

1 **Power production using a batch double-chamber microbial fuel cell from brewery wastewater:**
2 **Effects of electron acceptors**

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10

11 **Abstract**

12 In recent decades, shortage and crisis of energy being serious issues all over the world as the fossil
13 fuel reserves have been diminishing. A particular emphasis has been given for bio-energy
14 harvesting from waste and cellulosic biomass by employing an efficient conversion system.
15 Among these, a microbial fuel cell (MFC) systems are an emerging promising technology for the
16 effective waste water treatment. However, the collective effect of waste substrates, inoculum
17 composition, and catholyte concentrations on the performance of MFC system remain unclear.
18 Hence, this study aimed to investigate the effect of electron acceptors under different set of
19 parameters in response to its electrochemical performance. The inoculum COD concentration and
20 type of the electron acceptor on the performance of the electrochemical has been studied. A dual-
21 chamber MFC with 0.4-0.6 M values of potassium permanganate (KMnO₄) and Ferricyanide
22 K₃[Fe(CN)₆], (900-2520 mg/L) of COD values, and oxygen as a control substance were used
23 .The experiments were carried out in a batch mode for 20 days of operation. The results reveal that
24 MFC with 0.4 M KMnO₄ provides an external output voltage of 310.09 ± 0.06 mV and external
25 output power density value of 400.4 ± 0.46 mW/m² while 0.4 M [K₃Fe(CN)₆] results an external
26 output voltage of 252.18 ± 0.12 mV and an external output power density value of 380.28 ± 0.24
27 mW/m². Analysis of variance was done using central composite design approach to support the
28 significance of each experimental factors on the responses with 95% CI and the result shows that
29 all the parameters were statistically significant.

30 **Keywords:** Microbial Fuel Cell, Electron acceptors, Brewery waste water, Energy generation,
31 COD removal

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34 Introduction

35 In recent decades, energy shortage and crisis have been emerged as a serious issue of concern all
36 over the world as the fossil fuel reserves have been diminishing. More importantly, energy
37 generation from fossil fuels contributes to global warming, climate change, and the depletion of
38 non-conventional energy sources. energy sources. Hence, scholars of the field [1] put their effort
39 on other alternatives and renewable energy sources as part of the key strategies to alleviate the
40 problems faced by non-conventional energy resources thereby reducing environmental burden
41 released by fossil fuels. Moreover, the increasing cost and demand of fossil fuel were an aspiration
42 for looking renewable energy sources, and solve the huge dependent on fossil fuel. Hence, MFC
43 technology could give a significant role for solving energy shortages as well as waste water
44 treatment. However, membrane cost effectiveness, efficient electrogens electrode materials, and
45 electron acceptors of the MFC still remains the key bottlenecks for the practical applications [2]–
46 [4]. Biological reactor system such as aerobic sequencing batch reactors, anaerobic cross-flow
47 ultrafiltration membrane reactors, modified internal circulation (MIC), and up-flow anaerobic
48 sludge blanket reactors have been used for energy generation. Among these, microbial fuel cells
49 (MFCs) have recently given great attention due to its contemporary advantage of energy
50 generation and contaminant removal [5], [6]. Even though MFCs has appeared late to 20th century,
51 most of the improvement studies focused on optimization of parameters for synthetic/simulated
52 substrates and this system has not be practiced beyond the laboratory/conventional due various
53 reasons [7]. The power output of the MFC is affected by a variety of process parameters including
54 substrate type, exo-electrogenic microbial strains, circuit resistance, electrode material, reactor
55 configuration, surface area of the cathode relative to that of the anode, the surface of the membrane and
56 electron acceptors [8], [9]. Recently, oxygen was used as a terminal electron acceptor in the
57 cathode compartment due to its high oxidation potential and gives a clean product (water) after
58 reduction reaction for MFC application. However, using oxygen as an electron acceptors faces
59 various difficulties such as the energy consumption of the oxygen supply to the cathode
60 compartment, cathode air surface contact difficulties, and use of an expensive catalyst [10],[11].
61 Hence, great emphasis has been given for using an alternative electron acceptor to increase the
62 power generation potential of the MFC and to reduce the overall operating cost. With this regard,
63 variety of synthetic substrates employed as a carbon and energy source such as glucose, acetate,
64 sodium acetate, fatty acids and alcohols etc. can potentially provide different power generation
65 potential under different process parameters [12]. However, the effect of inoculum COD
66 concentration for fermentable and non-fermentable substances, the effect of electron acceptor
67 concentrations and inoculum composition on the performance of MFC system using real waste
68 water has not been studied well and the electro-chemical performance of MFC would be limited
69 to a range of operating conditions. These results failure to commercialize MFCs in real case
70 industrial application. Hence, this study aimed to investigate the performance of MFC for real case
71 applications with various molar concentration of potassium permanganate (KMnO₄) and
72 potassium cyanide K₃(Fe(CN)₆, inoculum COD concentrations as well as the electro-chemical

73 performance (e.g., voltage generation, coulombic efficiency, current density and power density)
74 using real brewery waste water.

75 **2. Methods**

76 **2.1. Materials, Chemicals and Reagents**

77 Potassium ferricyanide ($K_3[Fe(CN)_6]$ (99.5%)) and potassium permanganate ($KMnO_4$) (98.0%)
78 were used as an electron acceptor in the cathode chamber for MFC operation. KOH (97%) and
79 NaOH (97%) were used for pH regulation. Sulfuric acid (H_2SO_4) (90%), nitric acid (HNO_3) (90%),
80 potassium dichromate ($K_2Cr_2O_7$) (90%) and mercuric sulfate ($HgSO_4$) (90%) were used as a
81 reagents for digestion of the samples and the COD value determination. Phosphate (HI713-25
82 Phosphate LR reagents) was also employed. All the chemicals and reagents used for this study
83 were analytical grades and purchased from LBS Marg, Mumbai -400086, India. Sulfonated
84 tetrafluoroethylene copolymer (product of DuPont Inc. USA) was used as a proton exchange
85 membrane(PEM). The voltage and current values generated for the inoculated samples in the MFC
86 were measured using a digital multi-meter (Fluke multimeter 87, USA). An electrical conductivity
87 was measured with a conductivity meter (Oyster conductivity meter TM 34135A-P, India).

88 **2.2. Experimental Procedures, Set Up and MFC Inoculum Operations**

89 The power generation and treatment efficiency of the dual chamber of MFC performance was
90 evaluated with two different electron acceptors (i.e., $KMnO_4$ and $K_3Fe(CN)_6$). To allow proton
91 transfer from the anode to the cathode chamber, a polymer-electrolyte membrane was inserted
92 between two chambers in a flexible plastic tube with 4 cm length and 2 cm diameter. Graphite
93 electrodes with 4 cm by 5 cm dimension are employed in both the anode and cathode chambers
94 [13]. The electrodes were placed into the chamber through the openings on the top. The anaerobic
95 conditions were maintained through purging nitrogen gas from the anode chamber, while provide
96 aerobic conditions were obtained through the cathode chamber coupled to an oxygen pump. The
97 anode and cathode electrodes were connected by two copper wires. To create an open-circuit
98 voltage, the other two ends of copper wires were connected to a digital multimeter (**Figure 2.**) The
99 nutrients broth medium was collected form the brewery wastewater treatment plant's (anaerobic
100 digester) and was used to culture bacteria. 50 mL of mixed bacteria was cultivated for 24 hours at
101 37 °C in a 100 mL nutrient broth medium before being transferred to the anodic chamber. The

102 MFC was inoculated with brewery wastewater and mixed bacterial culture and operated in batch
103 mode. The authors of this study employed an anodic chamber with a total volume of 2 L and a
104 working volume of 1.5 L.

105 The anodic chamber was fed with a mixture of microbes (bacteria) and prepared substrates and it
106 was run in anaerobic mode at a constant pH [14]. The cathode chamber was fed with 0.4 M KMnO_4
107 and M $\text{K}_3[\text{Fe}(\text{CN})_6]$ in batch mode of operation in anaerobic conditions at the pH of 8.5 (**Table**
108 **1**). Atmospheric temperature was used in the MFC chambers. A digital multi-meter was used to
109 measure the voltage and current generated in the MFC.

110 **2.2. Characteristics of Brewery Wastewater, Microbes and Brewery Industrial Wastewater** 111 **Treatment**

112 The waste water treatment technologies employed in Dashen Brewery mainly incorporates
113 settling, anaerobic digestion for biogas generation, treated water disinfection for killing harmful
114 diseases causing organisms, and sludge treatment (thickening and digestion). The microbes
115 (*Geobacter* species) were isolated, enriched and morphologically analysed according to the
116 standard procedures of manual systematic bacteriology [15], which was initially collected from
117 brewery waste water at the secondary treatment tank. To avoid the degradation process of
118 bacteria in wastewater, raw brewery wastewater and laboratory cultivated microorganisms were
119 collected from Dashen Brewery in Ethiopia and maintained at 5 °C in refrigerator until it was fed
120 to the reactor [16]. The physico-chemical characteristics of the raw brewery wastewater were
121 measured and analysed (**Table 1**).

122 **2.3. Characterization**

123 For a high range COD value determination, a 10 mL sample was obtained and diluted with 40 mL
124 distilled water. The analytical grade reagents ($\text{K}_2\text{Cr}_2\text{O}_7$ and HgSO_4) were applied to a 2 mL diluted
125 sample and digested for 120 minutes at 150 °C. The COD value readings were then measured with
126 a photometer, and the findings were multiplied by a dilution factor of 10. Furthermore, a 10 mL
127 sample was obtained and diluted with 50% distilled water to assess the COD value. Then, a 2 mL
128 sample was taken from 50% diluted sample and then diluted to 40 mL. Again, 2 mL was taken
129 from this diluted sample and was added to the 90% reagents (H_2SO_4 and HNO_3) and then it was
130 digested for about 120 minutes at 148 °C. Then it was allowed to cool to room temperature and

131 its COD value was determined using a spectrophotometer. Then the COD value was multiplied by
132 40 to get the dilution factor. A conductivity meter was used to measure electrical conductivity
133 (Oyster conductivity meter). A portable pH meter was used to determine the pH of the samples
134 (Model HI9024, HANNA Instrument). A 5 mL of brewery wastewater was added to the test vial
135 with a reagent and then the TN measurement was conducted by using TN Persulfate Reagent
136 Powder Pillows. Then, this mixture was then well mixed and left for two minutes to finish the
137 reduction reaction. Moreover, the brewery wastewater was prepared without reagent and the
138 instrument was made blank after 2 minutes. Then, a photometer test was used to analysis these
139 prepared sample. Moreover, 10 mL of brewery wastewater was added to the test kit along with the
140 reagent and then the solution was thoroughly mixed to ensure complete reactivity of the sample
141 and the TP was determined by using HI713-25 Phosphate LR reagents. Similarly, blank solution
142 was prepared using a similar sample without the reagent. Then these prepared solutions were
143 analyzed using Photometer. The TP of the sample was measured inside the cuvette using HI96706
144 portable phosphorus photometer. The photometer was also used to measure the TSS in a 10 mL of
145 the sample within a cuvette. Moreover, bacteria were obtained from a brewery wastewater
146 treatment plant and nutrient broth was used to make a medium for bacteria growth and then were
147 used in the anaerobic digestion process. A total of 50 mL of mixed bacteria were grown for 24
148 hours at 37 °C in a 100 mL nutrient broth medium and then the cultured bacteria were placed into
149 the anodic chamber [17].

150 **2.4. Electrical Capacity of the MFC**

151 The voltage generated from the MFC system was measured using a digital voltmeter at 12-hour
152 intervals for consecutive 20 days. The Ohm's law was employed to calculate the current ($I = V/R$)
153 and power ($P = I \cdot V$) where V is the measured cell voltage in volts (V), R is the external load
154 resistor in Ohms (Ω), I is current in amperes (A), and P is the power output P in watts (W) as per
155 the method reported in [18]. By dividing the current (V/R) and power ($I \cdot V$) with the anode's
156 surface area (A in m^2), the power and current density were determined by dividing I and P with
157 the anode's surface area (A , m^2). The polarization curves (voltage versus current density) were
158 calculated using the measured voltage and current values at different external resistance values
159 (2000, 1500, 1200, 1000, 700, 500, 300, 150, 100, 50 Ω). In addition, the power and current density
160 values were calculated for each resistance values. Then, the external power density curve was

161 obtained from power density vs current density plot. The internal resistance of the MFC was
 162 determined using a method that has been reported somewhere else [19]. The COD removal
 163 efficiency of the MFC was calculated by using brewery wastewater with a COD concentration of
 164 2520mg/L in the anodic chamber. Then the anodic chamber was replaced with COD
 165 concentrations of 2250,1350, and900 mg/L consecutively. All measurements were done in a batch
 166 mode for a total of 20 inoculation days. The COD values of the samples were determined using a
 167 method described in [20] before and after the tests. The COD removal efficiency was estimated
 168 for each brewery wastewater sample by using $COD = COD_0 - COD_t / COD_0 * 100$ where COD_0 is
 169 the initial COD concentration at time zero and COD_t is the COD concentration at time t. The CE
 170 of the MFC system was calculated using Equation (1).

171
$$CE = \frac{M \int_0^t I dt}{(Fb V_{an} \Delta COD)} * 100\% \text{----- (1)}$$

172 where M is a molecular weight of O₂, b is 4 electrons exchanged per mole of oxygen, F is the
 173 Faraday’s constant (96485 C/mole - electrons), V_{an} is the volume of the anode medium chamber,
 174 and ΔCOD is the change in the COD over time. The overall experimental procedures was
 175 summarized in **Figure1**.

176 Further more ,the solution resistance was estimated from the solution conductivity (σ,mS/cm) as
 177 $R (\Omega) = 10^3 * l * A$, where A is the cross-sectional area between the electrodes (cm²), 10³ is to
 178 convert mS into S (where 1 S = 1), and l is the distance between the electrodes assuming equidistant
 179 (unit)for the whole MFC operational setup as per the methods suggested in[21],[22].

180 **2.5. Brewery Waste Water Characterization**

181 The physicochemical composition of brewery wastewater including COD, biological oxygen
 182 demand (BOD), TN, TP, total suspended solids (TDS), and pH values were determined by the
 183 standard method of the American Water Works Association (AWWA) (**Table 1**).

184 **Table 1. Average physicochemical composition of Dashen brewery wastewater (Note: All**
 185 **values were measured in mg/L. σ was measured in μS/cm).**

Parameters	pH	COD	TN	BOD	TP	TSS	TDS	σ
Values	8.15±0.72	2700±0.55	42±0.6	1200±0.41	45±0.97	460±0.21	505±0.37	152±0.56

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187 The COD values of the brewery effluent samples were in the range of 2500 to 5000 mg/L. The
 188 average COD value was 2700 mg/L, showing that it is appropriate and recommended for power
 189 generation[23] ,and already confirmed by[24]. The TN and TP levels were 42 and 45 mg/L,
 190 respectively and these values showed that the brewery waste can be used as a source of nutrition
 191 due to its food-derived nature that is suitable for bacterial growth [17]. The σ value was 152 μS
 192 /cm, indicating the ionic strength of the brewery wastewater and it would play a significant role in
 193 the power or voltage generation .In summary,the detail average measured physicochemical
 194 composition of the brewery wastewater (Table 1) confirmed that the brewery wastewater samples
 195 are the potential material for energy generation via MFC and it is consistent with the results
 196 reported somewhere else [14].

197 2.5. MFC Inoculation and Operational Conditions

198 The MFC was inoculated with brewery wastewater and mixed bacterial (exo-electrogen) and were
 199 cultured and operated in batch mode. The anodic chamber's and the networking volume were 2
 200 and 1.5 L, respectively. The anodic chamber was fed with a mixture of bacteria and prepared
 201 substrates and then it was kept at an anaerobic condition (pH = 8.15) (Table 1). Similarly, the
 202 cathodic chamber was fed with KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$ (pH = 8.15) and was maintained in an
 203 aerobic environment at ambient temperature.

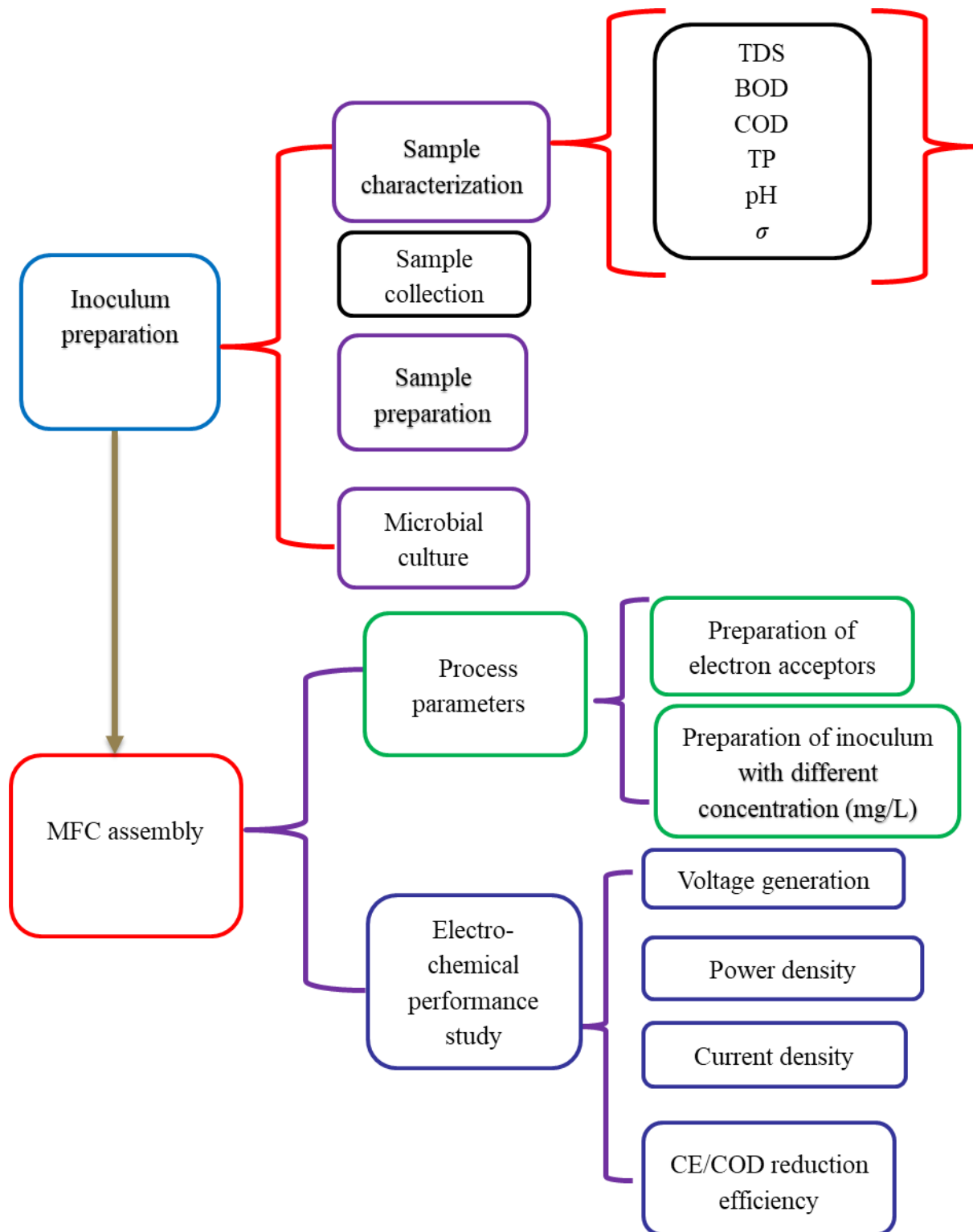
204 **Table 2. Volume of waste water sample, distilled water and culture medium (Note: All values**
 205 **are in mL. COD value is in mg/L).**

Volume of wastewater sample	Volume of culture medium	Volume of distilled water	Total volume of sample loaded to the MFC	COD
1400	100	0	1500	2520
1250	100	150	1500	2250
750	100	650	1500	1350
500	100	900	1500	900

206 **Table 3. Concentration of electron acceptor solution (catholyte).**

Parameters	Cathode ($\text{K}_3[\text{Fe}(\text{CN})_6]$)	Cathode (KMnO_4)
Electron acceptors solution	0.4 M	0.4 M
Concentration	0.6 M	0.6 M

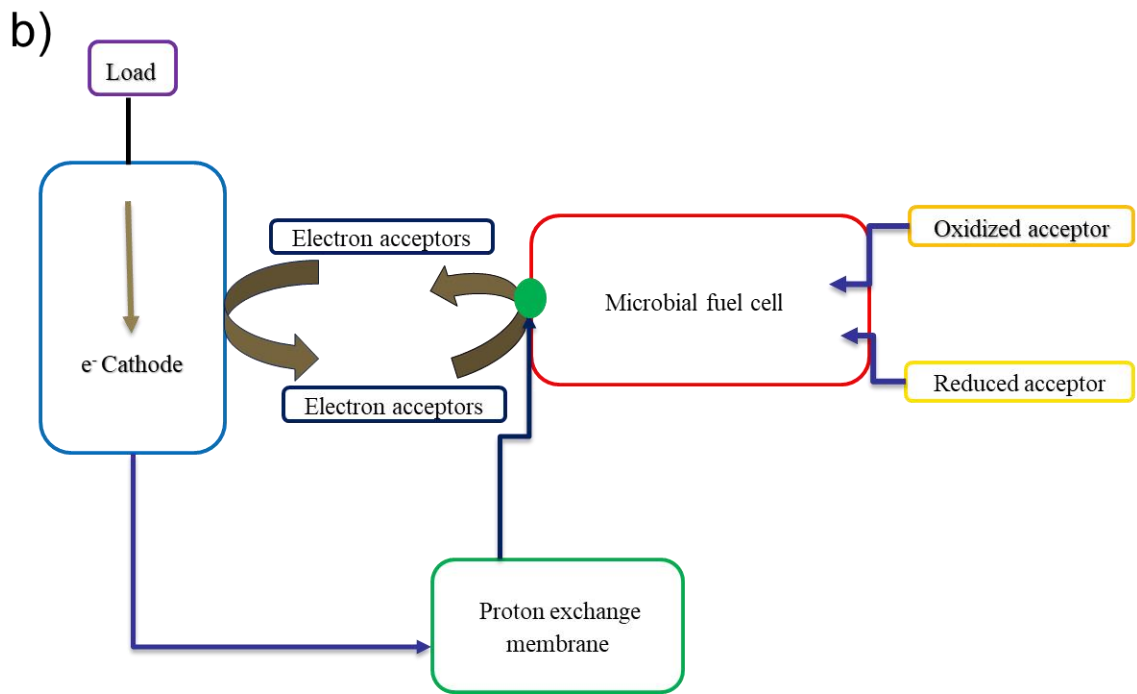
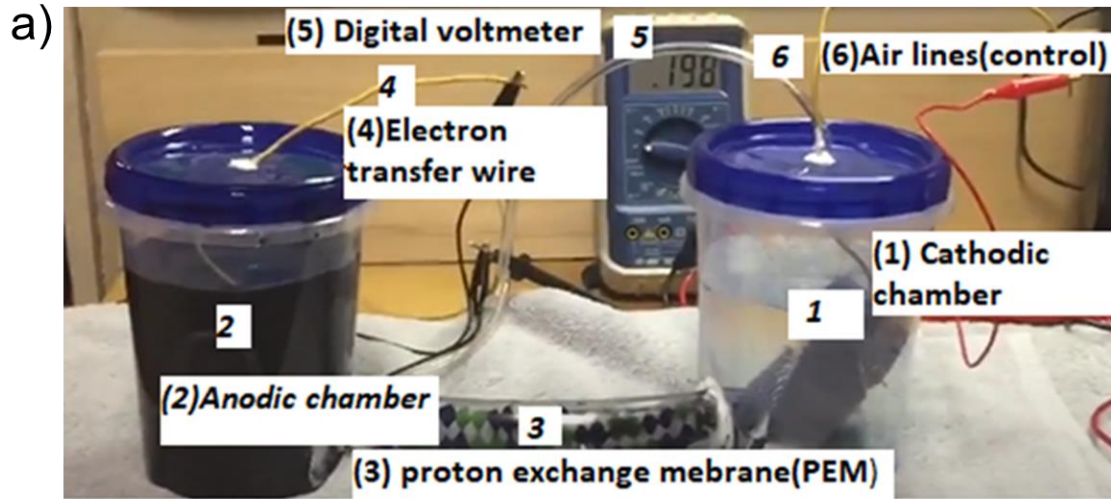
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Figure 1. Summary of the overall Experimental schemes .



210

211 **Figure 2:** Experimental set up. (a) The MFC Experimental configuration of the Double-
 212 Chamber MFC. (b) Schematic representation of the electrochemical process in MFC.

213

214 **2.6. Experimental Design, Statistical Tools Used for Data Analysis**

215 SPSS, IBMS 20 was used for analysis and statistical significance test. The statistical method of
 216 CCD method was used for analysis of variance to test the significance of each experimental factors
 217 on the responses. The three experimental variables namely sample COD values (900, 1350, 2250,
 218 and 2520 mg/L), type of electron acceptors (KMnO₄ and K₃[Fe (CN)₆], and electron acceptors
 219 concentration (0.4 and 0.6 M) were chosen for the MFC system (**Table 4**). All measurements were
 220 done in triplicate for each batch. All experimental measured values were presented in the
 221 supplementary materials provided as DIB at Mendeley [Data/Microbial fuel cell data](https://doi.org/10.17632/gdpxvj8gp.1), DOI:
 222 [10.17632/gdpxvj8gp.1](https://doi.org/10.17632/gdpxvj8gp.1)

223 **3. Results and Discussion**

224 The effect of electron acceptor concentrations had a pronounced impact on external voltage output. The
 225 external voltage output difference encountered between the two different electron acceptors and
 226 inoculum COD concentrations when tested via students- test (for p<0.05) showed statistically significant
 227 value(**Table 4-5**).

228 **Table 4: Effect of electron acceptor concentration, inoculum COD concentration and Voltage**
 229 **generation**

Factors COD (mg/L)	Electron acceptors			
	KMnO ₄ Concentration (M)		K ₃ [Fe(CN) ₆ Concentration (M)	
	0.4	0.6	0.4	0.6
	900	200.78 ± 0.026	213.70 ± 0.84	260.31 ± 0.21
	200.78 ± 0.26	213.10 ± 0.08	260.02 ± 0.21	280.15 ± 0.86
	200.78 ± 0.12	213.04 ± 0.4	260.25 ± 0.21	280.12 ± 0.86
1350	200.00 ± 0.05	227.03 ± 0.16	237.13 ± 0.16	260.02 ± 0.12
	200.01 ± 0.21	227.24 ± 0.1	237.02 ± 0.16	260.10 ± 0.12
	200.45 ± 0.16	227.41 ± 0.026	237.23 ± 0.16	260.12 ± 0.12
2250	192.200 ± 0.086	201.84 ± 0.026	205.02 ± 0.086	241.02 ± 0.03
	192.49 ± 0.043	201.07 ± 0.12	205.03 ± 0.043	241.21 ± 0.03
	192.32 ± 0.118	201.04 ± 0.12	205.09 ± 0.118	241.31 ± 0.03
2520	138.20 ± 0.37	195.00 ± 0.05	198.00 ± 0.03	195.02 ± 0.086
	138.15 ± 0.03	195.99 ± 0.05	198.30 ± 0.12	195.02 ± 0.086
	138.00 ± 0.12	195.51 ± 0.05	198.40 ± 0.05	195.02 ± 0.086

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The data presented in Table 4 was further analyzed using SPSS IBMS 20 (i.e., univariant analysis of means). **Table 5** illustrates the two-ANOVA test results for the cell voltage and the $p < 0.05$ value confirms that the interaction effect of the COD, type of electron acceptors and electron acceptors concentration on the cell voltages of the MFC system.

Table 5: ANOVA Tests of between-subjects effects, (α) = 0.05

Table 5: ANOVA a Tests of between-subjects effects, (α)=0.05

Dependent Variable: Cell Voltage							Remarks
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	
Corrected Model	46840.170a	12	3903.348	57051.513	.000	1.000	
Intercept	1443595.339	1	1443595.339	21099658.291	.000	1.000	
COD concentration	20648.816	3	6882.939	100601.357	.000	1.000	√
EC	32174.052	3	10724.684	156752.491	.000	1.000	√
COD concentration* EC	2592.016	6	432.003	6314.171	.000	.999	√
Error	1.779	26	.068				
Total	1814708.198	39					
Corrected Total	46841.949	38					
a. R Squared = 1.000 (Adjusted R Squared = 1.000)							
Note: “√” indicates the significance of the factors; COD conc ⁿ :Inoculum COD concentrations ; EC:Catholyte concentrations							

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3.1 Effect of Substrate Concentrations on COD Removal and Coulombic Efficiency

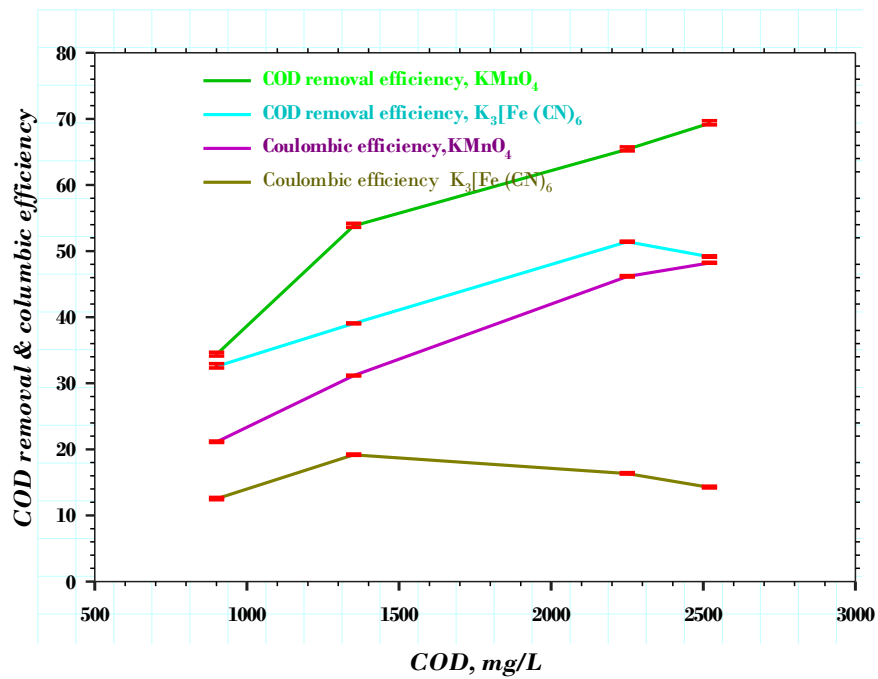
The grand peak voltage production potential values at 0.4 and 0.6 M KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$ were used for the COD removal and coulombic efficiency of the treated KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$

243 electron acceptors (**Figure 3**). A maximum COD removal efficiency of $69.25 \pm 2.5\%$ and
244 $45.12 \pm 0.28\%$ were obtained at 0.4 M KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$ respectively for the MFC system.
245 The 0.4 M treated KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$ at inoculum COD concentration values of 2250 &
246 2520 mg/L resulting in 64 and 32.49% COD removal efficiency respectively. Moreover, an
247 exponential trend was noticed up to 1350 mg/L inoculum followed by a steadily increase in %
248 removal for inoculum concentrations (1350-2520 mg/L) and at 0.4M KMnO_4 terminal electron
249 acceptors. On the contrary, a sharp decrement of COD % removal was observed starting from 2250
250 mg/L for 0.4 M $\text{K}_3[\text{Fe}(\text{CN})_6]$. These could be due to a high oxidation potential of KMnO_4 in than
251 $\text{K}_3[\text{Fe}(\text{CN})_6]$ as it dissipates all the electron in the electrode and results in a strong move from the
252 anode in the open circuit mode. This produces a high level of stress of the biocatalysts and may
253 stimulate the bacteria to degrade organic compounds more quickly, making it suitable for
254 wastewater treatment [2], [25]. Moreover, the efficiency of the MFC was evaluated based on the
255 coulombic efficiency (CE). The CE rate describes the performance of the MFC system and
256 shows how many electrons are transferred in a system to carry out an electrochemical reaction and
257 it is directly corresponding to the number of electrons recovered in the organic matter. The average
258 maximum values of $48 \pm 0.25\%$ and $19.1 \pm 0.1\%$ CE of the MFC system were obtained at 0.4 M
259 KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$, respectively. These results showed a 12 and 2 fold increase of CE for
260 KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$, respectively and this results maximum compared to the previously
261 reported CE values reported somewhere else using air and Sodium hypochlorite (NaOCl) [26].

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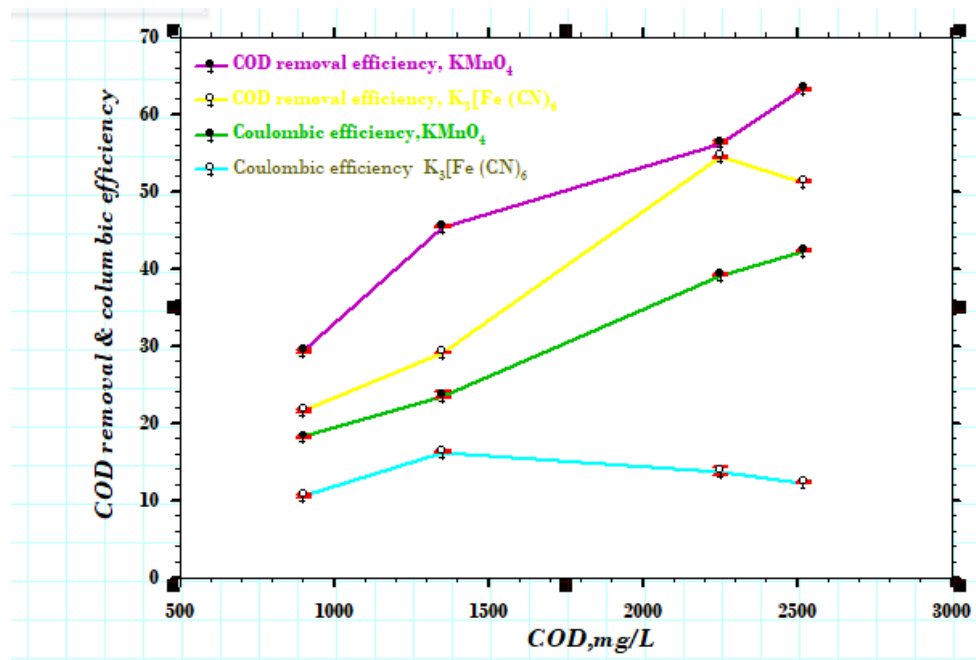
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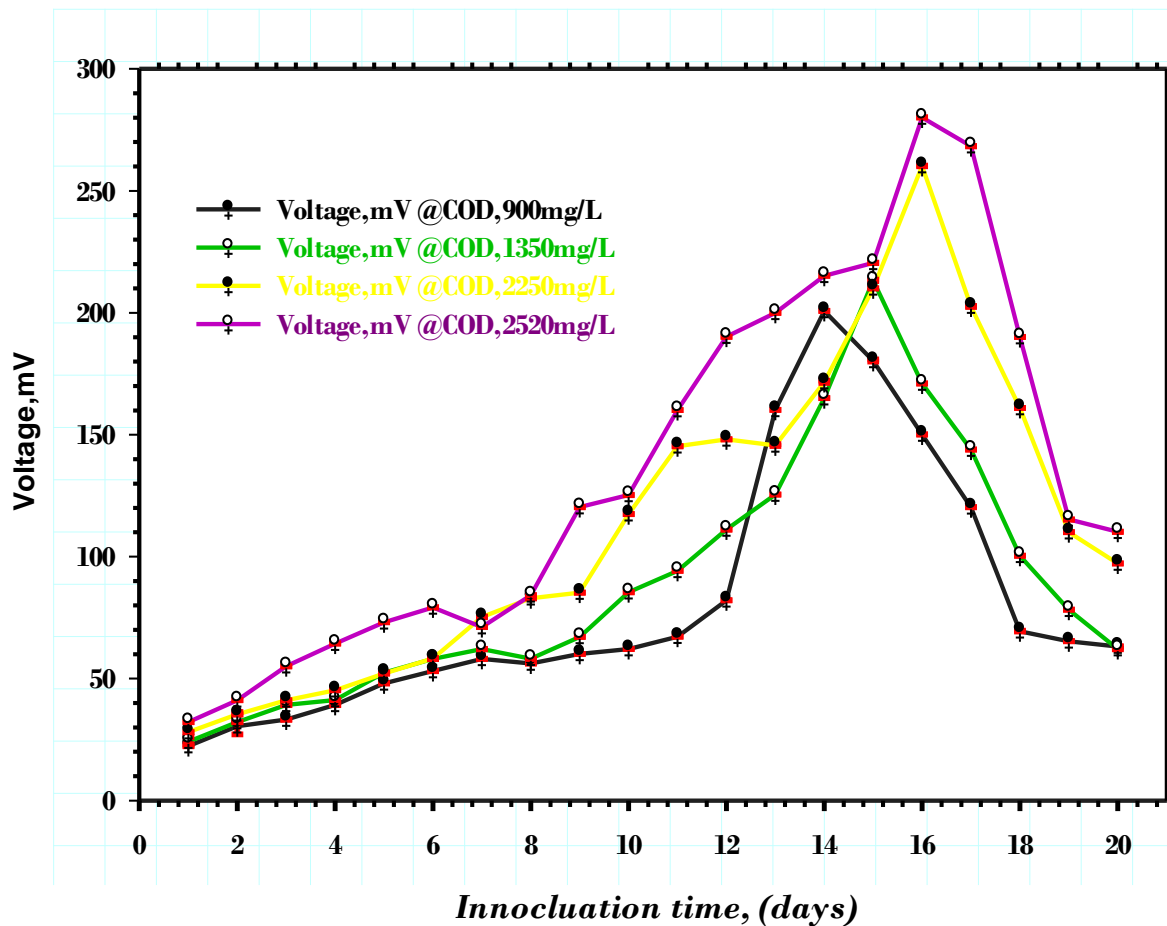
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268 **Figure 3.** CE and COD removal efficiency of the MFC with an error bar. (a) 0.4 M KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$
 269 $(\text{CN})_6$ electron acceptors. (b) 0.6 M KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$ electron acceptors.

270 Moreover, the voltage generation potential of the MFC with 0.4-0.6 M KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$
271 terminal electron acceptor has been investigated (**Figure 4-8**). As we can see from **Figure.4**, The
272 voltage generation potential of the MFC system with 0.4M KMnO_4 showed a similar trend with
273 a step wise exponential increment of external voltage out-put. However, an exceptional trend was
274 noticed at inoculum COD value of 2520 mg/L showing the non-stable nature of out-put cell
275 voltage. This could be due to the high organic load and less volume of microbial culture in the
276 inoculum that can seriously affecting the exponential growth of electro-active bacteria [27]. The
277 voltage generation potential of the MFC system (0.4 M KMnO_4 terminal electron acceptor) steadily
278 increased up to six days of operation and exponential increment of voltage generation observed
279 from at the 7th day to 13th day and the peak voltage values were recorded in between 13th and 16th
280 days of MFC system operation (**Figure 4**). This shows the positive correlation between the active
281 microbial strains (*Geobacter*) biofilm formation on the anode chamber with the number of days of
282 operation [28]. Similarly, the peak voltage values 200.8 ± 0.026 , 213.28 ± 0.298 , 260.193 ± 0.135
283 and 280.97 ± 0.05 mV was observed at the inoculum COD concentration of 900, 1350, 2250 and
284 2520 mg/L respectively at 20th day of operation, showing the effect of COD concentration and
285 microbial culture volume on the bacterial growth and activity. Moreover, the higher substrate
286 concentrations could distort the metabolism of microorganisms [25], [29]. After 16th day the
287 voltage generation potential of the MFC system was decreased, indicating the reduction in the
288 active electrogenic bacterial strains and the exhaustion of brewery waste water substrates for all
289 values of the inoculum COD concentrations. Hence, the production of voltages in MFC is directly
290 related to the availability of organic substrates in the inoculum [29].

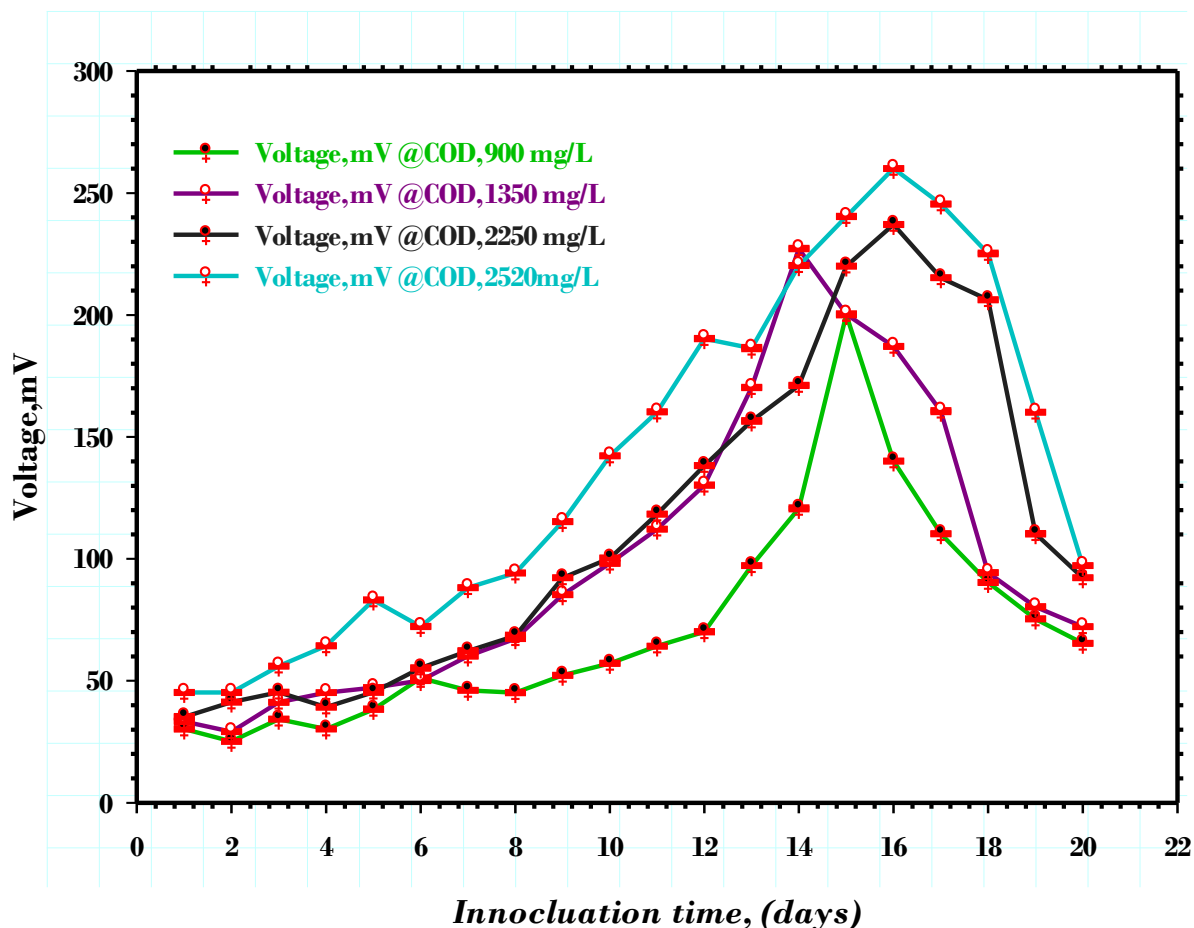


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292 **Figure 4:** Voltage generation potential of the MFC system with error bar at 0.4 M KMnO_4 .

293 Similarly, voltage generation potential of the MFC system at 0.6 M KMnO_4 for 20 days of operation
 294 has been investigated (**Figure 5**). The result shows that an exponential increase in the voltage
 295 generation potential were observed for up to the 7th day for all values of the inoculum COD
 296 concentrations and a sharp decline in voltage generation potential was observed from 13-17th days
 297 of MFC operation. The peak voltage generation potential was obtained at low values of inoculum
 298 COD concentrations (900 & 1350 mg/L) with a steadily increment and unstable voltage outputs
 299 were obtained for the high values of inoculum COD concentrations (2250 & 2520 mg/L). This
 300 could be due to the release of KMnO_4 through PEM to the anode chamber and development of
 301 osmotic pressure that may inhibit the movement of protons to the cathode chamber. Moreover, the
 302 high organic load in the inoculum could distort the biodegradation efficiency of exaelectrons [1].
 303 Moreover, there is a slight reduction of the cell voltage for all values of COD concentrations (900-

304 2520 mg/L) showing the electron acceptor molar concentration effect on the output external
305 voltage [30].

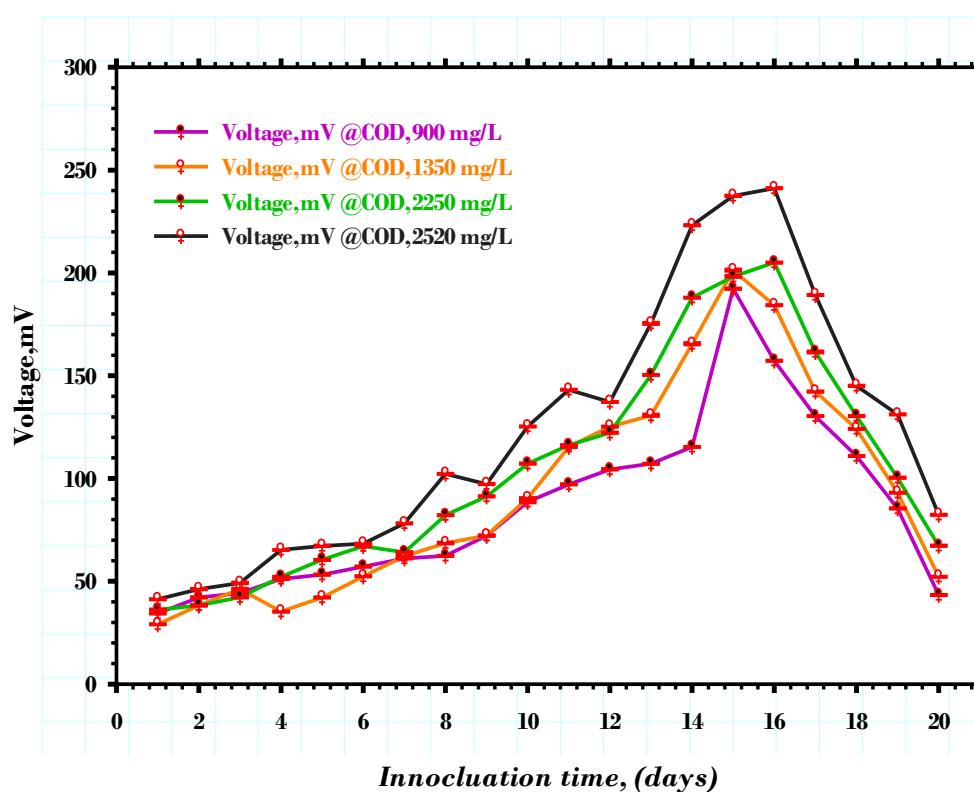


306

307 **Figure 5.** Voltage generation potential of the MFC system with error bar at 0.6 M KMnO_4 .

308 Furthermore, the voltage generation potential of the MFC using 0.4 M $\text{K}_3[\text{Fe}(\text{CN})_6]$ (**Figure 6**) and
309 0.6 M $\text{K}_3[\text{Fe}(\text{CN})_6]$ (**Figure 7**) catholyte was investigated. The voltage generation potential of 0.4 M
310 $\text{K}_3[\text{Fe}(\text{CN})_6]$ was increased exponentially for up to 15th days of operation and a sharp decline in
311 external voltage generation potential was obtained after 16-17th days of MFC system for all
312 inoculum COD concentration (**Figure 6**). However, the maximum external voltage output was
313 achieved at 14-15th days of MFC operation for low COD concentration values (900 and 1350
314 mg/L) and 15-16th days of inoculation time for the inoculum COD concentrations of 2250 and
315 2520 mg/L. The early achievement of peak voltages for low inoculum COD concentrations (900
316 and 1350mg/L) can be attributed to the presence of organic loads that were easily degraded by
317 microorganisms suggesting an early establishment of electrolyte and promotion of oxidation
318 process [31]. Similarly, the higher intensity of the external voltage output of the MFC at 2520

319 mg/L inoculum COD concentration was achieved as microorganisms increase their enzymatic
 320 production at higher value of the COD and or enhances of the ability of the microorganisms to
 321 generate external power [32]. During the high loading period, an exponential change was observed
 322 for the first 16th days and then getting declined. This was mainly due to the favor of microbes for
 323 a higher voltage generation at a specific substrate concentration and limited size of the MFC and
 324 the dilution of the ionic strength of the electron acceptor [2]. Besides, it can be noticed that the
 325 voltage generation potential of the MFC exceptionally increases up to 14 days of operation at an
 326 inoculum concentration of 2520mg/L showing the effect of the organic load of the MFC and the
 327 concentration of the ferricyanide could directly related to the oxidation rate of the substrate
 328 [33];[34].



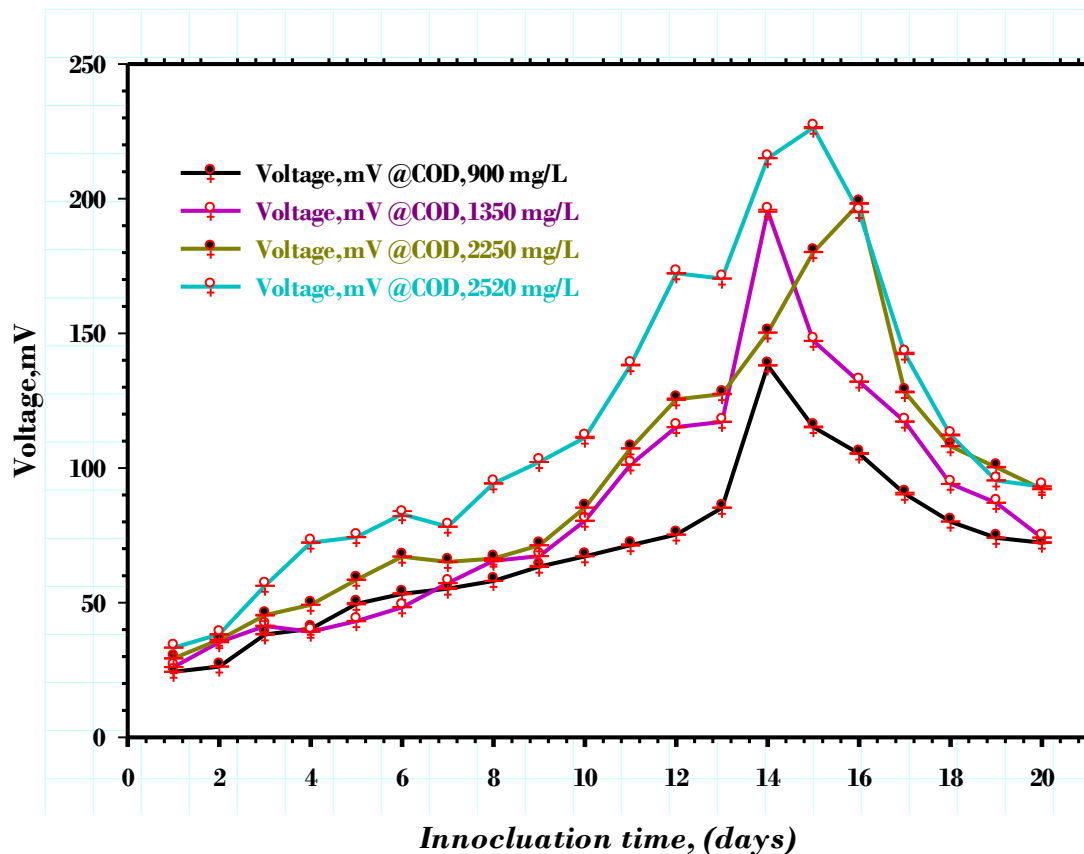
329
 330 **Figure 6:** Voltage generation potential of the MFC system with error bar at 0.4 M $K_3[Fe(CN)_6]$
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The effect of 0.6 M $K_3[Fe(CN)_6]$ at various inoculum COD concentration and time was investigated to further explore the effect of catholyte concentration on the voltage generation potential in the MFC system (**Figure 7**). The peak voltage values of 138.12 ± 0.85 , 195.5 ± 0.4 , 198.2 ± 0.17 , and 226.37 ± 0.27 mV were obtained at 900, 1350, 2250, and 2520 mg/L inoculum concentrations.

However, the overall trend of cell voltage generation profile for 2520mg/L inoculum COD concentration exhibit non uniform pattern and characterized by higher intensities. This can be explained as microbial activities were highly hampered by high inoculum COD concentrations and unable to maintain its exponential growth due to the stress caused by high organic loads of the inoculum. More importantly, when the concentration of the catholyte increases from (0.4M-0.6M) $K_3[Fe(CN)_6]$, a relative smooth exponential profile of voltage output was noticed even for high inoculum COD concentrations. Based on the work reported in [31], the lowest electron acceptor concentration in MFC system could lead to diffused from the catholyte to the anode chamber through the PEM, where they immediately absorbed electrons from the anolyte (competing with the anode material) and voltage out put get destabilized. In summary, the study of this result reveals the summation effect of increase in COD concentration could delay the microbial activity and a pronounced low voltage out put was observed in comparison to the work reported in[31],[33].

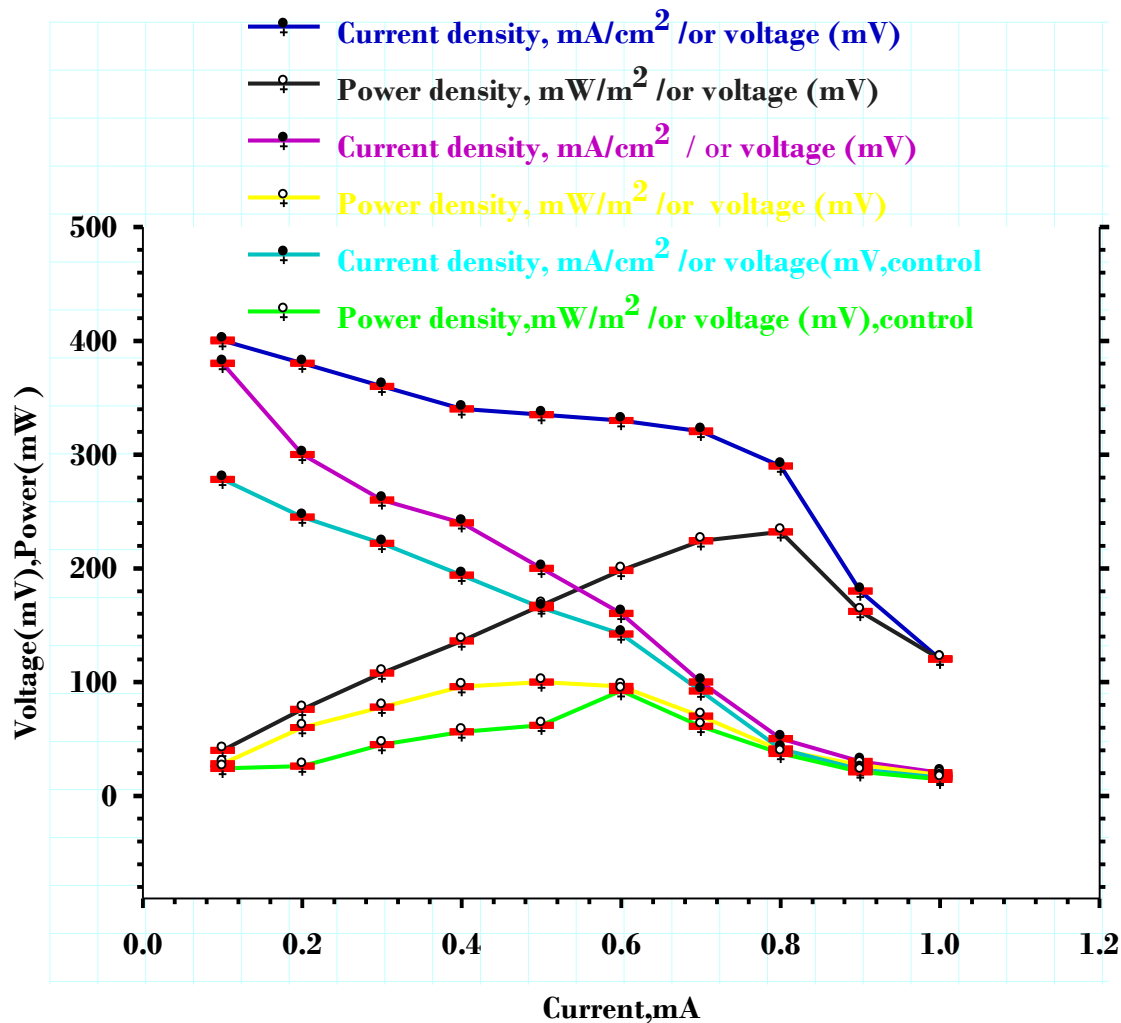


358

359 **Figure 7:** Voltage generation potential of the MFC system with error bar at 0.6 M $K_3[Fe(CN)_6]$

360 Finally, polarization curves and the external output power density for MFC system were obtained
 361 at inoculum COD concentration of 2520 mg/L using 0.4 M $KMnO_4$ and $K_3[Fe(CN)_6]$ electron
 362 acceptors (**Figure 8**). Polarization studies were carried out based on the internal resistance which
 363 is responsible for electron losses caused by ohmic and activation losses [25].The external
 364 resistance values were 2000, 1500, 1200, 1000, 700, 500, 300, 150, 100, and 50 Ω . The
 365 corresponding current and power density were calculated for each external resistance (**Figure 8**).
 366 The result showed that the power density increased moderately from 40.2 ± 0.05 to 232.2 ± 0.2
 367 mW/m^2 whereas the current density decreased from 0.9 to 0.8 mA/Cm^2 . These power density
 368 values were in good agreement with the one reported somewhere else [25], [35]. The decrease in
 369 the current density values and the moderate increment of external power density could be due to
 370 the activation energy required for the oxidation-reduction reaction and the rapid drop of voltage.
 371 Similarly,the voltage and power density reduced at a higher value of current density and this might
 372 be due to the over potential of the electrode material [36].The study of this result reveals a a

373 comparative external out power density was attained to the one reported values somewhere else
 374 [31], [37], [38].



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 378 **Figure 8.** Polarization and power density curves for the maximum efficiency of voltage generation
 379 (COD value of 2520 mg/L) with error bars. The blue and purple color represent the 0.4 M KMnO₄
 380 final electron acceptor. The orange and the light purple line represent the 0.4 M K₃[Fe(CN)₆ final
 381 electron acceptor. The light blue and the green line represent the control electron acceptor.

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385 **Conclusion**

386 The effect of two different electron acceptors using real brewery waste water as a substrate in dual
387 chamber MFC under a set of different operating conditions were conducted. During the
388 electrochemical study, the three experimental variables including COD values (900, 1350, 2250,
389 and 2520 mg/L), type of electron acceptors (KMnO_4 and $\text{K}_3[\text{Fe}(\text{CN})_6]$), and electron acceptors
390 concentration (0.4 and 0.6 M) were employed for the MFC system to achieve maximum voltage
391 generation, power density and COD reduction. The result showed that the power density and COD
392 reduction efficiency was affected by the process parameters and a pronounced effect was noticed by the
393 variation of inoculum composition, types and concentration of electron acceptors. Hence, MFC with 0.4
394 M KMnO_4 and $[\text{K}_3\text{Fe}(\text{CN})_6]$ provide an external maximum output voltage of 310.09 ± 0.06 and
395 252.18 ± 0.12 mV and an external output power density of 400.4 ± 0.46 and 380.28 ± 0.24 mW/m²
396 respectively. Similarly, the COD removal efficiency of $69.33 \pm 0.33\%$ and 51.41 ± 0.077 were
397 achieved for the MFC with 0.4 M KMnO_4 and $[\text{K}_3\text{Fe}(\text{CN})_6]$ correspondingly. More importantly, an
398 increased in COD concentration of the inoculum (substrate) in the MFC system results in a step
399 wise increment in the voltage. The higher power density values were obtained using KMnO_4
400 compared with $[\text{K}_3\text{Fe}(\text{CN})_6]$. However, in all the experiments runs an increase in COD concentration of
401 the inoculum (substrate) in the MFC yields nearly a step wise increment of voltage and an exceptional case
402 was noticed while the experiments were carried out at 2520 mg/L as the voltage curves behaves unstable
403 response and further research could be conducted to address the stability issue for high COD
404 concentrations in just to assure sustainable power generation at large scale application using batch MFCs.

405 **CRedit Author Statement**

406 **Tegen Dagnew Tessema:** Designed the experiments (conceptualization), collected and analyzed
407 the data, interpretation of results, and wrote the original draft, editing and proof reading.

408 **Temesgen Atnafu Yemata:** Designed the experiments (conceptualization), editing and reviewed
409 the paper.

410 **Declaration of Competing Interest**

411 The authors declare that they have no known competing financial interests or personal relations-
412 ships which could have appeared to influence the work reported in this paper.

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420 **Supplementary Materials**

421 Supplementary material associated with this article can be found in the online version at
422 <https://data.mendeley.com/datasets/gydpvxj8gp/1/> DOI:10.17632/gydpvxj8gp.1.

423 **References**

- 424 [1] L. Wei, H. Han, and J. Shen, “Effects of cathodic electron acceptors and potassium
425 ferricyanide concentrations on the performance of microbial fuel cell,” *Int. J. Hydrogen*
426 *Energy*, vol. 37, no. 17, pp. 12980–12986, Sep. 2012, doi:
427 10.1016/J.IJHYDENE.2012.05.068.
- 428 [2] A. J. T. Harewood, S. R. Popuri, E. I. Cadogan, C.-H. Lee, and C.-C. Wang,
429 “Bioelectricity generation from brewery wastewater in a microbial fuel cell using
430 chitosan/biodegradable copolymer membrane,” *Int. J. Environ. Sci. Technol.* 2017 147,
431 vol. 14, no. 7, pp. 1535–1550, Feb. 2017, doi: 10.1007/S13762-017-1258-6.
- 432 [3] P. Choudhury, R. N. Ray, T. K. Bandyopadhyay, O. N. Tiwari, and B. Bhunia, “Kinetics
433 and performance evaluation of microbial fuel cell supplied with dairy wastewater with
434 simultaneous power generation,” *Int. J. Hydrogen Energy*, vol. 46, no. 31, pp. 16815–
435 16822, May 2021, doi: 10.1016/J.IJHYDENE.2020.08.024.
- 436 [4] B. Neethu and M. M. Ghangrekar, “Electricity generation through a photo sediment
437 microbial fuel cell using algae at the cathode,” *Water Sci. Technol.*, vol. 76, no. 12, pp.
438 3269–3277, Dec. 2017, doi: 10.2166/WST.2017.485.
- 439 [5] A. S. Jatoi *et al.*, “Advanced microbial fuel cell for waste water treatment—a review,”
440 *Environ. Sci. Pollut. Res.* 2020 285, vol. 28, no. 5, pp. 5005–5019, Nov. 2020, doi:
441 10.1007/S11356-020-11691-2.
- 442 [6] S. Chong, T. K. Sen, A. Kayaalp, and H. M. Ang, “The performance enhancements of
443 upflow anaerobic sludge blanket (UASB) reactors for domestic sludge treatment – A
444 State-of-the-art review,” *Water Res.*, vol. 46, no. 11, pp. 3434–3470, Jul. 2012, doi:
445 10.1016/J.WATRES.2012.03.066.
- 446 [7] C. Donovan, A. Dewan, H. Peng, D. Heo, and H. Beyenal, “Power management system
447 for a 2.5 W remote sensor powered by a sediment microbial fuel cell,” *J. Power Sources*,
448 vol. 196, no. 3, pp. 1171–1177, Feb. 2011, doi: 10.1016/J.JPOWSOUR.2010.08.099.

- 449 [8] D. Pant, G. Van Bogaert, L. D.-B. Technology, and U. 2010, “A review of the substrates
450 used in microbial fuel cells (MFCs) for sustainable energy production,” *Elsevier*, vol. 101,
451 no. 6, pp. 1533–1543, 2010, doi: 10.1016/j.biortech.2009.10.017.
- 452 [9] D. Singh and Y. Baranwal, “Microbial fuel cells: A green technology for power
453 generation,” no. January 2010, 2018.
- 454 [10] D. P. B. T. B. Strik, H. V. M. Hamelers, and C. J. N. Buisman, “Solar energy powered
455 microbial fuel cell with a reversible bioelectrode,” *Environ. Sci. Technol.*, vol. 44, no. 1,
456 pp. 532–537, Jan. 2010, doi:
457 10.1021/ES902435V/SUPPL_FILE/ES902435V_SI_001.PDF.
- 458 [11] Heijne et.al, “Microbial fuel cell operation with continuous biological ferrous iron
459 oxidation of the catholyte,” *Environ. Sci. Technol.*, vol. 41, no. 11, pp. 4130–4134, Jun.
460 2007, doi: 10.1021/ES0702824/SUPPL_FILE/ES0702824SI20070313_124901.PDF.
- 461 [12] T. R. Eliato, G. Pazuki, and N. Majidian, “Potassium permanganate as an electron receiver
462 in a microbial fuel cell,” *Energy Sources, Part A Recover. Util. Environ. Eff.*, vol. 38, no.
463 5, pp. 644–651, Mar. 2016, doi: 10.1080/15567036.2013.818079.
- 464 [13] S. You, Q. Zhao, J. Zhang, J. Jiang, and S. Zhao, “A microbial fuel cell using
465 permanganate as the cathodic electron acceptor,” *J. Power Sources*, vol. 162, no. 2 SPEC.
466 ISS., pp. 1409–1415, 2006, doi: 10.1016/j.jpowsour.2006.07.063.
- 467 [14] Y. Feng, X. Wang, B. E. Logan, and H. Lee, “Brewery wastewater treatment using air-
468 cathode microbial fuel cells,” *Appl. Microbiol. Biotechnol. 2008 785*, vol. 78, no. 5, pp.
469 873–880, Apr. 2008, doi: 10.1007/S00253-008-1360-2.
- 470 [15] D. E. Holmes, K. P. Nevin, and D. R. Lovley, “Comparison of 16S rRNA, nifD, recA,
471 gyrB, rpoB and fusA genes within the family Geobacteraceae fam. nov.,” *Int. J. Syst. Evol.*
472 *Microbiol.*, vol. 54, no. 5, pp. 1591–1599, Sep. 2004, doi: 10.1099/IJS.0.02958-
473 0/CITE/REFWORKS.
- 474 [16] Y. Feng, X. Wang, B. E. Logan, and H. Lee, “Brewery wastewater treatment using air-
475 cathode microbial fuel cells,” *Appl. Microbiol. Biotechnol.*, vol. 78, no. 5, pp. 873–880,
476 2008, doi: 10.1007/s00253-008-1360-2.
- 477 [17] M. A. Islam, B. Ethiraj, C. K. Cheng, A. Yousuf, and M. M. R. Khan, “Electrogenic and
478 Antimethanogenic Properties of *Bacillus cereus* for Enhanced Power Generation in
479 Anaerobic Sludge-Driven Microbial Fuel Cells,” *Energy and Fuels*, vol. 31, no. 6, pp.
480 6132–6139, 2017, doi: 10.1021/acs.energyfuels.7b00434.
- 481 [18] B. E. Logan, “Exoelectrogenic bacteria that power microbial fuel cells,” *Nat. Rev.*
482 *Microbiol. 2009 75*, vol. 7, no. 5, pp. 375–381, Mar. 2009, doi: 10.1038/nrmicro2113.
- 483 [19] A. Al-Mamun, O. Lefebvre, M. S. Baawain, and H. Y. Ng, “A sandwiched denitrifying
484 biocathode in a microbial fuel cell for electricity generation and waste minimization,” *Int.*
485 *J. Environ. Sci. Technol.*, vol. 13, no. 4, pp. 1055–1064, 2016, doi: 10.1007/s13762-016-
486 0943-1.

- 487 [20] S. H. Jenkins, *Standard Methods for the Examination of Water and Wastewater*, vol. 16,
488 no. 10. 1982.
- 489 [21] R. Rossi, B. P. Cario, C. Santoro, W. Yang, P. E. Saikaly, and B. E. Logan, “Evaluation of
490 Electrode and Solution Area-Based Resistances Enables Quantitative Comparisons of
491 Factors Impacting Microbial Fuel Cell Performance,” *Environ. Sci. Technol.*, vol. 53, no.
492 7, pp. 3977–3986, Apr. 2019, doi:
493 10.1021/ACS.EST.8B06004/ASSET/IMAGES/LARGE/ES-2018-06004T_0006.JPEG.
- 494 [22] B. P. Cario, R. Rossi, K. Y. Kim, and B. E. Logan, “Applying the electrode potential slope
495 method as a tool to quantitatively evaluate the performance of individual microbial
496 electrolysis cell components,” *Bioresour. Technol.*, vol. 287, Sep. 2019, doi:
497 10.1016/J.BIORTECH.2019.121418.
- 498 [23] B. E. Logan, “Exoelectrogenic bacteria that power microbial fuel cells,” *Nat. Rev.*
499 *Microbiol.*, vol. 7, no. 5, pp. 375–381, 2009, doi: 10.1038/nrmicro2113.
- 500 [24] T. D. Tessema and T. A. Yemata, “Experimental dataset on the effect of electron
501 acceptors in energy generation from brewery wastewater via a microbial fuel cell,” *Data*
502 *Br.*, vol. 37, p. 107272, Aug. 2021, doi: 10.1016/J.DIB.2021.107272.
- 503 [25] P. Choudhury and etal, “Kinetics and performance evaluation of microbial fuel cell
504 supplied with dairy wastewater with simultaneous power generation,” *Int. J. Hydrogen*
505 *Energy*, vol. 46, no. 31, pp. 16815–16822, 2021, doi: 10.1016/j.ijhydene.2020.08.024.
- 506 [26] D. A. Jadhav, A. N. Ghadge, D. Mondal, and M. M. Ghangrekar, “Comparison of oxygen
507 and hypochlorite as cathodic electron acceptor in microbial fuel cells,” *Bioresour.*
508 *Technol.*, vol. 154, pp. 330–335, 2014, doi: 10.1016/J.BIORTECH.2013.12.069.
- 509 [27] J. Vilas Boas, V. B. Oliveira, L. R. C. Marcon, M. Simões, and A. M. F. R. Pinto,
510 “Optimization of a single chamber microbial fuel cell using *Lactobacillus pentosus*:
511 Influence of design and operating parameters,” *Sci. Total Environ.*, vol. 648, pp. 263–270,
512 Jan. 2019, doi: 10.1016/J.SCITOTENV.2018.08.061.
- 513 [28] A. E. Franks, N. Malvankar, and K. P. Nevin, “Bacterial biofilms: the powerhouse of a
514 microbial fuel cell,” <http://dx.doi.org/10.4155/bfs.10.25>, vol. 1, no. 4, pp. 589–604, Jul.
515 2014, doi: 10.4155/BFS.10.25.
- 516 [29] M. A. Islam, H. R. Ong, B. Ethiraj, C. K. Cheng, and M. M. Rahman Khan, “Optimization
517 of co-culture inoculated microbial fuel cell performance using response surface
518 methodology,” *J. Environ. Manage.*, vol. 225, pp. 242–251, Nov. 2018, doi:
519 10.1016/J.JENVMAN.2018.08.002.
- 520 [30] Z. Du, H. Li, and T. Gu, “A state of the art review on microbial fuel cells: A promising
521 technology for wastewater treatment and bioenergy,” *Biotechnol. Adv.*, vol. 25, no. 5, pp.
522 464–482, 2007, doi: 10.1016/j.biotechadv.2007.05.004.
- 523 [31] L. W. Negassa, M. Mohiuddin, and G. A. Tiruye, “Treatment of brewery industrial
524 wastewater and generation of sustainable bioelectricity by microbial fuel cell inoculated

- 525 with locally isolated microorganisms,” *J. Water Process Eng.*, vol. 41, p. 102018, Jun.
526 2021, doi: 10.1016/J.JWPE.2021.102018.
- 527 [32] A. Gonzalez del Campo, J. Lobato, P. Cañizares, M. A. Rodrigo, and F. J. Fernandez
528 Morales, “Short-term effects of temperature and COD in a microbial fuel cell,” *Appl.*
529 *Energy*, vol. 101, pp. 213–217, 2013, doi: 10.1016/J.APENERGY.2012.02.064.
- 530 [33] S. K. Foad Marashi and H.-R. Kariminia, “Performance of a single chamber microbial fuel
531 cell at different organic loads and pH values using purified terephthalic acid wastewater,”
532 *J. Environ. Heal. Sci. Eng. 2015 131*, vol. 13, no. 1, pp. 1–6, Apr. 2015, doi:
533 10.1186/S40201-015-0179-X.
- 534 [34] Y. Ye *et al.*, “Effect of organic loading rate on the recovery of nutrients and energy in a
535 dual-chamber microbial fuel cell,” *Bioresour. Technol.*, vol. 281, pp. 367–373, Jun. 2019,
536 doi: 10.1016/J.BIORTECH.2019.02.108.
- 537 [35] O. Sahu, “Sustainable and clean treatment of industrial wastewater with microbial fuel
538 cell,” *Results Eng.*, vol. 4, p. 100053, Dec. 2019, doi: 10.1016/J.RINENG.2019.100053.
- 539 [36] P. C. Nien *et al.*, “Power overshoot in two-chambered microbial fuel cell (MFC),”
540 *Bioresour. Technol.*, vol. 102, no. 7, pp. 4742–4746, Apr. 2011, doi:
541 10.1016/j.biortech.2010.12.015.
- 542 [37] Y. Feng, X. Wang, B. E. Logan, and H. Lee, “Brewery wastewater treatment using air-
543 cathode microbial fuel cells,” *Appl. Microbiol. Biotechnol. 2008 785*, vol. 78, no. 5, pp.
544 873–880, Apr. 2008, doi: 10.1007/S00253-008-1360-2.
- 545 [38] “A. Singh, Bioelectricity production from various wastewaters through microbial fuel cell
546 technology.”
547 [https://jbiochemtech.com/storage/models/article/CgDdzC0YImWKafpZZDRIAWyaeavHr](https://jbiochemtech.com/storage/models/article/CgDdzC0YImWKafpZZDRIAWyaeavHrQqDF1mYzPWgg62PvPhThbIWrbB94UTe4/bioelectricity-production-from-various-wastewaters-through-microbial-fuel-cell-technology.pdf)
548 [QqDF1mYzPWgg62PvPhThbIWrbB94UTe4/bioelectricity-production-from-various-](https://jbiochemtech.com/storage/models/article/CgDdzC0YImWKafpZZDRIAWyaeavHrQqDF1mYzPWgg62PvPhThbIWrbB94UTe4/bioelectricity-production-from-various-wastewaters-through-microbial-fuel-cell-technology.pdf)
549 [wastewaters-through-microbial-fuel-cell-technology.pdf](https://jbiochemtech.com/storage/models/article/CgDdzC0YImWKafpZZDRIAWyaeavHrQqDF1mYzPWgg62PvPhThbIWrbB94UTe4/bioelectricity-production-from-various-wastewaters-through-microbial-fuel-cell-technology.pdf) (accessed Jul. 09, 2022).
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