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CONSTRUCTION OF SEDIMENT BATTERY FROM RIVER MUD

O.D Ngerebara* and O.O Obande+

*Institute of Geosciences and Space Technology (IGST), Rivers State University of Science and Technology, Nkpolu-Oroworukwu, Port Harcourt, Rivers State, Nigeria.
e-mail: n_dago@yahoo.com

+MISWACO NIG. LTD, Plot 601, Westminster house, Adeola Hopewell, Victoria Island, Lagos, Nigeria.
e-mail:oorinya@slb.com

Corresponding Author- **O.D Ngerebara,** e-mail: n_dago@yahoo.com

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ABSTRACT

The construction of sediment battery from river mud for generation of electricity was done in response to the current challenge of energy production and supply due to the depletion of fossil fuel. River sediments were collected from three different points: Otamiri river at Isu Etche(E-510627.84; N-131566.60), Odugwu Etche(E-520087.04; N-113278.48) and Imo river at Umuebulu (E-521113.64; N-112436.74). Sediment textural analysis, physico-chemical analysis, total hydrocarbon content and microbial analyses were done for both rainy and dry seasons. The results showed the presence of various microorganisms in both seasons but with higher population in the rainy season. A laboratory scale sediment microbial fuel cells (SMFCs) construction were done in three 250 ml glass bottles labeled Otamiri Isu sediment, Otamiri Odugwu sediment and Imo rivers (Umuebulu) sediment respectively. SMFC was made of a non-corrodible anode (carbon) buried in anoxic sediments layer and connected via an electrical circuit to a cathode installed in surface water in the bottles. The voltage and current were measured on a daily basis for 14 days. The highest voltage of 0.93mV was recorded in sediment battery from Isu Otamiri river on day 12 with corresponding current value of $0.024mA/cm^2$, 0.83mV from Odugwu on the 10^{th} day with corresponding current value of $0.022mA/cm^2$ and 0.76mV from Umuebulu on the 9^{th} day with corresponding current value of $0.019mA/cm^2$ Anode surface areas were found to greatly influence both current and power density.

1. INTRODUCTION

Energy production and supply are presently facing challenges due to the depletion of fossil fuel. Emission of global warming gases such as CO_2 due to combustion of fossil fuels is more of concern. Concern about climate changes and increase in demand of energy resources are driving to search for alternative energy for fossil fuels [1].

Microbial energy technologies that employ microbes for the conversion of chemical energy in forms of fuels (biogas, bioethanol, biohydrogen) or directly to electricity by oxidation of organic substances are among the alternatives to fossil fuels. Microbial energy conversion in Microbial Fuel Cell (MFC), a bioreactor in which bacteria transforms chemical energy in biomass directly to electricity is a promising technology for renewable energy production [2,3,4].

It was reported that the distribution and abundance of the ecology of *Neritina* in the Lagos Lagoon were dependent on the silt content; total organic matter and contamination of sediment [5].The report also showed a wide variety of sediments ranging from fine, medium and coarse sands to admixture of silt and clay which provide wide selection of habitats. The abundance of *Capitella capitala*, *Nereis* sp. and *Polydora* sp. in polluted areas of Lagos Lagoon was also reported.

Sediment Microbial Fuel Cell (SMFC), is an electrochemical device that utilizes the potential developed by microbial oxidation of organic substances at anode for the generation of electricity [6,7,8]. Harnessing microbial power generation in seafloor consist of a graphite electrode (anode) embedded in sea sediment and other graphite electrode (cathode) overlaying in seawater can produce maximum power of 26.7 mW/m^2 (at 0.8V) with surface area of graphite electrode of 48.3 cm^2. Voltage gradient developed by the sediment microbes are utilized by the fuel cells by connecting anode and cathode by an external load (resistance) capable of dissipating power at constant voltage (figure 1).

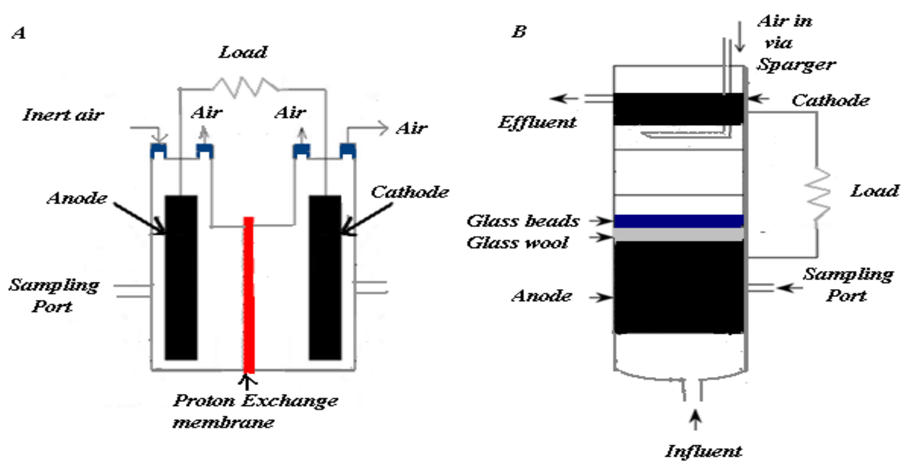


Figure 1.A: Simple design of Double Chambered Microbial Fuel Cell. Figure 1.B: Schematic Designs of Cylindrical Membrane-less fuel Cells [9]**.**

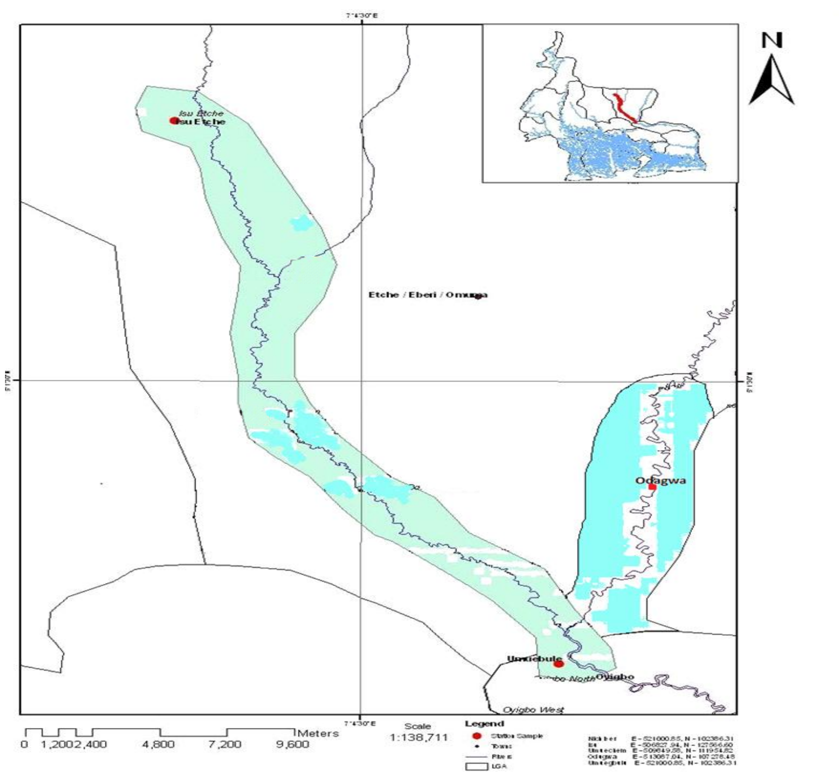
Microbes at anode in anoxic conditions donates electrons (e-) to the electrode, whereas the protons (H+) are permeable through the sea sediment-water interface which acts as natural membrane instead of semi permeable membrane for power generation.

The one in use for this study are electricigens in the family *Geobacteraceae* which are metal reducing bacteria *(MRB)* [6,2]. The present investigation is to develop SMFC for the bioelectricity production, utilizing sediment interface without membrane and these are environmental friendly, with zero-carbon emission which can be applicable to small and large scale processes.

2. THE STUDY AREA

Imo River is one of the major rivers in the southern part of Nigeria. It originates in the vicinity of Okigwe (in Imo State), and takes a southerly course until it is joined by the Otamiri River which rises from the neighborhood of Owerri. It then proceeds eastward strongly meandering close to Akwete from where it moves towards the Imo tidal basin as a smooth straight river. It is considered as part of Niger Delta basin. It is a deep freshwater river which cuts across several states such as Imo State, Abia State and Rivers State. The river flows through coastal plain, alluvium and mangrove swamp and empties into the Atlantic Ocean through the Opobo creek at the Bight of Benin.

The study area lies in the middle reaches of Otamiri/Imo River which occupies between longitudes 507385.00 E and 519954.39 E and latitudes 125256.00 N and 9996106 N. The dimension of the study area is approximately 94665.46 km^2 as shown in the map in figure 2. The two major tributaries, Otamiri and Aba River, drain into the river and play a major role in the hydrology of the Imo River



3. MATERIALS AND METHOD

3.1 Materials

The implementation of this research involves the following materials:

Two Graphite electrodes, Insulated electrical wire, Electrically Conductive epoxy, Non-electrically conductive epoxy, Resistor (100 – 1000 Ohm), Multimeter or voltmeter, Wire cutters, wire strippers, plastic bucket, mud, and water.

3.2 Methods

3.2.1 Sediment Collection

To assemble sediment MFCs in the laboratory, both anoxic freshwater sediments and surface water samples were collected from three different freshwater environments. The collections were performed in 20 litter sterilized air tight plastic containers. Sediments were collected an-aerobically by immersing the can to the depth of 5cm from the surface of the sea bed. One sample was collected from a tributary entering Imo river, the Otamiri river at Isu Etche (E-510627.84; N-131566.60) hereinafter referred to as Otamiri Isu sediment, another sample was collected from another tributary of Imo river at Odugwu Etche (E-520087.04; N-113278.48) hereinafter referred to as Otamiri Odugwu sediment, the other sample was collected at Imo river at Umuebulu (E-521113.64; N-112436.74) hereinafter referred to as Imo river sediment. Also, the surface water samples were collected from each of the three sites. The collected samples were immediately transferred to laboratory for simulation.

3.2.2 Analysis of Parameters

Sediment particle size, including bulk density and porosity, Physical and Chemical Parameters involving pH, conductivity, nitrates, sulphates and phosphates were analyzed. Also, total organic carbon content and total hydrocarbon contents were determined.

The presence of various microorganisms ((Total heterotrophic bacterial count (THBC), Total fugal counts (TFC), Total hydrocarbon utilizing bacteria counts (THUBC), Total hydrocarbon utilizing fungal counts (THUFC), Total coliform counts (TCC), Total salmonella-shigella counts (TSSC), and Total vibrio counts (TVC)) in the sediments from the three sample stations were determined with the nutrient agar using the spread plate techniques [10] and incubated for 24 hours and 5-10 days (for the case of THUBC and THUFC) at 37^{0}C and the mean determined.

3.2.5 Sediment Battery Construction

A laboratory scale SMFCs construction was done in three 250 ml glass bottles labeled Otamiri Isu sediment, Otamiri Odugwu sediment and Imo rivers sediment respectively, following the working scheme of laboratory scale of the SMFC in figures 3 and 4. A fourth bottle was also used to demonstrate a working scheme of the laboratory scale of the SMFC. Each bottle was filled up to 7-8 cm with river sediment mud of Otamiri Isu River, Odugwa River sediment mud, and Imo River sediment mud. A carbon electrode (anode) was buried in each of the sediment mud for the hosting of anaerobic biofilm on its surface. For current flow an insulated copper wire was connected with this electrode in each of the sample. Water from the sediment mud (from the same body of water) was collected carefully and poured over the mud and anode to ensure that the anode is not uncovered or the mud disturbed very much. The particles were allowed to settle overnight. The same was done for the other samples. In the same way the second carbon electrode (cathode) was suspended in water for hosting of aerobic biofilm. Insulated wires were glued to the carbon electrodes using conductive epoxy. During investigation, the whole apparatus were kept in room temperature and conditions. Voltages on anode and cathode terminals were recorded manually with Multi-Tester (Model: Samwa YX-360, China) on daily basis for 14 days. The experiment was performed in triplicate. For voltage parameter variations, standard deviation and average was calculated. Resultant data were presented graphically.

Figure 3: Working scheme of the laboratory scale of the SMFC

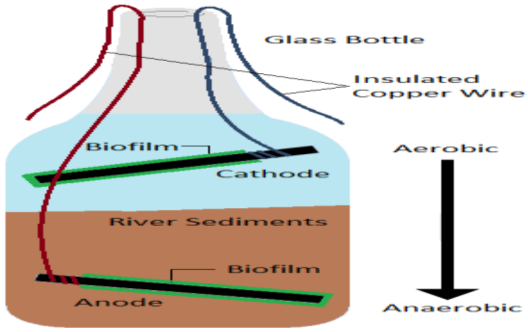


Figure 4: Working scheme of the laboratory scale of the SMFC

4. RESULTS

4.1 Sediment particle size

The variations in the sediment texture observed at the three different stations may be attributed to the fact that Otamiri Isu and Odugwu are tributaries of Imo River and are some distances apart which may suggest difference in their parent materials [11].

The results of soil porosity, bulk density, particle density and the percentage composition of sand, silt, and clay, of the samples from Otamiri/Imo River are presented in Table 1.

Table 1: Sediment Particle Size Analysis

Parameters	Sampling Points		
	Isu	**Odugwu**	**Imo river**
Sand(%)	80.24	83.82	90.64
Silt (%)	10.17	7.48	2.42
Clay (%)	15.72	6.96	7.00
Porosity (%)	63.24	79.34	75.22
Bulk Density(g/cm3)	2.43	3.01	3.22
Particle Density (g/cm3)	5.00	2.70	2.59
Textural Class	Loamy sand	sand	sand

Source: Field Survey 2010

4.2 Sediment physico-chemical parameters

The results of the Physical and chemical parameters in terms of pH, conductivity, organic carbon, nitrate, phosphate, sulphate and total hydrocarbon content of Otamiri/Imo River sediments are as shown in Table 2.

Table 2: Physco-chemical Parameters of the Sediments

Parameters	Sampling Points		
	Isu	**Odugwu**	**Imo river**
pH	5.24	5.12	5.03
Conductivity (μS/cm)	43	50	73.4
Organic Carbon (%)	5.463	3.046	2.943
Nitrate (mg/kg)	4.4	3.3	5.9
Phosphate(mg/kg)	15.2	9.43	17.0
Sulphate (mg/kg)	33.4	25.4	28.7
THC (mg/kg)	27.3	31.4	50.4

Source: Field Survey 2010

4.3 Microbiological Analysis

The presence and population of various microorganisms (Total heterotrophic bacterial count (THBC), Total fugal counts (TFC), Total hydrocarbon utilizing bacteria counts (THUBC), Total hydrocarbon utilizing fungal counts (THUFC), Total coliform counts (TCC), Total salmonella-shigella counts (TSSC), and Total vibrio counts (TVC)) in the sediments from the three sample stations for both rainy and dry seasons are showed in Tables 4.3 and 4.4.

Table 4.3: Microbial Counts of Sediment Samples at Rainy Season

Stations	THBC	TFC	THUBC	THUF	TCC	TSSC	TVC
Isu	4.6 x 10^6	6.7 x 10^5	4.2 x 10^5	3.0 x 10^5	2.5 x 10^6	7.6 x 10^5	4.0 x 10^5
Odugwa	2.8 x 10^6	6.0 x 10^5	3.7 x 10^5	2.5 x 10^5	2.0 x 10^6	7.8 x 10^5	3.5 x 10^5
Umubulu	2.0 x 10^6	4.0 x 10^5	4.0 x 10^5	1.6 x 10^5	1.6 x 10^6	4.0 x 10^5	2.0 x 10^5

Source: Field Survey 2010

Table 4.4: Microbial Counts of Sediment Samples at Dry Season

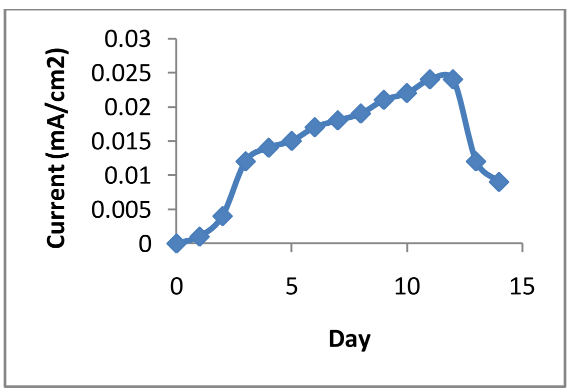
Stations	THBC	TFC	THUB	THUF	TCC	TSSC	TVC
Isu	4.0 x 10^6	3.5 x 10^5	2.0 x 10^5	1.4 x 10^5	1.3 x 10^6	2.8 x 10^5	3.8 x 10^5
Odugwa	2.5 x 10^6	3.0 x 10^5	1.2 x 10^5	1.0 x 10^5	0.8 x 10^6	1.4 x 10^5	1.6 x 10^5
Umubulu	2.0 x 10^6	2.0 x 10^5	1.0 x 10^5	0.7 x 10^5	0.6 x 10^6	1.0 x 10^5	1.0 x 10^5

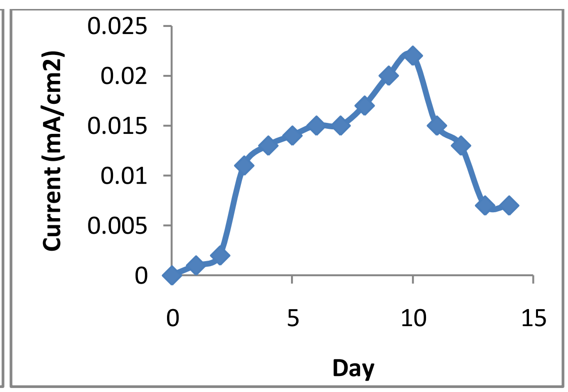
Source: Field Survey 2010

5. DISCUSSION

The analysis of the field and laboratory work done in course of this research work culminated in the construction of sediment battery from sediment mud taken from Imo river/Otamiri river for bio-electricity generation.

The results of current generation from the sediment of Otamiri River at Isu showed a good amount of generation. The current production was increasing on daily basis until the 11th and 12th day when optimal production of 0.024 (mA/cm^2) was recorded. The current density and power density at optimal electricity production were 3129.09 (mA/cm^2) x10^{-6} and 2910.04 (mw/cm^2) x10^{-6} respectively while Odugwu got to optimal on the 10th day after which the current generation started declining. The optimal current production was 0.022 (mA/cm^2). The current density and power density at optimal electricity production were 3384.62 (mA/cm^2) x10^{-6} and 2809.23 (mw/cm^2) x10^{-6} respectively. Then at Umuebulu it got to the optimal on the 8th and 9th days after which declining started. The optimal current production was 0.019 (mA/cm^2). The current density and power density at optimal electricity production were 3653.85 (mA/cm^2) x10^{-6} and 2776.92 (mw/cm^2) x10^{-6} respectively (figures 5a, b & c, and tables 3, 4 & 5 of the appendix).





Figures 5a & 5b: Current generated from Otamiri River Sediment at Isu and Odugwu

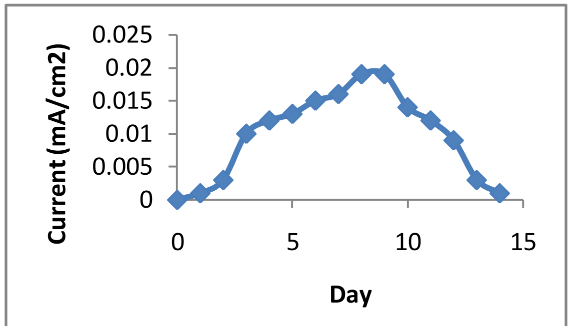


Figure 5c: Current generated from Imo river sediment at Umubulu

6. CONCLUSION

Concrete evidence has been shown that sediments from Otamiri river at Isu, Odugwu and Imo River at Umuebulu can be effectively used for SMFCs. Current and voltage production from the three different sampling points followed the same trend because they have same microorganism. But their production rate differs because microorganism population count differs from one sampling point to another. Sediment battery from Isu generated the highest voltage of 0.93mV, Odugwu 0.83mV and Umuebulu 0.76mV. Odugwu recorded the highest current density of 3384.62mA/cm^2 x10^{-6} and power density of 2809.23mW/cm^2 x10^{-6}. This may be due to surface area differential that influence both current and power densities. The observed decline in the electricity production after optimal time was attributed to depletion of carbon source at the region of anode electrode. Low current and power density recorded after optimal time might be due to the power bacteria colonization which simultaneously affected the electron transfer to the electrode. Improved bacteria colonization (monolayer development of microbes over the anode electrode) could increase the power and current with respect to the surface areas.

Populations of microorganism were more in the rainy season in the three sampling points than in the dry season. This may be due to contamination from overland runoff into the rivers which increases the population of organic matters in the rivers during the rainy season.

APPENDIX

Table 3: Electricity Generation from Otamiri River Isu (anode surface area = 7.67cm^2)

Day	Voltage (mv)	Current (mA/cm^2)	Power (mw/cm^2)	Current Density(mA/cm^2)x10^{-6}	Power Density (mw/cm^2)x10^{-6}
0	0	0	0	0	0
1	0.04	0.001	0.00004	1.3038	5.215
2	0.17	0.004	0.00068	521.51	88.657
3	0.26	0.012	0.00312	1564.54	406.68
4	0.33	0.014	0.00462	1825.29	602.35
5	0.46	0.015	0.00690	1955.67	899.61
6	0.56	0.017	0.00952	2216.81	1241.20
7	0.63	0.018	0.01134	2346.81	1478.49
8	0.78	0.019	0.01482	2447.72	1932.20
9	0.83	0.021	0.01743	2737.94	2272.49
10	0.88	0.022	0.01936	2868.32	2524.12
11	0.93	0.024	0.02232	3129.09	2910.04
12	0.92	0.024	0.02208	3129.09	2878.75
13	0.69	0.012	0.00828	1564.54	1079.53
14	0.52	0.009	0.00468	1173.40	610.17

Table 4: Electricity Generation from Otamiri River Odugwu (anode surface area=6.5cm^2)

Day	Voltage (mv)	Current (mA/cm^2)	Power (mw/cm^2)	Current Density(mA/cm^2)x10^{-6}	Power Density (mw/cm^2)x10^{-6}
0	0	0	0	0	0
1	0.05	0.001	0.00005	153.85	7.69
2	0.13	0.002	0.00026	307.69	40.00
3	0.20	0.011	0.0024	169.23	369.23
4	0.30	0.013	0.0039	2000.00	600.00
5	0.42	0.014	0.00588	2153.85	904.62
6	0.53	0.015	0.00795	2307.69	1223.08
7	0.67	0.015	0.01005	2461.54	1649.23
8	0.74	0.017	0.01258	2615.38	1935.38
9	0.82	0.020	0.01640	3076.92	2523.08
10	0.83	0.022	0.01826	3384.62	2809.23
11	0.77	0.015	0.01155	2307.69	1776.92
12	0.64	0.013	0.00832	2000.00	1280.00
13	0.38	0.007	0.00266	1076.92	409.23
14	0.29	0.007	0.00266	1076.92	409.23

Table 5: Electricity Generation from Imo River Umubulu (anode surface area=5.2cm^2)

Day	Voltage (mv)	Current (mA/cm^2)	Power (mw/cm^2)	Current Density(mA/cm^2)x10^{-6}	Power Density (mw/cm^2)x10^{-6}
0	0	0	0	0	0
1	0.07	0.001	0.00007	192.31	13.46
2	0.16	0.003	0.00048	576.92	9.23
3	0.24	0.010	0.00240	1923.08	461.54
4	0.32	0.012	0.00384	2307.69	738.46
5	0.46	0.013	0.00598	2500.00	1150.00
6	0.51	0.015	0.00765	2884.62	1471.15
7	0.62	0.016	0.00992	3076.92	1907.69
8	0.76	0.019	0.01444	3653.85	2776.92
9	0.76	0.019	0.01444	3653.85	2776.92
10	0.69	0.014	0.00966	3269.23	1857.69
11	0.60	0.012	0.00720	2307.69	1384.62
12	0.43	0.009	0.00387	1730.77	744.23
13	0.34	0.003	0.00102	576,92	196.15
14	0.28	0.001	0.00028	192.31	53.85

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