Power Generation through Wastewater using Microbial Fuel Cell

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Abstract— *A Microbial Fuel Cell (MFC) is a device that converts Chemical Energy into Electrical Energy with the help of microorganisms. This research uses MFC to compare the power generation from two wastewater samples using Carbon and Copper Electrodes. It is currently underway to explore the feasibility of utilizing MFC technology in Sri Lanka to generate electricity while simultaneously treating wastewater and identifying the system that produces the maximum electricity. Among the MFC technology systems, the Batch mode dual-chambered MFC system has been used throughout the research. This research compared four scenarios using 8 Microbial Fuel Cells, each with two unique wastewater samples and electrodes. A 1L wastewater could produce an Optimum Voltage power of 694.0 mV using a Copper Electrode and 545.1 mV using Carbon Electrodes. The two Wastewater Samples, the effluent of a Factory and a Treatment plant inlet have been comparatively tested on their performance. Parameters like BOD_5, COD, Total Nitrogen, Total Phosphorus, pH, and Temperature have been tested by a laboratory to check the possibility of treating the wastewater while Generating Electricity Power. Wastewater Samples were successfully neutralized with a pH level of 6.8-7, BOD_5 levels decreased by 7 mg/l and 6 mg/l, COD values dropped by 30 mg/l and 16 mg/l, Total Nitrogen levels reduced by 12.6 mg/l and 11.2 mg/l, Total Phosphorus levels decreased by 0.3 mg/l and 0.1 mg/l, in Plant inlet and Factory Effluent respectively at room temperature after using Microbial fuel Cells.*

Keywords— Microbial Fuel Cell, Wastewater Treatment, Effective Parameters, Bioelectricity

I. INTRODUCTION

Electricity production heavily relies on fossil fuels, which are limited and harmful to the environment. Their combustion releases carbon dioxide and toxic gases, contributing to global warming and climate change.(Rahimnejad *et al.*, 2011)

Microbial Fuel Cell (MFC) technology uses microorganisms to generate Renewable Energy. In the anode compartment, microorganisms decompose/oxidize organic matter, releasing electrons to the anode and protons to the solution, which is separated by a membrane. The exogenous transfer of electrons by bacteria facilitates the power generation process. Power is produced in a microbial fuel cell when microbes oxidize organic material at the anode and reduce oxygen at the cathode. Oxygen diffuses into the anode chamber through proton exchange membranes, which are permeable to oxygen in MFCs.(Virdis *et al.*, 2011) It is possible for a Microbial Fuel Cell to not only produce electricity but also treat wastewater simultaneously during the process.(Nguyen and Min, 2020)

This Research explores the impact of using Carbon and Copper electrodes on Microbial Fuel Cell (MFC) performance. The study investigates the amount of energy that can be generated by MFCs when using these electrodes with two different wastewater samples. Additionally, the research examines how the parameters in wastewater can be treated and the feasibility of implementing MFCs in Sri Lankan Wastewater.

Research Objectives are as follows.

- To Investigate the possibility of using Microbial Fuel Cell in treating Wastewater.
- To Identify the System used in MFC for Power Generation through Wastewater.
- To determine the amount of power that can be generated through wastewater using MFC Technology.

II. METHODOLOGY AND DATA

A. Building the MFC Prototype

Many types of MFCs are available, including cube, flat-plate, miniature, and horizontal tubular, etc.(Gul *et al.*, 2021) In this research, a Batch mode dual-chambered MFC system has been used. A Microbial Fuel Cell comprises three main components: two Anode and Cathode chambers, a Proton Exchange Membrane (PEM), and Electrodes. When these parts are connected, they function as a Single Cell. This Research involved nine MFC prototypes, four utilizing Copper Mesh Electrodes and the other four using Carbon Electrodes, as shown in Figure 1. A steel mesh electrode is utilized as a single unit to test the MFC mechanism with a random wastewater sample before applying it to the two primary wastewater samples in the research. During a test run with the steel mesh electrode unit mentioned above, excess pressure was generated in the container when the lid was closed as the anode chamber under anaerobic Conditions. To address this issue, syringes have been placed above the red-colored anode containers as a solution.

Figure 1 Microbial Fuel Cell Copper & Carbon Electrodes attachment to the Lid

The above solution method effectively prevents the pressure build-up caused by carbon dioxide air emissions in the anode chamber. Additionally, all eight units are enclosed in a wooden box covered with polythene and fitted with two aquarium pumps to provide aeration for four units.

In Microbial Fuel Cells, the red-colored anode containers are kept under anaerobic conditions. They are sealed, while the black-colored cathode container is aerobic and needs to be open to atmospheric air to communicate with oxygen. To facilitate this, holes have been drilled on every cathode container lid, with extra holes on four units with blue-colored Proton Exchange Membrane (PEM) for external oxygen supply from the Aquarium pumps for the aeration process. Figure 2 displays the Final Eight Microbial Fuel Cell Units for testing.

Figure 2 Final MFC 8 Units with all the components attached ready to be tested.

B. Wastewater Sample Collection

Two types of Wastewater samples were collected: one directly from drainage connected to a paper production industry's effluent pipe and the other from the treatment plant's inlet after the completed screening process.

C. 1st Parameter Testing for the Wastewater Samples

The Soysapura wastewater treatment plant laboratory tested the parameters of two factory effluent and treatment plant inlet wastewater samples. The tested parameters for both samples were BOD_5, COD, total nitrogen, total phosphorus, and pH.

D. Wastewater Application to the MFC Units

Table 1 is presented below, showcasing the outcome of the Wastewater Sample Application conducted on the eight MFC Units depicted in Figure 2.

Table 1 Wastewater application on the MFC Units

Unit	Aeration	Wastewater Type	Electrode
1	Yes	Treatment Plant	Copper
2	Yes	Treatment Plant	Carbon
3	Yes	Industrial	Copper
4	Yes	Industrial	Carbon
5	No	Treatment Plant	Copper
6	No	Treatment Plant	Carbon
7	No	Industrial	Copper
8	No	Industrial	Carbon

E. Measuring the voltage

Voltage measurement was conducted for eight days, as in Table 5, using a multi-meter at different intervals. It is worth noting that the readings were taken from the MFC unit without using a resistor to connect the anode and cathode electrodes. Moreover, all MFCs were open-circuited during the operation.

F. 2nd Testing the parameters after the MFC Application

To determine if the Microbial Fuel cell can effectively treat wastewater while generating power, another round of testing has been done using the same parameters as before. Specifically, the highest voltage value from the last voltage reading was taken for the Soysapura wastewater treatment plant. Table 5 displays the voltage values observed during testing, with the highlighted results indicating the tested units. All the Lab Results are mentioned in Tables 3 & 4.

III. Results and Discussion

A. MFC Voltage Result

When measuring the voltages, all the readings are not taken to equal time periods. This decision was taken to track any deviation happening during the reactions in each Unit and search for any Experimental faults such as leakage, Electricity cut, deformation in the Unit due to excessive pressure, etc. In the Eight MFC Units, Various voltage results are observed from the open circuit Microbial Fuel Cell, and some of these results are not theoretically Parallel to the theory of Microbial Fuel Cell Application throughout the operation. The following Table 2 shows the Voltage Comparison in each MFC Unit. The following Comparison was done with simultaneous electrodes with their aerated and non-aerated Units. Table 5 Shows all the Voltage Results.

Table 2. Four Comparison Arrangement between 8 MFC Units

Comparison	Unit	Aerat.	Wastewater	Electrode
Comparison 1	1	Yes	Treatment Plant	Copper
	5	No	Treatment Plant	Copper
Comparison 2	2	Yes	Treatment Plant	Carbon
	6	No	Treatment Plant	Carbon
Comparison 3	3	Yes	Industrial	Copper
	7	No	Industrial	Copper
Comparison 4	4	Yes	Industrial	Carbon
	8	No	Industrial	Carbon

i. Comparison 1 (Unit 1 & 5)

Average Voltage Values,
- MFC Unit 1 = 235.65 mV
- MFC Unit 5 = 517.61 mV

Minimum Voltage Values,
- MFC Unit 1 = 133.3 mV
- MFC Unit 5 = 354.8 mV

Maximum Voltage Values,
- MFC Unit 1 = 473.1 mV
- MFC Unit 5 = 694.0 mV

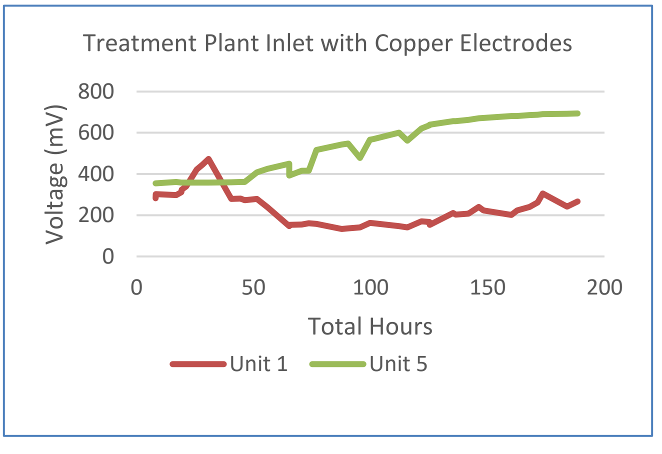

Figure 4. Comparison 1

ii. Comparison 2 (Unit 2 & 6)

Average Voltage Values,
- MFC Unit 2 = 241.74 mV
- MFC Unit 6 = 475.22 mV

Minimum Voltage Values,
- MFC Unit 2 = 1.1 mV
- MFC Unit 6 = 177.1 mV

Maximum Voltage Values,
- MFC Unit 2 = 354.8 mV
- MFC Unit 6 = 545.1 mV

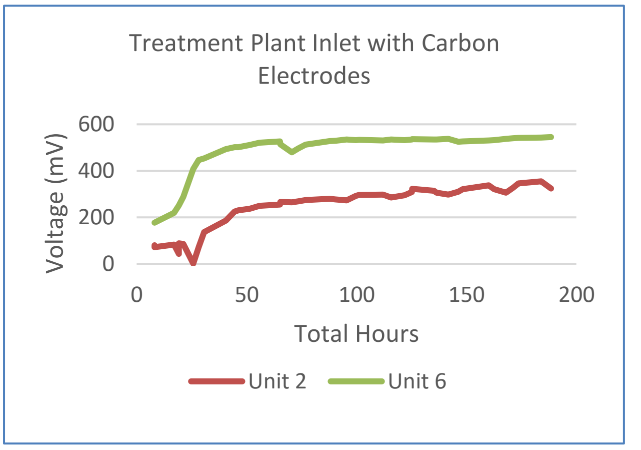

Figure 3. Comparison 2

iii. Comparison 3 (Unit 3 & 7)

Average Voltage Values,
- MFC Unit 3 = 332.83 mV
- MFC Unit 7 = 428.83 mV

Minimum Voltage Values,
- MFC Unit 3 = 162.8 mV
- MFC Unit 7 = 193.8 mV

Maximum Voltage Values,
- MFC Unit 3 = 518.8 mV
- MFC Unit 7 = 638.0 mV

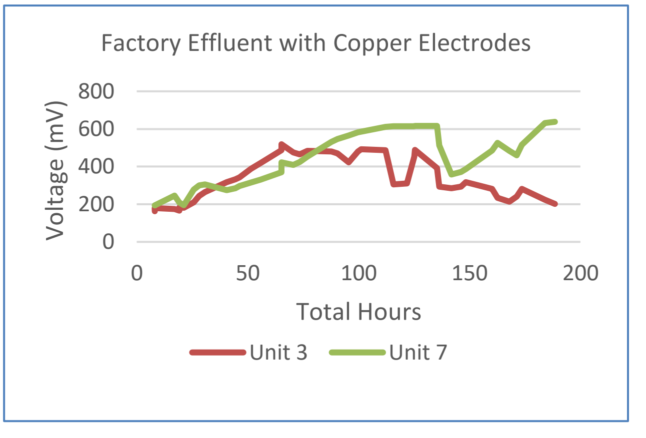

Figure 5. Comparison 3

iv. Comparison 4 (Unit 4 & 8)

Average Voltage Values,
- MFC Unit 4 = 282.1 mV
- MFC Unit 8 = 296.06 mV

Minimum Voltage Values,
- MFC Unit 4 = 53.3 mV
- MFC Unit 8 = 129.3 mV

Maximum Voltage Values,
- MFC Unit 4 = 571.9 mV
- MFC Unit 8 = 534.9 mV

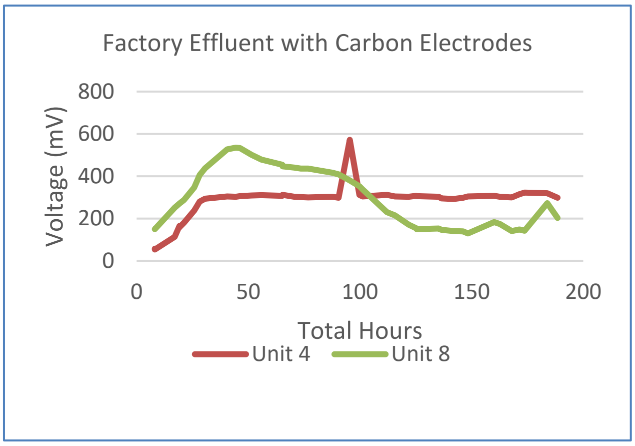

Figure 6. Comparison 4

B. Lab Test Result

Table 3. Treatment plant Inlet Parameter Result

Parameter	Method	Results 1	Results 2
pH	APHA 4500-H+B	6.6	6.8
Temp. (°C)	APHA 2550 B	29.4	29.4
COD (mg/l)	APHA 5220 B	594	564
BOD_5 (mg/l)	APHA 5210 B	147	140
Total N (mg/l)	Spectrophotometric	27.6	15
Total P (mg/l)	Spectrophotometric	3.2	2.9

Table 4. Factory Effluent Parameter Results

Parameter	Method	Results 1	Results 2
pH	APHA 4500-H+B	6.5	6.9
Temp. (°C)	APHA 2550 B	29.2	29.1
COD (mg/l)	APHA 5220 B	1376	1360
BOD_5 (mg/l)	APHA 5210 B	273	267
Total N (mg/l)	Spectrophotometric	16.1	4.9
Total P (mg/l)	Spectrophotometric	2.1	2

Table 3 displays the lab results for the Treatment Plant Inlet Wastewater. Table 4 shows the results for the Factory Effluent Wastewater. The data in the Result 1 column was tested before the MFC wastewater application, while the Result 2 data was tested after the application, which showed the highest voltage result.

C. Cause of Voltage Reduction in Aerated Units

Theoretically, the MFC mechanism boosts voltage by introducing external oxygen to the cathode chamber. In a microbial fuel cell, microorganisms oxidize organic matter at the anode and reduce oxygen at the cathode to produce power. This process is most observed in MFC units with copper electrodes. However, voltage values decrease after a certain period of time, even with an ample oxygen supply in the cathode chamber. This leads to non-aerated units having higher voltage values at the end of practical applications.

In order for metal nails to corrode, the presence of a wet surface and oxygen is required. This corrosion process occurs in the cathodic electrodes, which ultimately leads to a decrease in voltage values. These specific corrosion requirements are indeed present in the aerated cathodic chambers.

One reason is that the MFC units are not connected during operation. It was decided not to connect the anode and cathode electrodes to reduce energy consumption and take voltage readings from eight units using a single multi-meter. Therefore, this research is based on the open circuit structure in the MFC Unit.

The water in the cathodic chamber of the copper electrode has turned green due to the presence of Cupric Oxide. This compound is naturally green in color, and its oxidation reaction could decrease the voltage value of the aerated MFC Units.

The cathodic chamber of the MFC unit is typically filled with normal water, while the anodic chamber is filled with wastewater. However, in some research, distilled water is used instead. In a recent study, all the cathodic chambers were filled with bottled drinking water containing many minerals. As a result, the voltage reduction that occurred after a certain amount of time could be attributed to the mineral content in the water. Distilled water is often used in electricity generation cells as it does not contain minerals.

The reduction in voltage in the MFC unit can be attributed to using iodide salts in the PEM section. This is because iodine may react with the wastewater or water, leading to a decrease in voltage. The PEM has two visible ends that are open to the area of wastewater, which may also contribute to this reduction in voltage.

IV. CONCLUSIONS

According to the results, the Copper Electrodes produced the best values than Carbon Electrodes in Electricity Power Generation. The second round of testing utilized the ideal Voltage values for Units 5 and 7, resulting in an optimal value of 694.0 mV for Unit 5 and 638.0 mV for Unit 7. Unit 5 processed Inlet wastewater from the Treatment Plant, while Unit 7 processed Factory effluent wastewater. The study suggests that Copper electrodes may generate more electricity than Carbon electrodes.

The wastewater treatment process involved comparing two Units 5 and 7 samples, to determine their effectiveness. The results showed that the pH value was between 6.8-7, indicating successful neutralization. BOD_5 levels were reduced by 7 mg/l and 6 mg/l, respectively, for Plant inlet and Factory Effluent. Additionally, COD levels were decreased by 30 mg/l and 16 mg/l, respectively, for Plant inlet and Factory Effluent. Total Nitrogen values were decreased by 12.6 mg/l and 11.2 mg/l, respectively, while Total phosphorus values were decreased by 0.3 mg/l and 0.1 mg/l, respectively, all at room temperature.

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AUTHOR BIOGRAPHIES

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Table 5 Microbial Fuel Cell Voltage Results

Date	Tot Hours	Time	Voltage (mV)							
			Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8
27th April	8.13	23:38	281.5	80.2	162.8	57.9	354.8	177.1	193.8	149.3
	8.17	23:40	302.1	71.1	179.3	53.3	354.8	177.1	193.8	149.3
28th April	17.02	8:31	297.9	82.3	174.4	113.1	361.2	219.3	245.4	250.9
	19.20	10:42	311.4	42.7	165.7	164.3	358.3	251.4	207.8	270.6
	19.23	10:44	323.6	87.8	183.8	158.1	358.3	251.4	207.8	270.6
	21.20	12:42	339.1	86.1	180.7	179.7	358.3	287.6	195.1	287.3
	25.73	17:14	422.7	1.1	209.5	238.1	357.9	407.5	278.5	346.5
	28.22	19:43	445.5	71.2	244.6	280.2	358.5	446.2	301	405.9
	30.72	22:13	473.1	136.7	265	293.7	358.1	453.7	305.7	437.8
29th April	40.55	8:03	279.4	186	318	303.6	360.1	493.8	275.4	526.5
	44.48	11:59	280.8	224.6	333.2	302.2	361	501.5	285.4	534.9
	46.30	13:48	273.5	230.6	342.2	306.3	362.2	502	297.3	532.2
	51.50	19:00	279.4	237.3	388.8	308	407.7	511.3	315.8	500.8
	55.88	23:23	239.4	249.8	418.7	309.9	425.9	520.5	331.6	478.2
30th April	65.25	8:45	146.7	255.5	486.3	307.8	450.1	526.5	369.1	453.4
	65.30	8:48	152.7	266.2	518.8	311	391.8	514.4	422.7	446
	70.58	14:05	155.1	264.3	476	303	416.5	479.3	409.6	439.9
	73.53	17:02	160.7	268.4	465	301.4	416.3	496.3	424.8	435.3
	76.87	20:22	157.3	274.4	483	300	516.2	512.4	452.9	436.6
1st May	87.72	7:13	133.3	279.7	480.5	302.5	542.5	527.6	531.3	416.5
	90.43	9:56	135.8	276.7	469.3	298.5	548.1	529.5	546	408.6
	95.52	15:01	140.3	273.2	422.9	571.9	477.6	535.1	565.9	380.5
	99.77	19:16	163.2	292.2	480.9	311.8	566.5	532.6	581.5	352.3
	101.20	20:42	161.8	295.8	493	304	569.2	532.8	586	337.3
2nd May	112.12	7:37	147.6	298.4	487.8	311.3	600	531.1	610.4	229.6
	115.72	11:13	140.2	284.9	305.4	303.4	562.1	535.1	613.9	215.5
	121.78	17:17	170	295.2	310.9	303.2	621	532	614	170.4
	125.18	20:41	166.7	308.8	453.5	307.1	637	534.8	614.3	154.5
	125.35	20:51	153	321.9	489.3	305.6	639	535.5	615.9	150.3
3rd May	135.30	6:48	211.2	314.8	392	303.1	656	534.9	617	152
	136.42	7:55	203.4	306.2	293	295.8	657	535	512.7	146.9
	141.83	13:20	207.4	298.1	285.7	291.4	663	537.2	358.6	140.2
	146.25	17:45	240.1	310.4	292.8	298	670	524.4	372.2	139.2
	148.33	19:50	223.3	321	317.8	303.5	672	526.4	387.5	129.3
4th May	160.17	7:40	202	337.2	281.3	307.1	681	530.6	485	183.6
	162.67	10:10	223.3	321.5	234.3	301.9	681	532.1	526.4	174.6
	167.93	15:26	241	306.3	213.3	299	686	538	483.9	140.2
	171.37	18:52	261.9	328.3	241.3	315.1	687	539.9	459.3	148.4
	173.67	21:10	305.1	345.5	281.3	321.9	691	541.5	516.8	142.4
5th May	183.95	7:27	242.4	354.8	223	319.6	693	543.6	632	271.7
	188.50	12:00	266.7	324.2	200.9	298.4	694	545.1	638	202.4
Average			235.6	241.7	332.8	282.1	517.6	475.2	428.8	296.1
Maximum Value			473.1	354.8	518.8	571.9	694	545.1	638	534.9
Minimum Value			133.3	1.1	162.8	53.3	354.8	177.1	193.8	129.3