International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 6, Issue 1, pp: (33-47), Month: January - March 2018, Available at: www.researchpublish.com

Potential of Microbial Fuel Cells for Energy Production

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Abstract: **The study was aimed at evaluating the potentials of microbial fuel cells for energy production. The study was carried out within a period of six months. 500mls of domestic kitchen waste water was collected from various locations in Calabar Metropolis, into tightly corked plastic containers and transported to the laboratory for analysis. Microbial fuel cells was designed using plastic containers, graphite electrodes, salt bridge and domestic waste water. Microorganisms from the domestic waste water were identified using standard microbiological techniques. Results from the study showed that a higher mean voltage (1.58v) was recorded by stacked waste water microbial fuel cells (Stacked WWMFC) compared to unstacked waste water microbial fuel cells (WWMFC1 and WWMFC2) that had a mean voltage of 0.50 and 0.59v respectivelyafter 10 days. Microbial cells from the domestic waste water samples were identified as *Shigella, Serratia marcescens, Salmonella, Bacillus, Pseudomonas aeruginosa, Streptococcus faecalis,Staphylococcus,* and *Escherichia coli*. Among the identified isolates, Salmonella (NA3) had the highest (0.68v) voltage production compared to other isolates. The comparative analysis of voltage density among the fuel cells of both the mixed culture and axenic cultures showed that the stacked microbial fuel cells (stacked WWMFC) had the highest voltage density (0.072) compared to others. However, this study has shown that microbial fuel cells are evolving to become a simpler and more robust technology. Provided the biological understanding increases,the electrochemical technology advances and electrode price decreases, the technology could serve as anew core technology for conversion of waste to electricity in the future.**

Keywords: **microbial fuel cells, plastic containers, graphite electrodes, energy production.**

1. INTRODUCTION

The current energy crisis that has gripped the globe due to the over dependence on fossil fuel (i.e. crude oil, coal, natural gas, etc) has made research efforts in free, renewable energy relevant in today's world.(Logan, 2006) Energy sources such as solar, wind, hydroelectricity, geothermal among others has been brought into the limelight. In this so called mad race to satisfy the growing energy concerns for today and tomorrow, more research has been and will be carried out in other to make the field of microbiology and microorganisms a major stakeholder in the energy production of the new age.In the future, renewable energy will constitute a greater portion of the world's energy consumption and production (Potter, 2003; Allen &Bennetto,2004; Rabaey &Verstraete, 2003; Davis &Higson, 2003; Ieropoulos *et al*, 2006; Park &Zerkus, 2000; Tender *et al*, 2008). Recent predictions for the global energy have lead to the quest for alternative energy resources (Lovley, 2003; Ringeisen *et al* 2006; He *et al*, 2005). The rate of reduction in non renewable sources of energy implies that there is urgent need for highly efficient enegy transformation technologies and ways to use alternative renewable energy sources (Rosenbaum *et al*, 2006),. Microbial fuel cells (MFC) technology represents a new path of energy production by harvesting electricity from what would have been regarded as a waste material (Alterman *et al*, 2006). This technology utilizes mostly anaerobic bacteria which may be present in the waste water and works as catalysts to produce electricity while treating waste water (Moon *et al* 2006). Microorganisms have the capacity to generate electricity from a wide range of organic waste while oxidizing the waste to less harmful forms (Logan, 2006). Although MFCs generate small amount of power than hydrogen fuel cells, a blend of both electricity generation and waste water treatment could reduce the cost of primary treatmentof effluent waste water (Rabaey *et al*, 2005).

Currently, studies performed on MFCs are concerned with how to increase the power density of the system with regards to the peripheral anode surface area, while little investigation has been carried out on determining the infulence of voltage

output in contract to the varying fuel cell components. The main aspect of fuel cell research is to reduce the treatment costs and simplify process implementation conditions . Many of the current relevant research are focused on the development of the ways and means to convert chemical energy stored in biomass to electricity (Kim *et al*, 2008). The energy transformation from burning of biomass- chemical to heat, and subsequent utilization to heat for different purposes is less efficient. Since most rural population depend on subsidized yet scarce electricity supply, a technology such as MFCs can convert the energy stored in organic wastes via enzymatic reactionsassociated with the activity of microorganisms (Min *et al*, 2005; Rabaey & Versaete, 2003).

Two different types of MFCs can be utilized viz- single chambered or double chambered MFCs having both the anodic as well as the cathodic compartments. Microorganisms in the anodic compartments, utilize the biomass for growth forming electrons and protons (He *et al*, 2005), and these electrons can be transported out of the cell using mediators (Davis & Higson, 2007; Niessen *et al*, 2004)while other microorganisms have the tendency or ability to expel electrons for the reduction of substrates which can be absorbed by the electrode (Min *et al*, 2005; Lie *et al*, 2005). The protons or H^+ ions is oxidized to water in the cathode chamber with no other byproduct formed (Ringeisen *et al*, 2006). MFCs systems are very adaptable, practical and hold much promise to provide energy in sustainable fashion. Mostly, mixed cultures are preferred over single medium (AXENIC) as they would have a wide range of substrates. Sulphates and sulphides mediated system have a major role to play in power generation, as most times, sludge is rich in these compounds (Tender *et al*, 2008). Thus, large scale reactors can be synthesized to use sludge and sewage sources as substrates for electricity generation (Bond & Lovley, 2003).

2. MATERIALS AND METHODS

MATERIALS:

The microbial fuel cell used in this study was constructed with the following materials; Plastic containers with lid to serve as the anode and cathode, PVC pipe for use as the salt bridge, Graphite rods from dry cell battery to serve as electrodes, Other materials included:PVC glue, agar-agar, salt (Sodium chloride), insulating masking tape, copper wires, measuring cylinder, petri dishes, pipette, beakers, funnel, conical flasks, microscope, test tubes, syringes,digital multimeter, etc.

SAMPLE COLLECTION:

500ml of Domestic kitchen waste water was collected from various locations in calabar metropolis. The samples were dispensed into tightly cork plastic containers and transported to the University of Calabar Microbiology laboratory for analysis.

MEDIA:

The media used forn the study were Nutrient agar and MacConkey agar.

METHODS:

PREPARATION OF A MIXED CULTURE MICROBIAL FUEL CELL FROM WASTE WATER:

The plastic containers used were washed and air dried, the graphite electrodes were also washed and dried to remove any salt and acid residue. Copper wires where attached to the electrodes with the means of soldering iron so as to enable the transmission of electrons between the compartments. A known volume of 150ml of domestic kitchen waste water was added into the container that was to serve as the anode and sealed to ensure that the microorganisms contained are forced into anaerobic condition. Equal volume of sterile distilled water was put into the container to serve as the cathode and a salt bridge was used as the proton exchange membrane (PEM) for the transfer of protons across compartments (Delaney *et al*., 2008).

The following method was employed in preparing the salt bridge; the agar and salt mixture was to be mixed in the ratio of 3:1 to the required volume of distilled water and heated in an autoclave at 121^{o}Cfor 15 minutes at 15 PSIwhich is aseptically transferred into a sawed PVC pipe with diameter of 2 inches, that was sealed at one end to hold the agar and is left to cool and solidify(Deka & Barua, 2010).

The anode, cathode and salt bridge is joined together in a H-shaped configuration as described by Logan *et al*., (2006). Holes where bored into the lids to pass wire already solder to the electrodes and all were connected to a multimeter to detect the passage of electric current measured in milliamperes (mA) and the voltage in millivolts (mV)

PLATE 1: photograph of the graphite electrodes

PLATE 2: photograph of double chambered waste water microbial fuel cell

SAMPLE PREPARATION FOR MIXED CULTURE MICROBIAL FUEL CELL:

The anodic electrode was washed with 9.0ml of sterile distilled water to rinse the biofilm already accumulated on the electrode. Thereafter, 1.0 ml of the waste water sample was taken for serial dilution.

PLATING PROCEDURES:

1.0 ml of waste water aseptically withdrawn was diluted with 9.0 ml of distilled water and mixed thoroughly, then 1.0 ml of the mixture was withdrawn and mixed with another 9.0 ml of distilled water. Serial dilutions of 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7} was performed using both the diluted as well as the undiluted waste water samples. The samples were then plated using pour plate method on Nutrient agar and MacConkey agar and incubated at room temperature of 37^{O}C for 24 hours.

PURIFICATION OF ISOLATES:

After 24 hrs of incubation , discrete colony types were noted and were sub-cultured onto nutrient agar plates. Agar slants were prepared for the storage of the bacterial colonies.

METHOD FOR PREPARING A TEN (10) STACKED MICROBIAL FUEL CELL USING DOMESTIC WASTEWATER:

Ten (10) individual fuel cells were prepared using the H-shaped double chambered technique as described by Logan *et al.*, 2006). The anodic electrolyte was maintained as waste water while the cathodic electrolyte was changed from sterile distilled water to an oxidizing agent-Potassiumferricynide. The cells were then connected in series using flexible copper wires, with the single positive and negative terminals connected to the multimeter for measurement of the voltage. The setup was left to stand for 10 days.

PLATE 3: Stacked wastewater microbial fuel cell

3. RESULTS

WASTEWATER MICROBIAL FUEL CELL:

The project results come in two parts; the first part is the results gotten from the incubation of the waste water. The wastewater was gotten from the domestic kitchen i.e. water which has been used for washing various items in the house. The waste water was subjected to the treatment using the microbial fuel cell technique to see how much electricity it generates. The microbial fuel cell was observed daily for ten (10) days and the results were recorded to show an increase or decrease in voltage and current according to the growth phase of the microbes in the water sample-lag, log, stationary and decline phases. The results obtained and recorded are gotten from a batch type culture. The MFC was also allowed to stand for about a month without replacing the waste water for about a month until it ran out of electrical power.

The double chambered microbial fuel cell as the name implies, consists of two parts or chambers the cathode and the anode separated by a proton exchange membrane (salt bridge). According to Logan 2006, which states that the H-shape systems are acceptable for basic parameter research, such as examining power production using new materials, or types of microbial communities that arise during the degradation of specific compounds, but they typically produce low power densities. The H-shape system was also found easy to build and manage had has been adopted by various researchers in their work Jang *et al*, 2004, park & Zeikus 2003 etc thus conforming to the statement of Logan 2006. Thus the reason for using this system for the determination of electrical energy generated by the waste water notwithstanding the many disadvantages that arises in using the system.

The anode compartment is negatively charged using the interactions of the microbes to generate protons and electrons. The protons are transported across the PEM to the positively charged cathode chamber where it is oxidized either by the oxygen in air or by an oxidizing agent.

The equation for the cathode reaction is given below:

$24H^+ + 24e^- + 6O_2 \longrightarrow 12H_2O$ (cathode reaction)

The reaction for the anode compartment is given as follows:

$C_6H_{12}O_6 + 6H_2 \longrightarrow 6CO_2 + 24H^+ + 24e^-$ (anode reaction)

The general equation for both anode and cathode is given as:

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ (overall reaction)

The fuel cell was setup with the anode containing the wastewater and the cathode sterile distilled water the amount of voltage observed was within the voltage density range of the research works done by various authors/ researchers for waste water and microbial fuel cell in general which is about 0.1-1.5mV and a voltage density of 0.06 (Wang et al, 2009a). The results are shown in Table 1.

TABLE 1: Domestic kitchen wastewater microbial fuel cells voltage records

	DAY 0	DAY 1	DAY 2	DAY 3	DAY 4	DAY 5	DAY 6	DAY 7	DAY 8	DAY 9	DAY 10	TOTAL	MEAN	D=V/A
WWMFC 1	0	0.05	0.1	0.3	0.3	0.5	0.5	0.8	0.8	1.1	1.1	5.55	0.505	0.039
WWMFC 2	0	0.1	0.2	0.4	0.4	0.6	0.8	0.8	1.2	1.2	0.8	6.5	0.591	0.046
STACKED WWMFC	0	0.4	0.8	1	0.8	1.5	1.9	2.02	2.5	3	3.5	17.42	1.584	0.072

Legend: WWMFC= wastewater microbial fuel cell.

D=V/A

Where

D= voltage density

V=voltage

A=area of electrode (v/m^2)

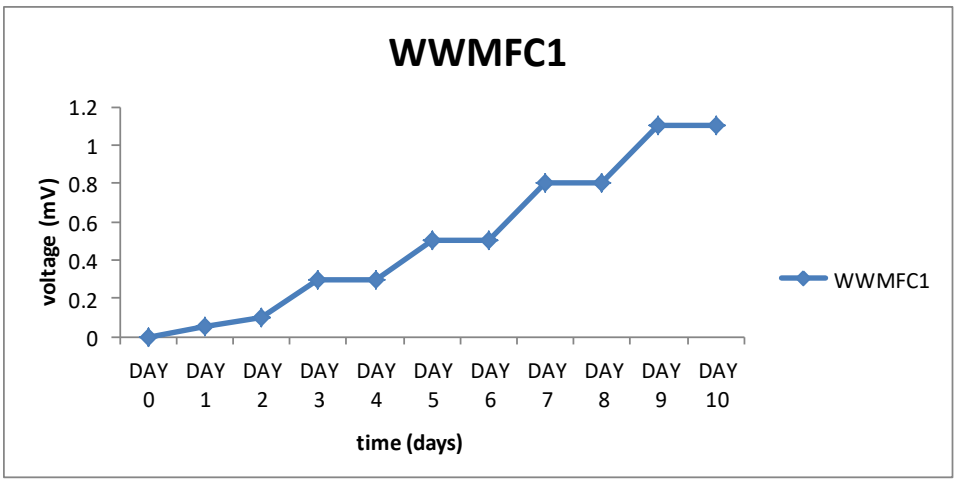

FIGURE 1:

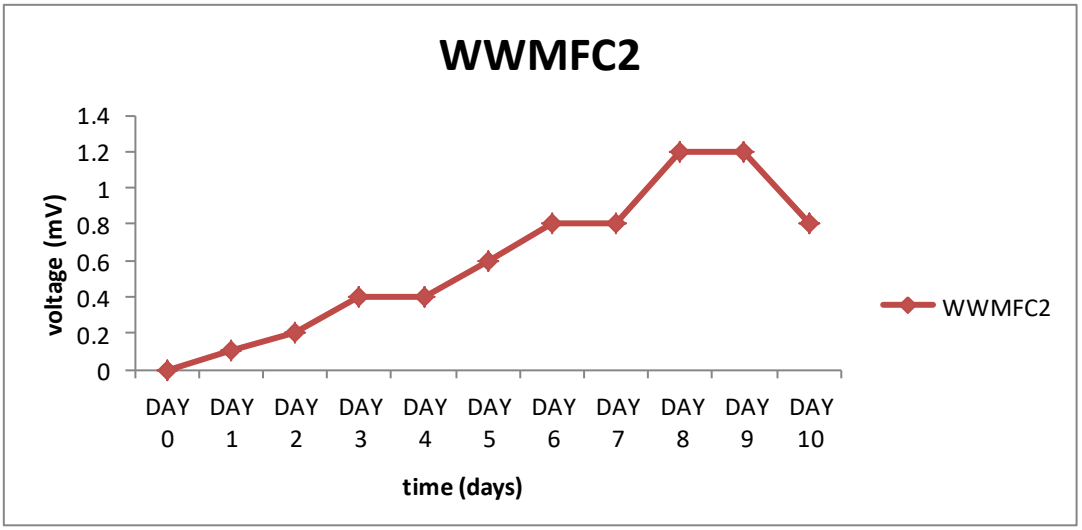

FIGURE 2: Graph of voltage (mV) against time (days) for wastewater fuel cell 2

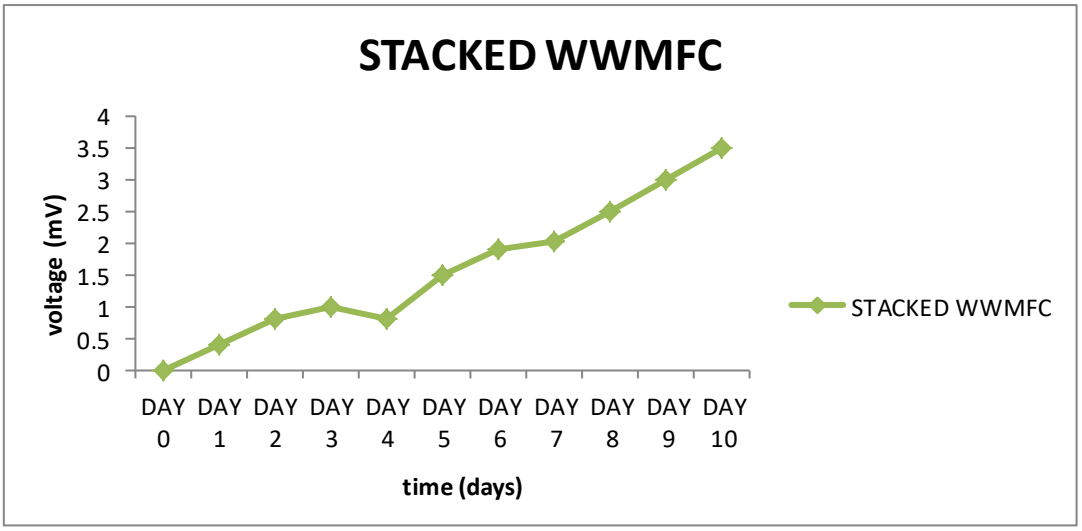

FIGURE 3: Graph of voltage (mV) against time (days) from stacked wastewater fuel cell

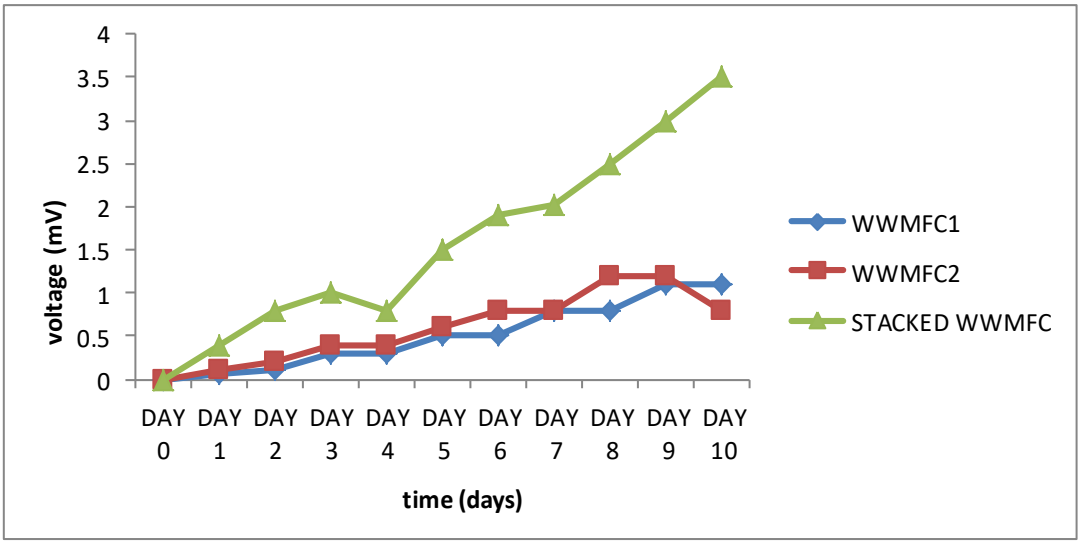

FIGURE 4: combined for all fuel cells; Graph of voltage (mV) against time (days)

LEGEND:

Y-axis = voltage reading (mV)

X-axis = time (days)

PLATE COUNT AND CULTURAL MORPHOLOGY:

The sample was incubated in triplicates and the plate count and cultural morphologies were observed as shown in Tables 2 and 3 below.

BIOCHEMICAL ANALYSIS:

The purified isolates were subjected to various biochemical tests to identify the various organisms isolated from the kitchen wastewater. The following results were obtained as shown in Table 4.

TABLE 2: Total bacterial count from domestic kitchen wastewater

	NUMBER OF COLONIES	DILUTION FACTOR	PLATING FACTOR	COLONY FORMING UNIT (CFU)
NA ISOLATES				
10^{-3}	TNTC	10^{-3}	0.1	TNTC
	TNTC	10^{-3}	0.1	TNTC
10^{-5}	80	10^{-5}	0.1	8.0×10^{5}
	110	10^{-5}	0.1	1.1×10^{4}
	130	10^{-5}	0.1	1.3×10^{4}
10^{-7}	50	10^{-7}	0.1	5.0×10^{7}
MAC ISOLATES				
10^{-3}	69	10^{-3}	0.1	6.9×10^{3}
	120	10^{-3}	0.1	1.2×10^{2}
	60	10^{-3}	0.1	6.0×10^{3}
10^{-5}	80	10^{-5}	0.1	8.0×10^{5}
	40	10^{-5}	0.1	4.0×10^{5}
	40	10^{-5}	0.1	4.0×10^{5}
10^{-7}	30	10^{-7}	0.1	3.0×10^{7}
	42	10^{-7}	0.1	4.2×10^{7}
	36	10^{-7}	0.1	3.6×10^{7}

LEGEND:TTNC= Too Numerous To Count; NA isolates= nutrient agar isolates; MAC isolates = macConkey agar isolates

TABLE 3: CULTURAL MORPHOLOGY AND CHARACTERSTICS

	SIZE	SHAPE	COLOUR	EDGE	ELEVATION	SURFACE	OTHER OBSERVATIONS
NA							
I	LARGE	SWARMING	MILKISH	RHIZODIAL	FLAT	DRY	NIL
II	MODERATE	ROUND	RED	RHIZODIAL	FLAT	DRY	DIFFUSED GROWTH
III	SMALL	ROUND	MILKISH	ENTIRE	RAISED	MUCOID	0.5-1MM DIAMETER
IV	SMALL	ROUND	COLOURLESS	ENTIRE	RAISED	MUCOID	EDGES OF THE COLONIES ARE FLAT WHILE THE CENTRE WAS SLIGHTLY RAISED
V	SMALL	ROUND	MILKISH	ENTIRE	RAISED	MUCOID	NIL
VI	SMALL	ROUND	YELLOW	ENTIRE	RAISED	MUCOID	1-2MM DIAMETER
VII	SMALL	ROUND	COLOURLESS	ENTIRE	RAISED	MUCOID	0.5-1MM DIAMETER
VIII	MODERATE	ROUND	YELLOW	RHIZODIAL	FLAT	MUCOID	NIL
IX	MODERATE	ROUND	COLOURLESS	ENTIRE	FLAT	DRY	NIL
MAC							
I	MODERATE	ROUND	DEEP PINK	ENTIRE	RAISED	MUCOID	NIL
II	SMALL	ROUND	SLIGHTLY YELLOW	ENTIRE	CONVEX	MUCOID	NIL
III	SMALL	ROUND	WHITE-MILKISH	ENTIRE	RAISED	MUCOID	COLONIES HAD A SHINEY SURFACE
IV	MODERATE	ROUND	MILKISH	UMBONATE	RAISED	MUCOID	COLONIES WERE SERATED
V	SMALL	ROUND	PINK	ENTIRE	RAISED	MUCOID	NIL

TABLE 4: BIOCHEMICAL SCREENING OF ISOLATES FOR IDENTIFICATION

ISOLATE	GRAM'S RXN	OXI	GAS	CATA	UREA	CIT	MOT	INDO	ORNT	LAC	SULF	SUC	GLU	M.R.	V.P	DISCRIP	M/O
NA1	NEG	+	-	+	-	-	-	-	-	-	-	+	-	+	-	Long rods in pairs	*Shigella spp*
NA2	NEG	-	-	-	-	+	+	-	-	-	-	-	+	-	+	short rods	*Serratia marcescens*
NA3	NEG	-	-	+	+	+	+	-	-	-	+	-	+	-	+	short rods	*Salmonella spp*
NA4	NEG	+	-	+	-	-	-	-	-	-	-	+	-	+	-	Long rods in pairs	*Shigella spp*
NA5	POS	+	-	+	-	+	+	-	+	-	+	-	+	-	+	rods in chains	*Bacillus spp*
NA6	NEG	+	-	+	-	+	+	-	-	-	-	-	-	-	+	small rods	*Pseudomonas aeruginosa*
NA7	POS	-	-	-	-	-	-	-	-	+	-	+	+	-	+	large coccobaccilli	*Streptococcus faecalis*
MAC1	NEG	-	-	-	-	+	+	-	-	-	-	-	+	-	+	short rods	*Serratia marcescens*
MAC2	POS	-	-	+	-	-	-	-	+	+	-	-	+	-	+	cocci	*Staphylococcus spp*
MAC3	POS	+	-	+	-	+	+	-	+	-	+	-	+	-	+	rods in chains	*Bacillus spp*
MAC4	NEG	-	+	+	-	-	+	+	+	+	-	+	+	+	-	rods in chains	*Escherichia coli*

LEGEND: NA=NUTRIENT AGAR; MAC=MAcCONKEY AGAR; GRA=-GRAM STAINING REACTION; OXI-OXIDASE TEST; GAS-GAS PRODUCTION; CATA-CATALASE TEST; UREA-UREASE TEST;CIT=CITRATE UTILIZATION TEST; MOT=MOTILITY TEST;INDO=INDOLE TEST; ORNT=ORNITHINE DECARBOXYLASE TEST; LAC=LACTOSE FERMENTATION TEST; SULF=SULFIDE PRODUCTION;GLU=GLUCOSE FERMENTATION TEST;M.R=METHYL RED TEST;V.P=VOGES PROSKAUER;DISCRP=DISCRIPTION OF ISOLATES UNDER MICROSCOPE;M/O=NAME OF IDENTIFIED MICROORGANISM.

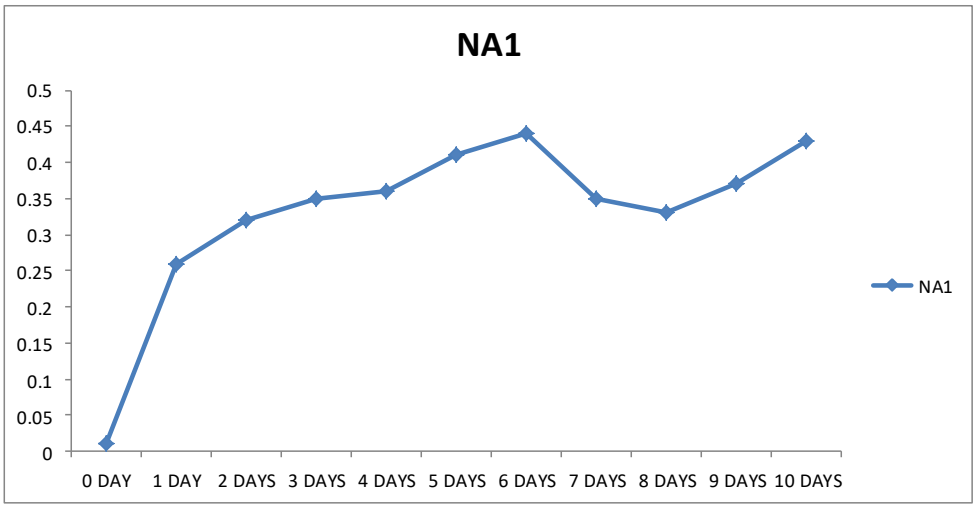

FIGURE 5: isolate NA1 MFC; Graph of voltage (mV) against time (days)

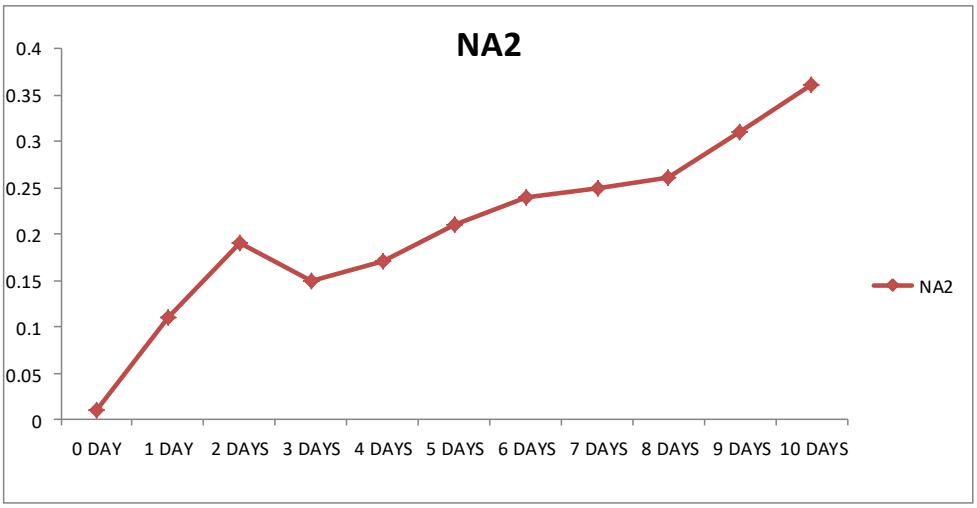

FIGURE 6: isolate NA2 MFC; Graph of voltage (mV) against time (days)

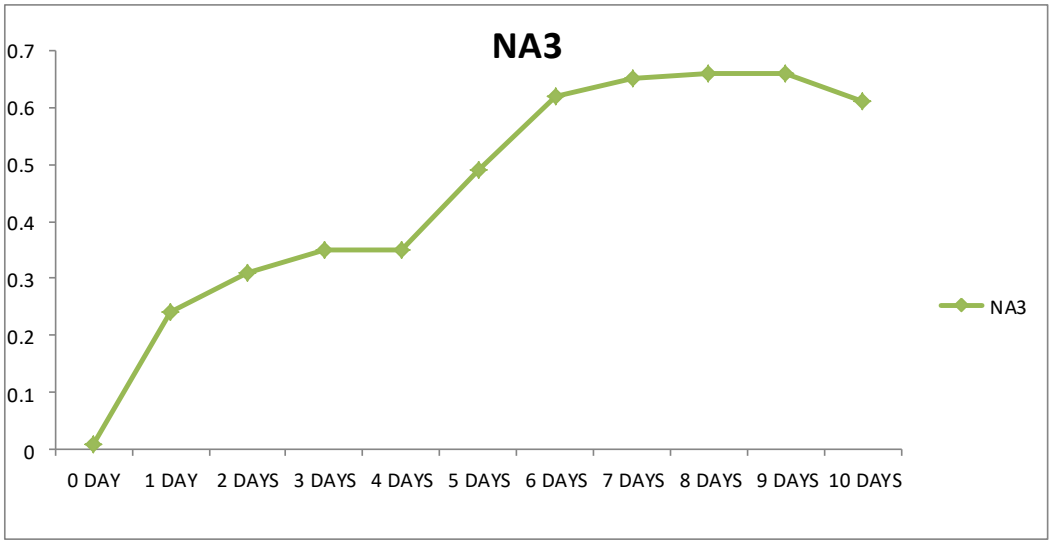

FIGURE 7: isolate NA3 MFC; Graph of voltage (mV) against time (days)

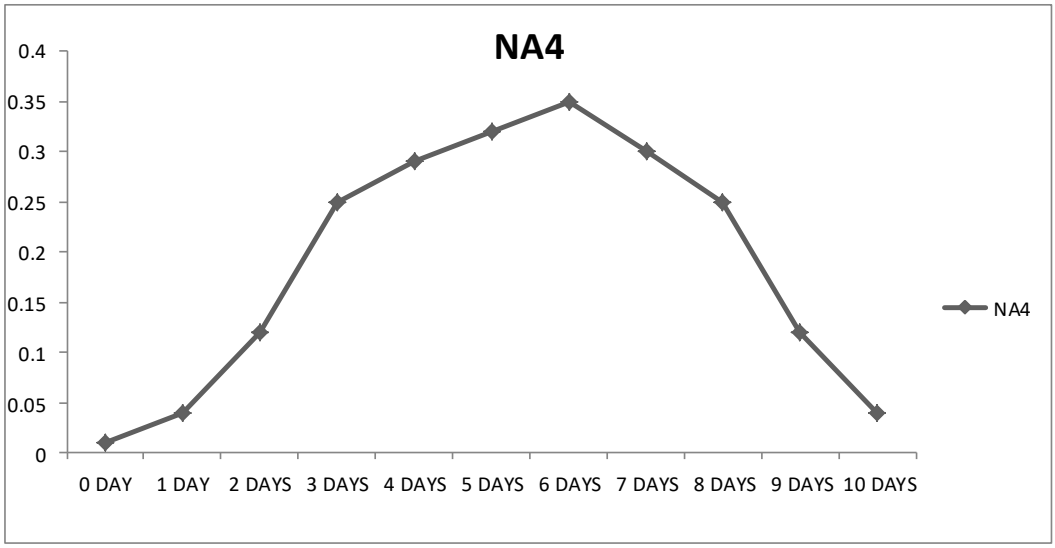

FIGURE 8: isolate NA4 MFC; Graph of voltage (mV) against time (days)

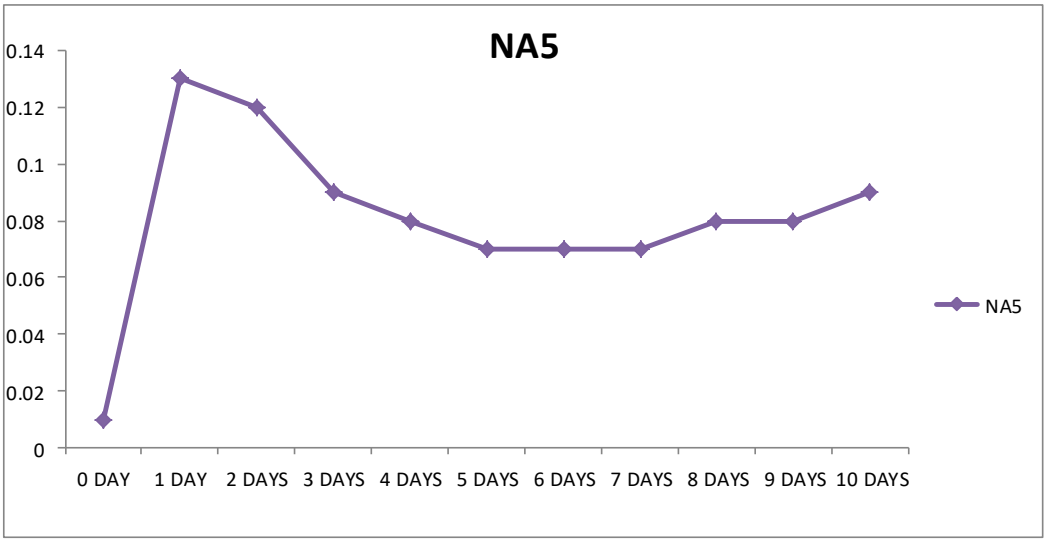

FIGURE 9: isolate NA5 MFC; Graph of voltage (mV) against time (days)

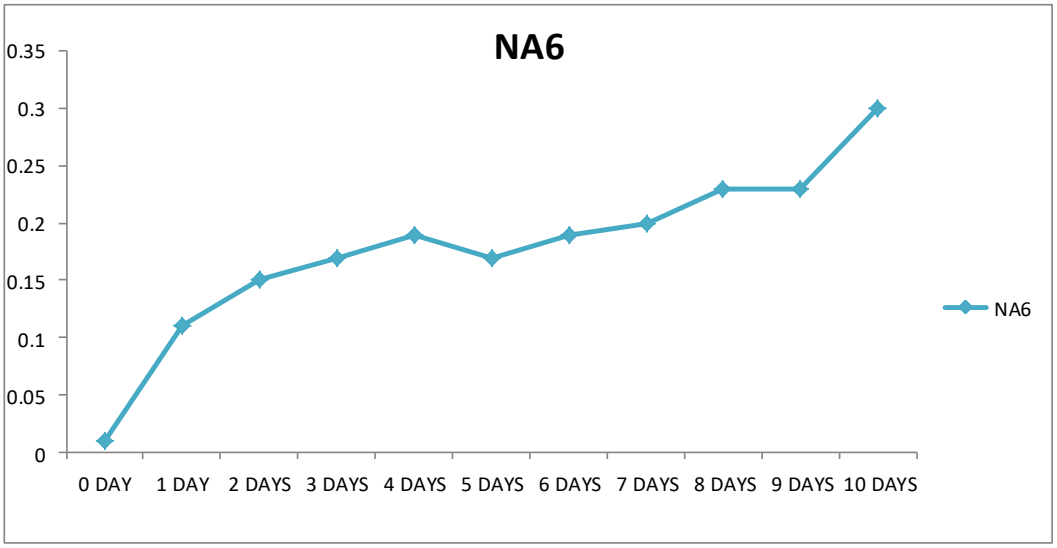

FIGURE 10: isolate NA6 MFC; Graph of voltage (mV) against time (days)

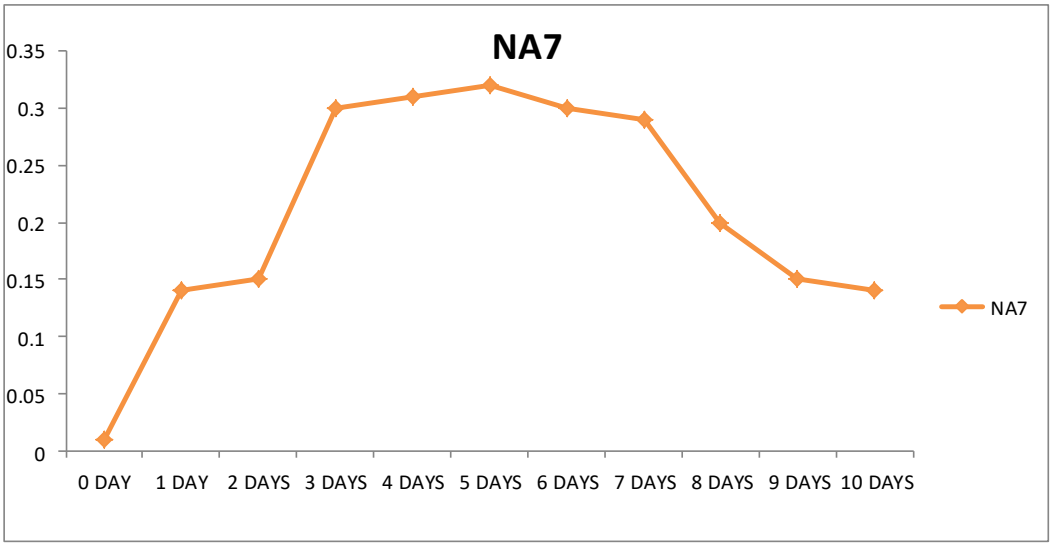

FIGURE 11: isolate NA7 MFC; Graph of voltage (mV) against time (days)

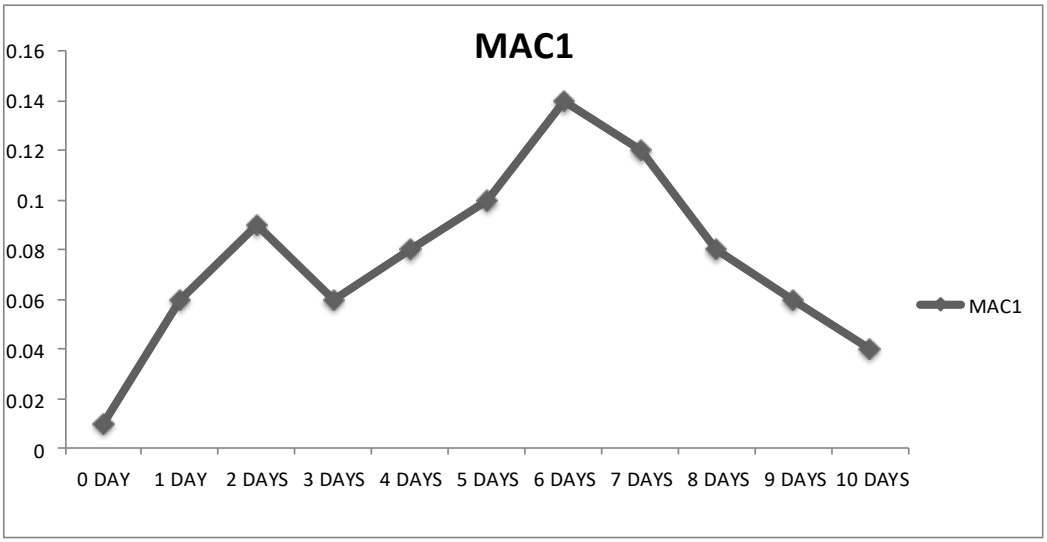

FIGURE 12: isolate MAC1 MFC; Graph of voltage (mV) against time (days)

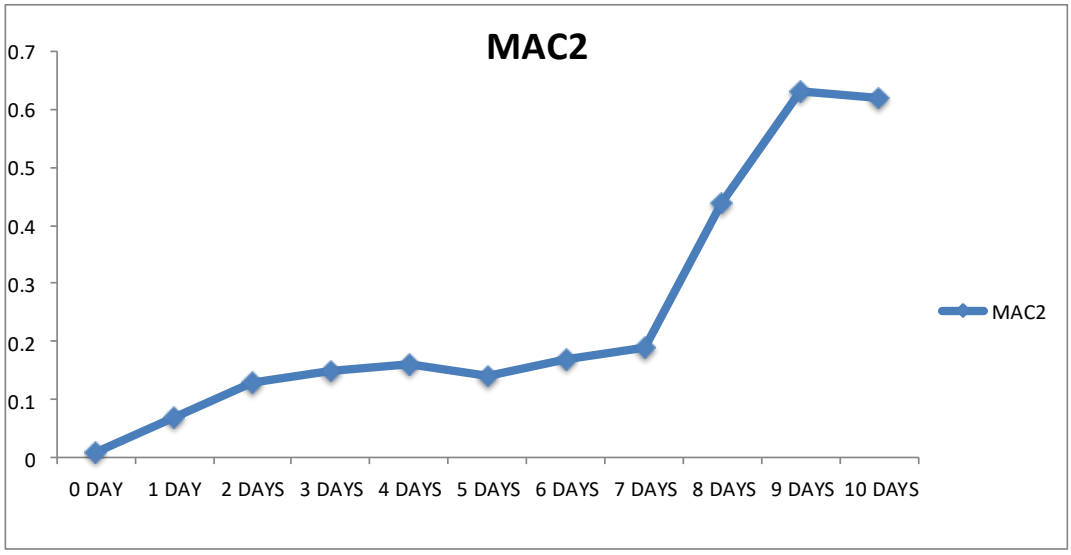

FIGURE 13: isolate MAC2 MFC; Graph of voltage (mV) against time (days)

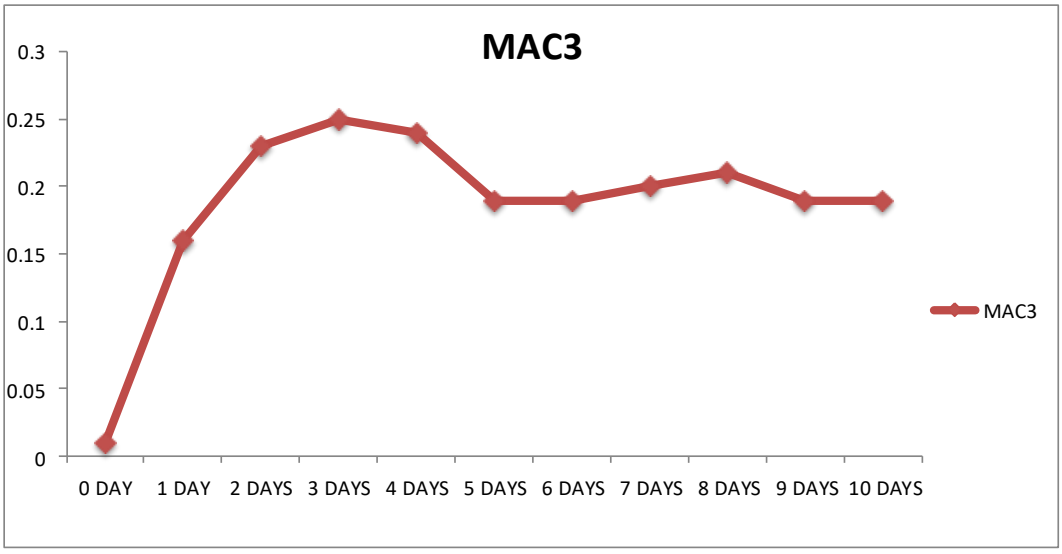

FIGURE 14: isolate MAC3 MFC; Graph of voltage (mV) against time (days)

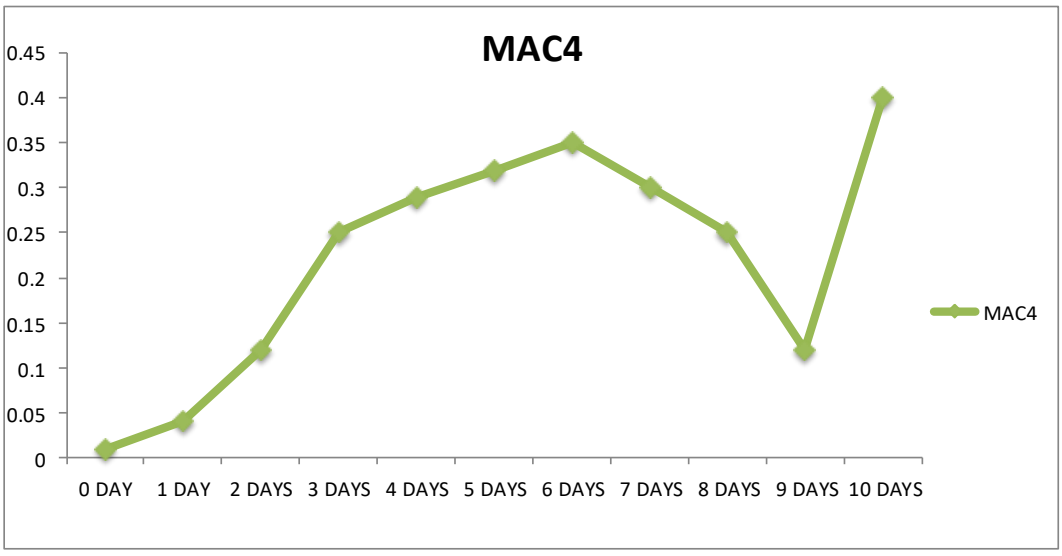

FIGURE 15: isolate MAC4 MFC; Graph of voltage (mV) against time (days)

VOLTAGE DENSITY:

Voltage density is a property of microbial fuel cell used to calculate the efficiency of the cells. It is calculated by measuring the area of the electrode used and dividing it by the voltage. It is measured in voltage per unit area.

Formular for calculating voltage density is given by:

Voltage Density = Voltage ÷ Area Of Electrode

V.D. = V/A (mVM^{-2})

WHERE:

V.D. = Voltage Density

V = Voltage Of Fuel Cell

A = Area Of Electrode (12.8648)

TABLE 5: VOLTAGE DENSITY OF FUEL CELLS BOTH MIXED CULTURE AND AXENIC CULTURES

	V.D
WWMFC1	0.038
WWMFC2	0.046
STACKED WWMFC	0.072
NA1	0.026
NA2	0.016
NA3	0.035
NA4	0.015
NA5	0.006
NA6	0.014
NA7	0.009
MAC1	0.006
MAC2	0.019
MAC3	0.014
MAC4	0.032

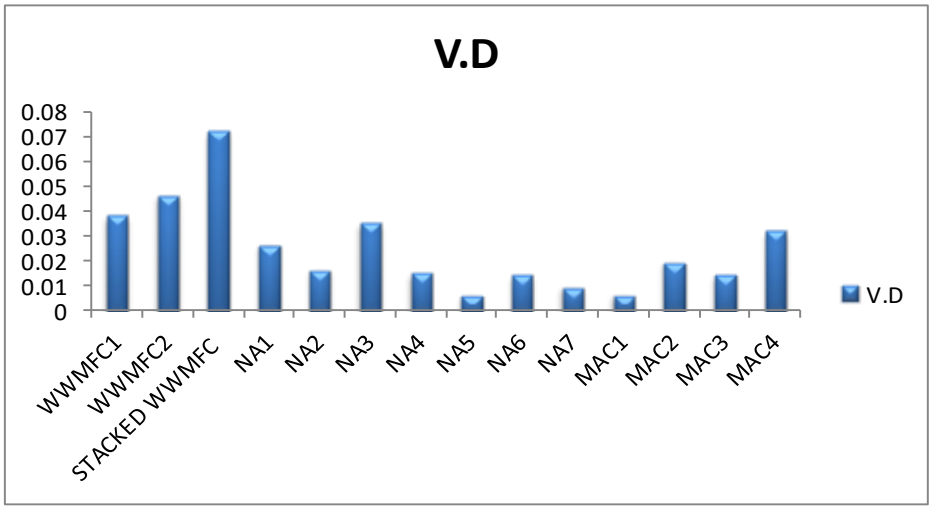

FIGURE 16: voltage densities of both the mixed and axenic cultures

4. DISCUSSION

In this rasearch, a bioelectrochemical device that is capable of producing bioelectrity by the driect act of microbes in the environment while dgrading waste was designed. This is probably the last frontier in the role of microorganisms in our environment as they will directly and/or indirectly improves the life of the hoi polloi in the society by generating electricity instead of its predominant economic importance which is to cause disease. In line with the objectives of the research project, a low cost Microbial fuel cell using readily available materials- plastic containers, PVC pipes, graphite electrodes, domestic wastewater among others which are virtually inexpensive was designed.

It has been able to generate electricity from both a consortium of microbes and from single genera isolated from the parent stock-wastewater. In the first scenario of study with Waste water microbial fuel cells (WWMFC) 1, 2 and the stacked configuration which contained various microorganisms from diverse species. After months of modelling, trials and modifications, the H-shaped system was used for the purpose of the experiment and it proved most effective and efficient due to its easy of assembly and maintenance.

Wastewater microbial fuel cell 1 (WWMFC1) after a careful 10 day observation and recording it showed a voltage of 0 volts on preparation thus conforming to the lag phase growth of a batch culture which is the time needed for microorganism in a new system to acclimatize into the new environment. The zero reading of the multimeter also signifies that the system is still in the aerobic state which is less preferred to the anaerobic condition needed for the optimum performance of the fuel cell as it displaces oxygen as the terminal electron acceptor to enable the transfer of those electrons through the anode into the cathode for oxidation; a considerable increase was observed after 24hrs of incubation from 0 to 0.05 volts and from 0.05 to 0.1volts after another 24hrs, the system showed a graceful increase as the system slowly achieved its ideal anaerobic state and consequently the complete displacement of oxygen as the terminating electron acceptor in the anode and so an increase in the density of electrons in the electrode and hence the conductance through the copper wire attached. The voltage progressively increased until about 10 days when a peak voltage of 1.1volt was realized and this was maintained for 4 more days this implies that the configuration has achieved a stationary state after which it was terminated. A total voltage of 5.5volts was observed and the mean was 0.5 volts with a voltage density of 0.039v/m^2.

After the success of WWMFC1 a second fuel cell was constructed to further confirm the results obtained from the first experiment, this system performed comparably to WWMFC1 by showing a gradual increase from 0volts preparation to 0.1 volts on the first day and to about 1.2volts by the 9^{th} and 10^{th} day after which a slow decline was observed. Its total voltage was 6.5volts, with a mean average of 0.59 and a voltage density of 0.046v/m^2.

A total of eleven (11) isolates where gotten from the process of incubating, purifying and identifying the organisms present at the anodic electrode as biofilm. These organisms belong to the following genera- *Shigella spp*, *Serrentia marcense*, *Salmonella spp*, *Bacillus spp*, *Pseudonomas aeruginosa*, *Streptococcus feacalis*, *staphylococcus aeurus*, and *Escherichia coli*. This is in accordance with Akshay *et al*, (2016) who reported *Proteus vulgaris*, *Erwinia dissolvens*, *Shewanella putrefacians*, *Pseudonomas aeruginosa* and *Escherichia coli*. These isolates where further subjected to MFC treatment using sterile peptone water as the anodic electrolyte.

NA1 which is *Shigella spp* recorded a voltage of 0.01 on preparation, 0.26volts after 24hrs and at termination after 10days, a voltage of 0.43volts was observed. *Shigella spp* also recorded a total voltage of 3.63volts and average voltage of 0.33volts and a voltage density of 0.026v/m^2

NA2 was observed to be *Serrentia marcescen* at preparation gave a voltage of 0.01 and after 24hrs the voltage rose to 0.15volts and by the 10^{th} day, a voltage of 0.36volts was observed. Its total voltage was 2.26volts, an average of 0.21volts and a voltage density of 0.016v/m^2

NA3- *Salmonella spp* showed a voltage of 0.24 after 24hrs and at the end of the 10^{th} day it rose to 0.61volts; with a grand voltage of 4.95 and a mean average of 0.45 volts, its voltage density totalled 0.035v/m^2.

NA4 which is *Shigella spp* showed a voltage of 0.01 on preparation, after 24hrs, a voltage of 0.04 was observed and at termination after 10days, a voltage of 0.04volts was observed. It also recorded a total voltage of 2.09volts and average voltage of 0.19volts and a voltage density of 0.015v/m^2

NA5 which was identified as *Bacillus spp* in the first 24hrs after setup showed a voltage of 0.13, this was fairly steady and so by the end of the 10^{th} day, its voltage dropped slightly to 0.09volts. A total voltage of 0.89 was computed and its mean voltage was 0.08 with a voltage density of 0.006v/m^2.

Pseudomonas aeruginosa was the next isolate with a voltage of 0.11 after 24hrs of preparation, and by the day 10, a voltage of 0.30 was observed, a total of 1.95 volts and a mean of 0.19 volts was computed; its voltage density was 0.014v/m^2.

Streptococcus feacalis was also subjected to the same treatment and the following results were obtained: 0.14volts was observed after 24hrs, an increase to 0.32 volts was recorded by the 5^{th} day after which the voltage fell back to 0.14 on the 10^{th} day. A total of 2.31 volts was calculated with a mean average of 0.21 volts and its density was 0.009v/m^2

Finally, the result for Escherichia coli was gotten as 0.04volts after 24hrs, and by the 10th day, a voltage of 0.4volts was recorded. Its mean total was 2.45 volts with a mean of 0.41 volts and a voltage density of 0.032v/m^2.

By means of a series connection, a configuration known as the stacked microbial fuel cell was constructed. My stacked system consisted of 7 single domestic waste water fuel cells connected in series. The result of this system is thus; after 24hrs a voltage of 0.4 volts was obtained and this increased over a 10 day period to 3.5volts. a total of 17.42volts was recorded with an average voltage of 1.5volts and its voltage density was 0.072v/m^2.

Voltage density (V.D.) is a property used to measure the efficiency of the fuel cell. It is the defined as the voltage passing through a unit area (m^2) of an electrode. This property was used in the study to compare the production of electricity between the consortium and the axenic systems. And after computation of the various V.Ds, it was observed that none of the single bacterial species could match up to the voltage density of the consortium. The voltage density of the wastewater MFCs was calculated as 0.038 and 0.046v/m^2 for WWMFC 1 and 2 respectively, while the highest voltage density for the axenic cultures *Salmonella spp*, stood at 0.035 making it the bacteria of choice in an axenic culture. *Escherichia coli* had a V.D of 0.032 and a *Bacillus spp* microbial fuel cell had the least voltage density of 0.006v/m^2.

5. CONCLUSION

Microbial fuel cells are evolving to become a simpler and more robust technology. However, to increase the power output towards a stable 1kW per m^3 of electric power in a scaled up reactor, many technological improvements are needed. Provided the biological understanding increases, the electrochemical technology advances and the overall electrode prices decrease, this technology could serve as a new core technology for conversion of waste to electricity in the future.

REFERENCES

[1] Akshay,D., Namrata, S., & Jabez., O. (2016). Microbial fuel cells in bioelectricity production. Journal of Frontiers in Life Science, 9(4):252-266

[2] Allen, R.&Bennetto, H. (2004). "Microbial fuel cells, Electricity production from carbohydrates". *Applied Biochemistry and Biotechnology*. 39, 27–40.

[3] Alteman, P.,Rabaey, K., Pham, H., Boon N. &Verstraete, W. (2006) Continuous electricity generation at high voltages and currents using stacked microbial fuel cells, *Environmental Science and Technol*ogy40, 3388-3394.

[4] Bond D. R. & Lovley,D. (2003)Electricity production by *Geobactersulfureducens* attached to electrodes, *AppliedEnvironmental Microbiology*, 69, 1548–1555.

[5] Chen, T., Barton, S.C., Binyamin, G.,Gao, Z., Zhang, Y., Kim, H. & Heller, A. (Sep 2001). "A miniature biofuel cell.".*Journal of American Chemical Society*123 (35), 8630–1.

[6] Cheng S., Liu H. & Logan, B. E. (2006) Increased power generation in a continuous flow MFC with advective flow through the porous anode and reduced electrode spacing. *Environmental Science & Technology*, 40, 2426-2432.

[7] Cheng, K.Y.,Ho, G & Cord-Ruwisch, R. (2006)"Affinity of microbial fuel cell biofilm for the anodic potential.".*Environmental Science & Technology*42 (10), 3828–34.

[8] Choi, Y., Jung, S. & Kim, S. (2000) Development of Microbial Fuel Cells *Using Proteus Vulgaris.Bulletin of the Korean Chemical Society*, 21 (1), 44–48

[9] Cho, Y.K., Donohue, T.J.,Tejedor, I., Anderson, M.A., McMahon, K.D. &Noguera, D.R., (2008) Development of a solar-powered microbial fuel cell. *Journal on Applied Microbiology*. 104, 640–650.

[10] Clauwaert P., Vander H. D. & Boon, N. (2007) Open air biocathode enables effective electricity generation with microbial fuel cells, *Environmental Science and Technology*, 41, 7564–7569.

[11] Cohen, B. (1931). The Bacterial Culture as an Electrical Half-Cell, *Journal of Bacteriology*, 21, 18–19

[12] Davis F. &Higson S. (2007). Biofuel cells-recent advances and applications, *Biosensor and Bioelectron*, 22, 1224–1235

[13] Delaney, G. M.,Bennetto, H. P., Mason, J. R., Roller, S. D., Stirling, J. L. & Thurston, C. F. (2008)."Electron-transfer coupling in microbial fuel cells. 2. Performance of fuel cells containing selected microorganism-mediator-substrate combinations". *Journal of Chemical Technology and Biotechnology.Biotechnology*34, 13.

[14] He Z.,Minteer S. D. &Angenent, L. (2005) Electricity generation from artificial wastewater using an upflow microbial fuel cell, *Environmental Science and Technology*.39, 52-54

[15] Ieropoulos I. A.,Greenman J.,Melhuish C & Hart J. (2006). Comparative study of three types of microbial fuel cell, *Enzyme and Microbiological Technology*,37,238–245

[16] Kim I. S.,Chae K. J., Choi M. J. &Verstraete, W.(2008)Microbial fuel cells, recent advances, bacterial communities and application beyond electricity generation. *Environmental Engineering Res*ource13(2), 51–65.

[17] Lie H., Cheng S. & Logan, B. E. (2005)Production of electricity from acetate or butyrate using a single chamber microbial fuel cell, *Environmental Science and Technol*ogy 39, 658–662.

[18] Logan, B. (2006). Graphite fiber brush anodes for increased power production in air-cathode microbial fuel cells, *Environmental Science and Technology*41, 3341– 3346.

[19] Lovley D. R. (2003). Dissimilatory metal reduction, *AnnualReview on Microbiology*, 47, 263–290.

[20] Min B., Kim J. R., Oh S. E., Regan, J. M. & Logan, B. E. (2005) Electricity generation from swine wastewater using microbial fuel cells, *Water Research*, 39, 4961–4968.

[21] Moon H., Chang I. S. & Kim B. H. (2006) Continuous electricity production from artificial wastewater using a mediator-less microbial fuel cell, *Bioresource Technology*97, 621–627.

[22] Niessen J., Schroder U. &Scholz, F. (2004) Exploiting complex carbohydrates for microbial electricity generation—a bacterial fuel cell operating on starch, *Electrochemical Communiqué*, **6**, 955–958.

[23] Park D. H. &Zeikus J. (2000) Electricity generation in microbial fuel cells using neutral red as an electronophore, *Applied Environmental Microb*iology 66,1292–1297.

[24] Potter M. C. (2003) Electrical effects accompanying the decomposition of organic compounds, *Proceedings of the Royal Societyof London.*84,260–276.

[25] Rabaey, K. &Verstraete, W. (2003) Microbial fuel cells, novel biotechnology for energy generation, *Trends in Biotechnology*, 23,291–298.

[26] Rabaey K., Boon N., Ho¨ M. &Verstraete, W. (2005)Microbialphenazine production enhances electron transfer in biofuel cells, *Environmental Science and Technol*ogy 39, 3401–3408.

[27] Ringeisen B. R., Henderson E., Wu P. K.,Pietron J., Ray R. & Little, B (2006) High power density from a miniature microbial fuel cell using *Shewanellaoneidensis DSP10*, *Environmental Science and Technology*, 40, 2629-2634.

[28] Rosenbaum, M.,Schröder, U. &Scholz, F., (2006) Utilizing the green alga *Chlamydomonas reinhardtii* for microbial electricity generation, a living solar cell.*Applied Microbiology and Biotechnology* 32, 753–756.

[29] Tender L., Gray S.,Groveman E., Lowy D.,Kauffma P.,Melhado R.,Tyce R., Flynn D.,Petrecca R.&Dobarro, J. (2008) The first demonstration of a microbial fuel cell as a viable power supply, Powering a meteorological buoy, *Journal on Power Source*, 179, 571–575.