, fuel cells were connected in series.

4.0 Conclusion

In this study, a prototype fuel cell was designed using scrap metal as its feedstock and the performance of the fuel cell was studied. The results of this design demonstrate that electricity generation can be obtained by use of a Fuel Cell using scrap metal as feedstock. Specifically, the investigation shows that:

a) Scrap metals can be used to generate electricity, by utilizing it as a feedstock in metal/air fuel cell.
b) Plaster of Paris ($CaCO_3.5H_2O$), cement and Crestal Water Seal can be utilized as an effective proton exchange membrane in metal/air fuel cell.
c) The nature of circuit connection can affect power density of the cell system and power tends to be higher when connected in series than in a single connection.
d) It was observed that the metal/Air fuel cell would perform better when they are connected in series which tends to optimize the voltage of the cell system and increase the cell discharge rate.
e) The introduction of this innovative technology will add a significant boost to green electrical capacity and will have a positive impact on the environment; reducing carbon dioxide, other gas emissions and pollution.
f) It would help to reduce the quantity of heavy metals that may potentially leach from solid waste landfills.
g) It would help reduce the environmental pressures that modern society has placed upon the earth's limited supply of mineral resource.

Given its inherent environmental advantages, relatively good economics and availability, fuel cell should eventually become an important part of the renewable energy industry. Obviously, the viable commercialization of the technologies is still in its initial stages, but the potential remains and the most difficult technical barriers have been overcome.

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