Bioelectricity from Microbial Fuel Cell Using Wastewater with Carbon/Copper Electrodes

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Abstract

Three dual chamber microbial fuel cells (MFCs) labeled MFC-A, MFC-B and MFC-C were fabricated with agar-agar salt bridge as the proton exchange membrane. Each of the MFCs contained wastewater as catholyte. Biochemical and Physiological tests was carried out on the wastewater sample to obtain characteristics which will be helpful in the identification of microbial species in the sample and measure some physiological parameters. Readings of voltage and current with different resistors of 10Ω, 100Ω and 1000Ω and with no resistor was taken for 10 to 12 hours daily for 14 days.

The power density was calculated for the MFCs. Also, the MFC performance was calculated in terms of various parameters such as Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS), pH, Conductivity and Temperature. MFCs A, B and C showed a maximum voltage output of 0.987V, 1.621V and 1.409V respectively. The maximum power densities for MFCs A, B and C were calculated as 0.329W/cm^2, 2.56 x 10^{-5}W/cm^2 and 0.00197W/cm^2 respectively. The BOD removal efficiency of MFCs A, B and C was calculated as 71.70%, 73.35% and 72.00% respectively.

Keywords: Microbial fuel cell; Biological oxygen demand (BOD) removal efficiency; Potassium permanganate.

1. Introduction

A microbial fuel cell (MFC) is a device that converts the energy stored in chemical bonds in organic compounds to electrical energy achieved through the catalytic reactions by microorganisms. The challenges facing electricity supply in Nigeria has been enormous right from the days of ECN (Electric Corporation of Nigeria) to NEPA (Nigeria Electric Power Authority), PHCN (Power Holding Company of Nigeria) and finally the various distribution companies. During the days of ECN, electric supply depended mainly on coal, and there was adequate supply of this. With surplus income from Petro-naira in the early 70s, new hydro power plants were built to the neglect of the coal fired power plants.

During the era of NEPA, the source of generation was hydropower. One of the major disadvantages of depending mainly on hydro power generation is the issue of seasonal rainfall that affects the volume of water available in the dams. As NEPA became extinct, efforts were made to rapidly develop gas fire power plants which are in vogue all over the world and which has its own advantages considering the fact that Nigeria has abundance of natural gas.

The various national integrated power projects (NIPP) which became pronounced from 2005, under former president Olusegun Obasanjo, came ostensibly to boost the power supply through public-private initiatives in designated areas in Nigeria. With the privatization of power generation and distribution and with the government largely retaining the transmission infrastructure, Nigerians have been expecting a tremendous improvement in availability of power for both domestic and industrial consumption.

Though the expectation has not yet been met in this regard. The ever-increasing demand and insufficient supply of energy in Nigeria has become a great developmental challenge to her. This situation has become critical, with

increasing population not balanced by an adequate energy development program. The incessant power generation failure has grossly affected the economy, seriously slowing down development in rural and sub rural settlements, with present energy policy mainly benefiting urban dwellers. Globally, energy projections stipulate that between 2002-2025, global energy needs may rise by over 34%, with that of developing nations doubling this percentage. A robust solution must be found to end the nation's energy crisis.

These can form the basis for alternative energy sources to solve the nation's energy crisis. Microbial fuel cells (MFCs) have been proposed as a promising technology for the generation of energy from oxidation of organic matter using exoelectrogenic bacteria [8]. The idea of using microorganisms as catalysts in fuel cells was explored from the 1970s [14] and microbial fuel cells treating domestic waste water were presented in 1991 [6]. Bacteria are used as catalyst in microbial fuel cells use to oxidize organic and inorganic matter and generate current [3] [13] [12]. Recent studies have reported that oil and other fossil fuels will not be available in the next 100 years and it is expected that the demand for oil will exceed the production [2].

One estimate of population growth, coupled with economic growth at current levels puts a global demand of 41TW in 2050 at current energy growth rates. However, considering anticipated energy trends, a more reasonable projection is 27TW by 2050 and 43TW by 2100 [10]. By 2100 it is estimated that CO_2 concentration will reach anywhere from 560ppm to 970ppm [2].

MFCs have operational and functional advantages over the technologies currently used for generating energy from organic matter. First, the direct conversion of substrate energy to electricity enables high conversion efficiency. Second, MFCs operate efficiently at ambient, and even at low, temperatures distinguishing them from all current bio-energy processes.

Third, an MFC does not require gas treatment because the off-gases of MFCs are enriched in carbon dioxide and normally have no useful energy content. Fourth, MFCs do not need energy input for aeration provided the cathode is passively aerated [7].

Fifth, MFCs have potential for widespread application in locations lacking electrical infrastructures and also to expand the diversity of fuels we use to satisfy our energy requirements. The purpose of this study is to: (1) To improve on the existing microbial fuel cells whose voltages are low. (2) construct and test a prototype microbial fuel cell that would be portable and environmental friendly. (3) obtain data for future reference and research in the area.

2. Materials and Methods

2.1 Sample Collection (Collection of Waste Water)

The wastewater was collected from a mini dam cited at an abattoir at relief market located along Egbu road adjacent to the young shall grow transport company in Owerri, Imo state, Nigeria. The waste water was screened properly for the removal of large objects with the use of a rake.

It was collected on the day of the analysis in order to prevent the degradation of the organic content of the sample by microorganisms. Before analysis, the waste water sample was stirred thoroughly in order to produce a defined sample. The organic content is the target substrate for the microbial oxidation which will produce the electrons desired for MFC set up.

2.2 Preparation of the Salt Bridge

The salt bridge was prepared using 2% Lab 1M, 20g Agar-agar and 1M, 58.44g of analytical NaCl. A 12cm salt bridge was made using a PVC 1.5-inch diameter pipe. Firstly, 20g of agar-agar and 58.44g of sodium chloride was added to 1000ml of water in a conical flask. It was then dissolved by swirling the conical flask. The mixture prepared was autoclaved at a temperature of 120^{o}C under high pressure and left for 15 minutes.

One end of a PVC tube is sealed with aluminum foil in an easily detachable way and held standing vertically using a support. The autoclaved mixture is allowed to cool to about 50-55°C before it is emptied into the PVC tube. This is then allowed to cool and solidify thereby forming the salt bridge which is used for the MFC set up.

2.3 Preparing the Chambers

A 1-litre poly acrylic container was purchased to serve as the cathode and anode chamber. A hole, equal in diameter to the 1.5-inch Adopter used for plumbing work was made 5.6cm from the base of the 1liter poly acrylic container. The 1.5-inch adopter serves as a point of attachment for the salt bridge which is supposed to interconnect the two chambers. After the hole is made, the 1.5-inch adopter is glued using an Abro sealant purchased from a plumbing shop.

The sealant is used to seal the edges of the point of contact between the 1.5-inch adopter and the chamber to avoid leakages after which it was left for 20-25 minutes for the set-up to dry and solidify. Then, a hole each was drilled into the top cover of both chambers to allow the passage of wires.

2.4 Preparing the Electrodes

Equal-diameter and equal-length of copper electrodes were purchased commercially as two separate electrodes with a screw cap allowing attachments for wire. These are readily made for experimental purpose. The copper electrode was purchased with a length of 12.2cm and the total surface area of the flat copper electrode was calculated to be 61.92cm^2.

Also, Graphite rods were purchased and the height of the rod was adjusted to a length of 14cm**,** this produced an area of 0.65cm^2. These electrodes were prepared and wire attachments were formed to aid conductivity. The area for the cylindrical carbon electrode was calculated from equation (1).

$$\boldsymbol{A = 2\pi R\ (R + h)} \qquad \textbf{(1)}$$

Where R is the radius and h are the height of the electrode.

2.5 Preparation of the Potassium Per-manganate (VII) ($KMnO_4$)

$KMNO_4$ was purchased and prepared. The preparation of the potassium per-manganate was done by weighing some amount of about 28g designed by the user guide and diluted with distilled water in a conical flask of 1000 mL, stirred properly and then transferred to a 5-liter keg. Before usage, the $KMNO_4$ was be diluted to a concentration of 0.2 Mole by pouring the $KMNO_4$ into a container with the same measurement in addition with distilled water. This process is done twice for proper dilution of the $KMNO_4$.

2.6 Coupling the Microbial Fuel Cell

The salt bridge was made a day before the set-up is coupled. The sample water was collected the same day the set-up was to be coupled. The set-up was coupled by joining the two chambers using the salt bridge with the aid of the 1.5-inch adopter inch using an Abro sealant.

The waste water was placed into the anode as the anolyte and the top cover of the chambers was used to passively aerate the cathode using oxygen as the terminal electron acceptor. The multimeter is connected to the cathode and the anode with the aid of the low resistance copper wire before they are inserted into the chambers.

Next the multimeter is set at 2000m for measuring DC voltage in millivolts and 2000micro in measuring DC current in milliamp. The initial reading is taken at 00h and allowed to acclimatize for 30minutes to 1h before subsequent readings are taken. All raw data were converted to conventional units using calibration factors.

3. Results and Discussion

3.1 Voltage Production

From the start of the experiment, there was observation of voltage production of different ranges in accordance to the resistance load by the copper and carbon electrodes respectively. These voltages produced were taken as the initial (T_o) voltages which is because of the acclimatization period of the microbial community in the wastewater.

Acclimatization period is the period taken by the microbial/bacterial community to produce or release their enzymes needed for the transfer of electrons and thus, for the generation of electricity as well as wastewater treatment [10].

There was subsequent increase in the electricity production for the first few days of the experiment signifying the utilization of the organic substrates in the wastewater and exponential growth phase of the exoelectrogens. Later on, the voltage production started fluctuating or subsequently decreased as the organic matter contained in the wastewater got used up leading to a decline growth phase.

This is illustrated in the microbiological results. The initial microbiological result on the Nutrient agar plate showed a colony forming unit (cfu/g) of 4.8×10^{10} whereas the final result showed a colony forming unit of 8.0×10^{7}, 2.0×10^{7}, and 1.78×10^{8}.

This reduction in the colony forming unit can be attributed to the use up of the organic substrate as well as the production of toxic metabolites by the exoelectrogens in the wastewater. Over the 14 days period, the maximum voltage obtained from the cells was 1.621V from MFC-B with copper-copper electrode on the last day of the observation.

The maximum voltage from MFCs A and C with carbon-carbon and carbon-copper electrodes respectively was 0.987V and 1.409V respectively recorded on the last day. The maximum voltage compares favorably with other studies (0.81V for single dual chamber MFC with copper-copper electrode and potassium permanganate as catholyte [1], 1.56V for graphite electrode and bleaching powder dissolved in water as catholyte [11], 1.532V using permanganate solution [15], 1.812V using ferricyanide as catholyte [4]).

The readings of voltage and current output with no resistor for the first, second and fourteenth day of observation are shown in tables 1, 2, and 3 for MFCs A, B and C respectively. The average values of the voltages for MFCs A, B and C are 0.171V, 0.639V and 0.357V respectively for the first day. The average values for the second day are 0.196V, 0.814V and 0.461V respectively for MFCs A, B and C.

The average values for the last day are 0.974V, 1.216V and 0.977V respectively for MFCs A, B and C. Figure 1 shows a graph of voltage against time for the first day, while Figure 2 shows a graph of voltage against time for the second day of the study for MFCs A, B and C. Figure 3 shows the graph of voltage against time for MFCs A, B and C on the last day of observation.

On the first day, MFCs B and C showed fluctuations in the voltage but MFC A showed a fairly stable reading for voltage output (Figure 1). These fluctuations could be inferenced to be due to the microbial community acclimatization period.

It was observed that MFC-A took a shorter time to attain its maximum value of voltage. It attained this voltage in 236 hours as compared to 265 hours for both MFCs B and C as shown on Tables 1, 2 and 3. This could be inferenced to the fact that the bacterial community took lesser time to acclimatize in MFC A. This is also illustrated in Figure 1 as MFC-A shows a relatively stable voltage output compared to MFCs B and C.

Table 1: Modelled readings with no resistance as measured on the first, second and last days of the study for MFC-A with carbon-carbon electrodes

Day 1			
Time (h)	**#OCV (V)**	**##OCI (mA)**	**Temp(°C)**
0	0.160	0.301	27.0
1	0.166	0.315	26.8
2	0.171	0.322	26.0
3	0.180	0.332	27.0
4	0.176	0.325	27.0
5	0.173	0.323	27.0
6	0.170	0.313	28.0
7	0.170	0.313	26.2
8	0.171	0.313	27.1
9	0.171	0.313	26.4
10	0.159	0.305	27.2
11	0.171	0.325	26.8
12	0.180	0.350	28.0
Day 2			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
17	0.193	0.403	28.4
18	0.197	0.406	29.0
19	0.196	0.407	28.4
20	0.195	0.400	27.6
21	0.196	0.407	27.4

22	0.200	0.433	28.0
23	0.200	0.433	28.0
24	0.200	0.422	28.0
25	0.199	0.438	27.8
26	0.193	0.422	26.7
27	0.193	0.420	27.0
28	0.192	0.421	27.0
29	0.193	0.420	28.0
Day 14			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
227	0.955	0.1965	27.0
228	0.948	0.187	27.0
229	0.946	0.1965	29.1
230	0.981	0.1991	29.3
231	0.982	1.000	28.6
232	0.982	1.000	27.0
233	0.981	1.000	28.9
234	0.984	1.000	28.0
235	0.984	1.000	29.0
236	0.987	1.000	27.9
237	0.984	1.000	28.0

#Open circuit voltage

Open circuit current

Table 2: Modelled reading with no resistance as measured on the First, second and last day of the study for MFC-B with copper-copper electrode

Day 1			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
0	0.536	0.290	29.1
1	0.563	0.296	28.7
2	0.728	0.260	28.1
3	0.689	0.290	29.3
4	0.638	0.480	28.6
5	0.752	0.688	27.0
6	0.730	0.652	28.9
7	0.747	0.649	28.0
8	0.585	0.634	27.0
9	0.580	0.630	27.3
10	0.585	0.661	27.0
11	0.585	0.667	27.3
12	0.585	0.640	27.2
Day 2			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
40	0.812	0.550	28.3
41	0.810	0.574	28.4
42	0.794	0.583	27.9
43	0.788	0.593	28.4
44	0.814	0.677	28.5
45	0.801	0.644	28.4
46	0.813	0.704	28.1
47	0.814	0.700	281
48	0.817	0.717	28.3
49	0.816	0.719	27.9
50	0.870	0.716	27.7
Day 14			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
255	0.924	1.461	26.0
256	0.927	1.473	27.0
257	0.977	1.499	28.0
258	1.112	1.615	28.7
259	1.172	1.679	29.3
260	1.222	1.712	28.4
26	1.279	1.744	27.5
262	1.352	1.900	29.3
263	1.379	1.990	29.0
264	1.415	2.300	28.9
265	1.621	2.742	27.4

Table 3 : Modelled reading with no resistance as measured on the First, second and last days of the study for MFC-C with carbon-copper electrodes

Day 1			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
0	0.335	0.247	29.0
1	0.336	0.250	27.0
2	0.383	0.358	27.4
3	0.383	0.342	27.4
4	0.350	0.333	29.1
5	0.356	0.377	28.7
6	0.335	0.333	27.0
7	0.338	0.342	27.4
8	0.344	0.550	28.2
9	0.370	0.556	29.0
10	0.393	0.513	27.0
11	0.347	0.564	28.7
12	0.377	0.514	27.0
Day 2			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
40	0.354	0.537	27.0
41	0.370	0.543	26.0
42	0.364	0.577	27.2
43	0.384	0.566	27.0
44	0.397	0.549	27.4
45	0.500	0.588	28.2
46	0.490	0.600	29.0

47	0.550	0.688	27.0
48	0.554	0.690	28.0
49	0.559	0.697	28.7
50	0.546	0.662	29.3
Day 14			
Time (h)	**OCV (V)**	**OCI (mA)**	**Temp(°C)**
255	0.692	1.000	26.0
256	0.717	1.062	27.0
257	0.899	1.210	28..0
258	0.893	1.215	28.7
259	0.892	1.236	29.3
260	0.892	1.449	28.4
261	0.910	1.513	27.6
262	1.122	1.612	29.3
263	1.131	1.674	29.0
264	1.191	2.042	28.9
265	1.409	2.414	27.4

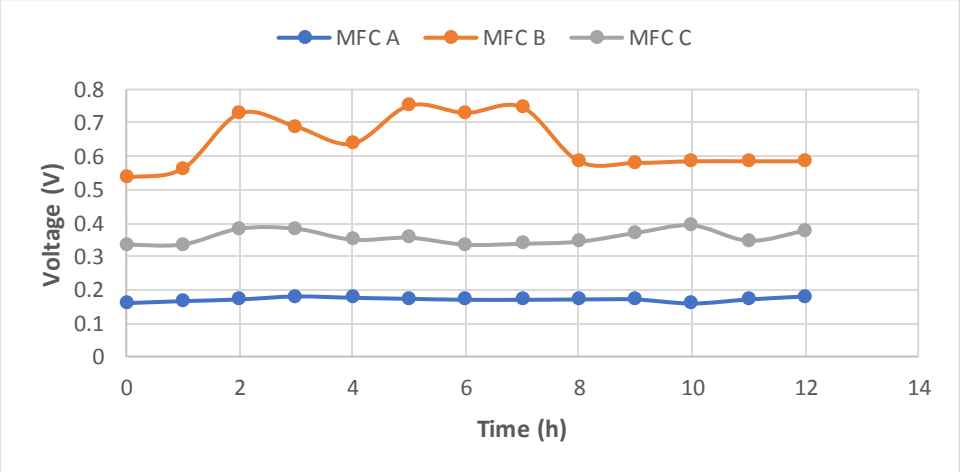

Fig. 1 Graph of voltage against time for Day 1 for MFCs A, B and C

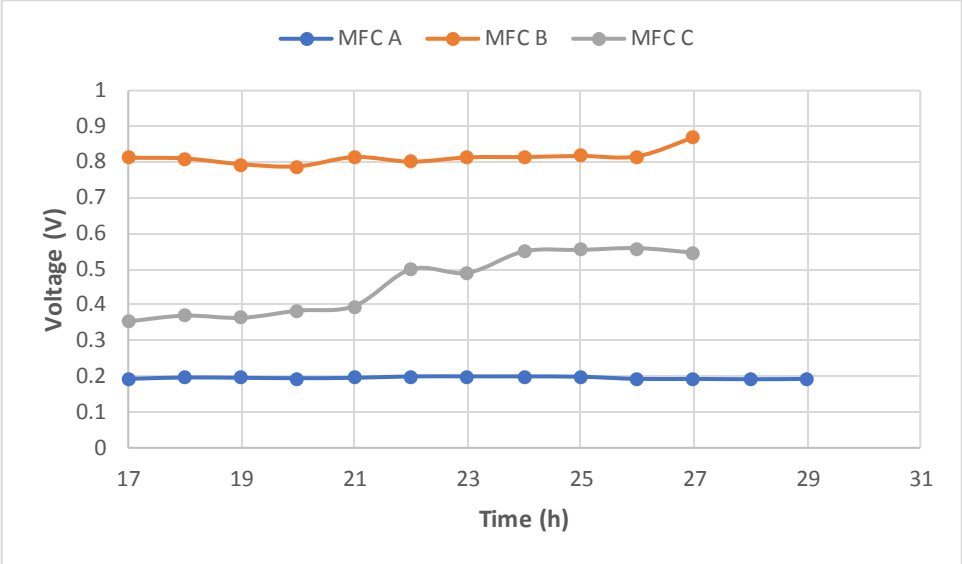

Fig. 2. Graph of voltage against time for Day 2 for MFCs A, B and C

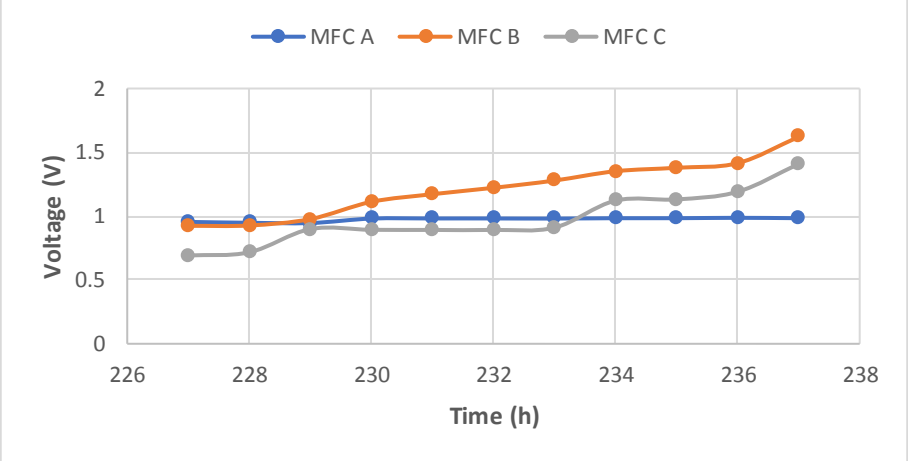

Fig. 3. Graph of voltage against time for Day 14 for MFCs A, B and C

3.2 Power Density

Readings of voltage and current was taken with resistors of 10Ω, 100Ω and 1000Ω over the 14-day period. The maximum power density recorded over the study period was 0.329W/cm^{2,} obtained using a 100 Ω resistor. This was recorded by MFC-A. MFCs B and C showed maximum power density values of 0.0000256W/cm^2 and 0.00197W/cm^2 respectively, obtained from a 1000 Ω resistor. The power density was calculated from equation (2).

$$\mathbf{P.D} = \frac{\mathbf{V^2}}{\boldsymbol{RA}} \qquad \textbf{(2)}$$

Where V is the voltage, R is the resistance of the resistor and A is the area of the electrode.

3.3 Wastewater Treatment Ability

The ability of the MFC to treat wastewater was examined. This was obtained in efficiencies and calculated from the equation (3):

$$efficiency = \frac{initial\ parameter\ value - final\ parameter\ value}{initial\ parameter\ value} \times 100 \quad (3)$$

Parameters examined in this study include Biological oxygen demand (BOD) removal efficiency, Total dissolved solids (TDS) removal efficiency, pH, Temperature, and conductivity. The BOD reflects what can be removed biologically [10]. Wastewater treatment efficiencies of the MFCs are shown on table 4. These figures are plotted on a graph as shown in figure 4. While treating the wastewater, the MFCs displayed different efficiencies in the removal of the parameters. The experiment showed that there was at least 72% removal of the BOD as shown by the MFC-A and then a highest BOD removal of 73% represented by the MFC-B. This explains good treatment ability by the MFCs because "BOD removal is important especially where sewage effluent flows to a leaching field in tight soils" [5]. Also, the MFCs A, B and C efficiency in terms of Conductivity were recorded to be 43.9%, 33.3%, and 28.1%, respectively. The MFC-A showed the highest efficiency while the MFC-C showed the least. In the aspects of the acidity and alkalinity of the MFC recorded 1.45%, 2.12% and 1.16% respectively.

Table 4: MFCs performance

MFC	#BOD	PH	Conductivity	Temperature	##TDS
A (Carbon- Carbon)	71.70	1.45	43.90	3.50	76.30
B (Copper- Copper)	73.30	2.12	33.30	6.60	75.00
C (Copper- Carbon)	72.00	1.16	28.10	8.81	64.20

 # Biological Oxygen Demand

Total Dissolved Solids

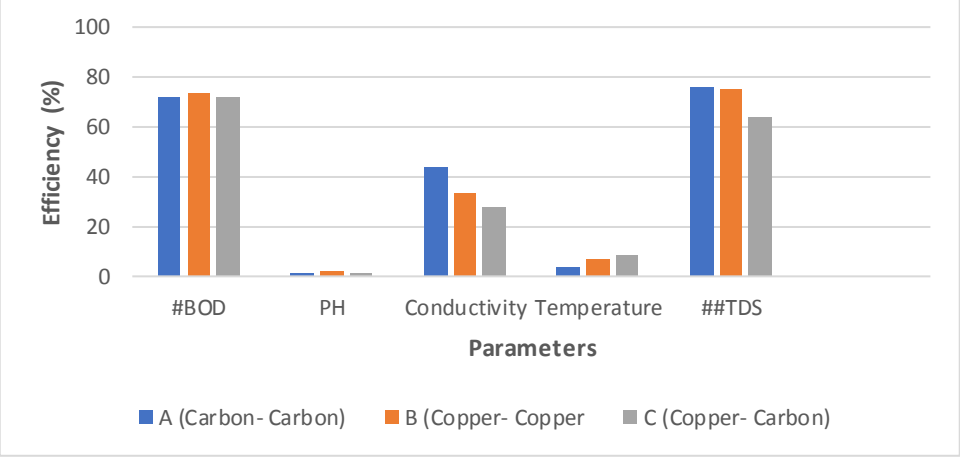

Fig. 4. Bar graph showing wastewater treatment efficiencies of MFCs A, B and C

 # Biological Oxygen Demand

Total Dissolved Solids

3.4 Microbial Community

Biochemical test for the identification and characterization of the microbial community isolated from the sample was done. The test revealed a community of *Enterococcus spp, Bacillus spp, Staphlococcusspp, Escherichia coli, Salmonella spp, Shigella, Saccharomyces spp, penicilumnotatum, Aspergillus spp,* and *Rhizopusnigricans*. The results are represented in table 5.

Table 5: Biochemical and Carbohydrate Fermentation Test of Bacteria Isolated from samples.

Cat, catalase; Oxi, oxidase, Coag, coagulase, In, Indole; MR, Methyl red; VP, Voges Proskaeur, Cit, citrate; No_3, Nitrate reduction; Glu, glucose; Suc, sucrose; Mal, maltose; Lac, Lactose; Mann, mannose; Xyl, xylose.

Colony code	Cat	Oxi	Coag	In	MR	VP	Cit	NO_3	Urease	Carbohydrate fermentation						Identity of Isolates
										Glu	Suc	Mal	Lac	Mann	Xyl	
X1	+	-	-	-	+	-	+	+	-	+	-	-	-	-	-	*Bacillus spp*
X2	+	-	+	-	-	+	-	+	+	+	+	+	+	+	-	*Staphylococcus aureus*
X3	+	-	-	-	+	-	+	-	+	-	-	-	-	-	-	*Micrococcus luteus*
X4	+	+	-	-	+	-	+	+	+	+	-	-	-	+	+	*Pseudomonas aeruginosa*
X5	-	-	-	-	+	-	+	+	-	+	+	-	+	+	-	*Enterococcus faecalis*
X6	+	-	-	-	-	+	+	+	-	+	-	-	-	+	+	*Vacilluss ubtilis*
Xa	+	-	-	-	-	+	-	+	-	+	+	-	+	+	-	*Enterobacter spp*
Xb	+	-	-	+	+	-	-	+	-	+	+	+	+	+	+	*E. colli*
XA	-	-	-	-	+	-	-	+	-	-	-	+	-	-	-	*Shigella spp*
XB	+	-	-	-	-	+	-	+	-	+	-	+	-	+	+	*Salmonella spp*

4. Conclusion

A microbial fuel cell produces electricity from biological cells. It describes the generation of power through wastewater with the aid of a bacteria present in it. We noticed different output results when measuring the voltage and current with different resistors and also noticed that the results were increased when a Copper-Copper electrode was used in both the anode and cathode chamber compared to the Carbon-Carbon electrode. It was also observed that for the copper electrode, using potassium permanganate, increasing the length of the salt bridge causes a decrease in the voltage output compared to the previously published work by the authors [4].

A microbial fuel cell can purify/treat wastewater while simultaneously generating electricity. It can be used effectively for wastewater treatment with a BOD removal of about 70%-80%. As compared to the previous work done by the authors [4], the wastewater treatment ability of the MFC increased when the number of electrodes in the cell is increased. If the system is improved, MFC technology may provide a new method to offset wastewater treatment plant operating costs, making wastewater treatment more affordable. The possibility of direct conversion of organic matter in the wastewater to bioelectricity is exciting, but fundamental understanding of the microbiology and further development of technology is required. With continuous improvements in MFC, it may be possible to increase power generation rates and lower their production and operating cost. Thus, the combination of wastewater treatment along with electricity production may help cutting the cost of wastewater treatment at present.

Competing Interests

Authors have declared no competing interests exist regarding the publication of this work.

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