Investigation of brewery wastewater as a potential of power generation and co-degradation of organic wastes using microbial bio-reactors (MFC): Case study for dashen brewery, Ethiopia.

Tegen Dagnew*, Bassazin Ayalew, Tadele Assefa

Department of Chemical and Food Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia

Abstract

The demand for searching bio-energy resource with an efficient conversion system is increasing worldwide. Microbial Fuel Cell (MFC) systems represent a new promising and emerging technology that generates electricity satisfactorily while Co-reduction of the organic matter in wastewater. In terms of performance, only few methodologies availability and major pollutants loads of Brewery wastewater in the country Ethiopia were the inspirations of this study. The study aims investigation of brewery wastewater as a potential of generating electricity and Co-treatment using microbial fuel cell system. A dual chamber microbial fuel cell system was assembled with graphite electrode as an anode and cathode with Nafion membrane for proton exchange, copper wire and different resistors were used.More importatntly The MFC with 4000, 3000, 2000, 1000 and 500 mg/L Chemical Oxygen Demand (COD) was inoculated with 150 ml mixed-culture of well-mixed sludge sample used anaerobically in the anode chamber (2.5 L). Potassium permanganate ($KMnO_4$) at 0.3 M, 0.5 M and 0.8 M concentration was used aerobically as a final electron acceptor in the cathode chamber (2.5 L). Alternatively, instead of potassium permanganate, air was used in the cathode chamber as the final electron acceptor. The MFC bio electro-chemical batch process was operated for 20 days. Voltage and current generation were measured by digital voltmeter and ammeter. A maximum voltage of 1060 mV was obtained at 0. 5 M $KMnO_4$ and 1000 mg/L COD on the 15th day. Taking polarization curve as a base line, the maximum power density and current density with 200 Ω external resistor were 682.83 mW/m^2 and 1.54 mA/cm^2 respectively at 0.5 M $KMnO_4$ and 1000 mg/L COD concentration. Increasing the Ohmic resistance decreased from the point of the maximum attainable power from 682.83 mW/m^2 to 69.14 mW/m^2. The current also decreased consistently with increasing of the resistance from 1.54 to 0.07 mA/cm^2 at an external resistor of 5 kΩ. The chemical oxygen demand removal efficiency of MFC was found to be 45-67% at 0.5 M of $KMnO_4$ and 21-34% when air was used as the electron acceptor. Maximum removal efficiency was obtained when potassium permanganate was used as the final electron acceptor in the cathode chamber. This research result demonstrated performance enhancement of producing electricity from brewery wastewater and co-reduction of the brewery waste at the same time with possible efficiency enhancement and reveals satisfactory results.

Keywords: Microbial fuel cell, Columbic efficiency, Brewery waste water, Polarization curve.

Accepted on June 22, 2021

Introduction

Energy need and energy crisis have become serious economical and policy issues all over the world. Electricity production from fossil fuel contributes to global warming, climate change, and non-renewable resource depletion. For this reason, it is necessary to explore other alternatives and renewable energy sources.

On the other hand, there is increased environmental pollution from effluents released from industrial wastes. One of the industrial wastes that can cause severe environmental pollution is brewery wastewater, which is generated in large volumes and discharged [1]. It has been estimated that approximately 3-10 L of wastewater is generated per liter of beer produced in breweries.

More attention is given to wastewater as a renewable resource for the production of electricity using biological systems. Biological systems usually utilized for wastewater treatment include aerobic sequencing batch reactor cross-flow ultrafiltration membrane anaerobic reactors and up-flow anaerobic sludge blanket reactors.

The use of a biological system for energy production and simultaneous wastewater treatment has fascinated the attention of researchers worldwide. Microbial Fuel Cell (MFC) systems represent a new promising more sustainable technology that produces electricity while simultaneously treating wastewater. Moreover, the simultaneous production of energy and the degradation of contaminants in wastewater can provide economic and environmental benefits from microbial fuel cells. A variety of readily degradable compounds such as glucose, acetate, and various types of wastewater such as domestic,

starching and paper recycling plant wastewater have operated successfully as a substrate in MFC [2].

MFC is a biochemical method can help achieve a considerable Chemical Oxygen Demand (COD) removal efficiency accompanied by electricity generation. MFC technology in which microorganisms present in wastewater mediate the direct conversion of chemical energy stored in organic substrate and the microbes used as a biocatalyst to oxidize the biodegradable substrates in generating electricity while simultaneously treating wastewater. MFCs are Electrochemical conversion devices, similar to most fuel cells, except that the power generated is derived from bacterial metabolism. Microbial Fuel Cell (MFC) is a kind of new technology for wastewater treatment and electricity generation. It can directly convert environment-polluting biomass into electricity by using microbes as catalysts.

Microbial fuel cells have two chambers, each containing an electrode; an anode and a cathode. An electron donor on the anode side often hydrogen or methanol is oxidized on the anode surface leading to the formation of electrons and cations [3]. A voltage difference across the circuit is the driving force for the reaction.

During electron production protons are also produced in excess. The protons migrate through the cation exchange membrane into the cathode chamber. The electrons flow from the anode through an external resistance to the cathode where they react with final electron acceptors such as oxygen and protons.

In view of the importance of MFC, this research explored the electrical capacity of MFC with potassium permanganate or air as the electron acceptor [4]. Higher voltage generation is expected from potassium permanganate acceptor that compared with oxygen from the air as cathode electron acceptor due to a possible cathode polarization in the later. The motivation for this work is that Dashen brewery discharges wastewater that could be utilized to produce electrical energy with high COD removal efficiency.

Materials and Methods

Sample collection and preparation

Brewery waste water and microorganisms (anaerobic mixed sludge in type) was collected from dashen brewery industry wastewater treatment plant in Gondar, located 730 km north of Addis Ababa, Ethiopia and 180 km away from the Bahir Dar City, Amhara Regional State. Brewery wastewater was characterized in terms of COD, BOD, Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solids (TSS) and pH using standard APHA method. After that, the wastewater and mixed sludge (microorganism) were stored in a refrigerator at 4^{o}C until further use.

Brewery wastewater characterization

Chemical Oxygen Demand (COD): For high range of COD determination, 10 mL sample was taken and diluted with 40 mL distilled water. A 2 mL from a diluted sample was added to the reagent ($K_2Cr_2O_7$ and $HgSO_4$) and digested for 120 min at 150°C. Then the COD value was measured using HACH DR900 photometer and it was multiplied by the dilution factor of 5. In low range COD determination, 10 mL sample was taken and diluted to 50% with distilled water. Then a 2 mL sample from 50% diluted sample was taken and further diluted to 40 mL. A 2 mL diluted sample of the prepared solution was added to a reagent (90% H_2SO_4, Ag_2SO_4 and $HgSO_4$) and then it was digested for 120 min at 148° C. Next, it was cooled to room temperature and after that, the value was determined using HACH DR3900 spectrophotometer and it was multiplied by the dilution factor of 40.

Biochemical Oxygen Demand (BOD): When the biological oxygen demand was determined, initially 45 ml of brewery wastewater was taken from Equalization (EQ) and it was mixed with 5 ml of final effluent as a buffer. After mixing 43.5 ml of the sample was taken into the OxiTop bottles which were placed in an incubator (Universal Schrank UF55) that was used for digestion at 20°C for 5 days while stirring a universal magnetic stirrer. After 5 days the OxiTop displays value was multiplied with buffer factor of 5 times than the original sample.

Electrical Conductivity and pH: Electrical Conductivity (EC) was measured with a conductivity meter (Oyster conductivity meter). The pH of the samples was measured with a portable pH meter (Model HI9024, HANNA Instrument).

Total Nitrogen (TN): Total Nitrogen was determined using TN Persulfate Reagent Powder Pillows. Initially, 5 ml of brewery wastewater was added to test vial with a reagent. Then it was shaken well and allowed to stay 2 min for complete reduction reaction. After 2 min, the instrument was made blank with a similar sample without reagent. Finally, the sample was read using a Hach DR900 photometer.

Total Phosphorus (TP): Total Phosphorus was determined using Hach phosver3 phosphate reagent powder pillows. Initially, 5 ml of brewery wastewater was added to test vial with reagent (Hach phosver3 phosphate reagent powder pillows). Then it was shaken well and allowed to stay 2 min for complete reaction. After 2 min the instrument was made blank with a similar sample without reagent. Finally, the sample was read using Hach DR900 photometer to measure total phosphorous.

Total Suspended Solid (TSS): Total Suspended Solid was determined by taking 10 ml sample in a cuvette using Hach DR900 photometer.

Assembly of MFC: The design of the Microbial Fuel Cell consisted of two plastic chambers with 2.5 L capacity. A Proton Exchange Membrane (PEM) was installed between two chambers in a plastic tube (4 cm in length and 2 cm in diameter) to allow proton passage from the anode chamber to the cathode chamber. Both the anode and cathode chamber consists of graphite electrodes (3 cm × 5 cm). The electrodes were inserted through a hole on the top of the chamber. The anode chamber was kept in anaerobic condition by purging

nitrogen gas and the cathode chamber was connected with an oxygen pump to form aerobic condition. One end of the two copper wires was attached to each anode and cathode electrodes. The other two ends of copper wires were connected to a digital multimeter to form open circuit voltage with different resistors. The setup of a two-chamber MFC is shown in (Figure 1).

Figure 1. *Experimental set up with auxiliary equipment.*

Medium preparation: Nutrient broth medium was used for culturing of bacteria. The bacteria were brought from brewery wastewater treatment plant, in the anaerobic digester. A 50 ml of mixed bacteria were cultured on 100 ml nutrient broth medium at 37°C for 24 hrs. After culturing the bacteria was transferred into the anodic chamber (Tables 1 and 2).

Table 1. *Substrate samples in anodic chamber.*

Brewery wastewater, mL	Distilled water, mL	Culture medium mL	Total volume mL	COD mg/L
1000	0	150	1150	4000
750	250	150	1150	3000
500	500	150	1150	2000
250	750	150	1150	1000
125	875	150	1150	500

Table 2. *Catholyte solutions used in catholic chamber.*

Parameters	Cathode with $KMnO_4$	Cathode without $KMnO_4$
	0.3 M	-
$PMnO_4$ solution	0.5 M	-
	0.8 M	-
Air	-	Air (21% oxygen)
Distilled water	-	1150 mL

Then after feeding the MFC results of voltage and current was measured using a digital multimeter (Figure 2).

Figure 2. *Brewery waste inoculated MFC reactors.*

Analysis and determination of electrical parameters

The generated voltage in MFC system was recorded from the digital voltmeter at an interval of 24 hours for 20 days. The corresponding current, power, power density and current density was calculated using Eq. (1), (2), (3) and (4) according to Ohm's law.

$I=V/R$ ...(1)

Where V is the measured cell voltage in volts (V) and R is the known value of the external load resistor in Ohms (Ω). From this, it is possible to calculate the power output P in watts (W) of the MFCs by taking the product of the voltage and current i.e.

$P=I \times V$ …(2)

The power density and current density was calculated using:

$Powerdensity=((I \times V))/A$ …(3)

$Current\ density=((V/R))/A$ …(4)

Where: I=current in amperes (A), P=power in watts (W), V =voltage in volts (V), R=the resistance in Ohms (Ω) and A is the surface area of the anode.

Determination of polarization and power density curve: The polarization curves were determined from the voltages and currents which were measured by varying external resistors (5000, 4000, 3000, 2000, 1000, 400, 300, 200, 100, 40, 30, 20, 10 Ω). From the corresponding values, power density and current density were determined using equation (3) and (4). Then the polarization curve was drawn in terms of voltage versus current density and power density curve was found from the plot of power density versus current density. From which the internal resistance of MFC was determined according to the polarization slope method.

Measuring of COD reduction efficiency: To compute the potential of COD removal efficiency of MFC, initially 4000 mg/L COD brewery wastewater was used in the anodic chamber, and then it was replaced by 3000, 2000, 1000 and 500 mg/L COD concentrations. All experiments were batch tested within 20 days of operation. The Chemical Oxygen Demand (COD) values were measured before and after the experiments. COD values of the analyte were measured according to the APHA standard method.

Statistical analysis

All experiments were conducted using microbial fuel cells. When a one MFC was used the experiments were repeated at least three times. The results were presented as average values where applicable. All experimental error was analyzed with the aid of statistical methodology provided by Two-way ANOVA (Factorial design) (IBMS Statistics 20 statistical software).

Results

Brewery waste water characterization

The results of brewery wastewater properties such as Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Nitrogen (TN), Total Phosphorus (TP), Total Dissolved Solids (TDS), Conductivity and pH were analyzed using standard APHA method as shown (Table 3).

Table 3. *Ultimate analysis of average brewery wastewater characteristics.*

Parameter	Value	Unit
Ph	8.15	-
COD	4025	mg/L
BOD	1440	mg/L
TN	33	mg/L
TP	45	mg/L
TSS	460	mg/L
Conductivity	152	µS/cm

The high amount of COD (4025 mg/L) was found and the COD concentration of brewery wastewater which varies in the range of 3000-5000 mg/L recommended for power generation. Due to its food-derived nature, the brewery wastewater served as microbial food sources (TN=33 mg/L and TP=45 gm/L) to grow and multiply bacteria [5]. The electrical conductivity in (Table 3). shows that the ionic strength of brewery wastewater would play a significant role in the power or voltage outputs.The results in (Table 2 and 3) indicate that brewery wastewater has the potential for electricity generation using MFC.

Voltage generation using air as a final electron acceptor: As shown (Figure 3) voltages was generated at different COD concentration of substrates. The initial voltage generation between the 1st and 6th days was smaller due to the low microbial activity in the anode chamber because the microorganisms were not adapted and multiplied the environment. After the 6th day the voltage was increased to 15th days due to the microbial adaptation of the environment and higher biological activity for voltage generation, but starting to 16th days of oxidation it was decreased due to substrate depletion and microbial death.

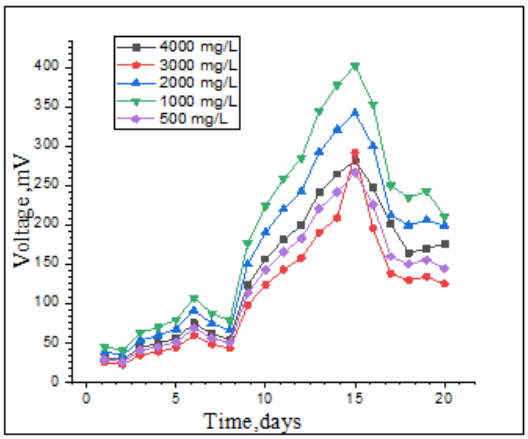

Figure 3. *Voltage generation using air cathode.*

The voltage generation in MFCs with oxygen as a final electron acceptor were 282 mV, 222 mV, 343 mV, 402 mV, and 257 mV (4000, 3000, 2000, 1000 and 500 mg/L COD) respectively. The maximum voltage was found 402 mV at 1000 mg/L COD. The previous studies had found similar results and trends.

Voltage generation using $KMnO_4$ as a final electron acceptor The voltage generation at different molar concentrations of $KMnO_4$ is shown in (Figure 4). The voltage generation for the different concentration began immediately when MFC was inoculated and startup oxidation process. The MFC produced different pick values at a different concentration from 0.3-0.8 M $KMnO_4$ and different COD concentrations with the same operational condition [6].

(Figure 4) shows that highest peaks of voltages obtained on 15th days at 0.3 M $KMnO_4$ of each cell was 598, 797, 822, 999 and 736 mV (4000, 3000, 2000, 1000 and 500 mg/L COD) respectively. As (Figure 4) illustrates, the maximum voltage generation was obtained at 0.3 M $KMnO_4$ and 1000 mg/L COD concentration which is 999 mV. However, the voltage generation in 4000 mg/L COD has minimum value (598 mV) due to high COD concentration hindered the bacterial growth and activity. Therefore, the other COD concentrations (3000, 2000 and 500 mg/L) voltages at 0.3 M $KMnO_4$ were found between 598 and 999 mV.

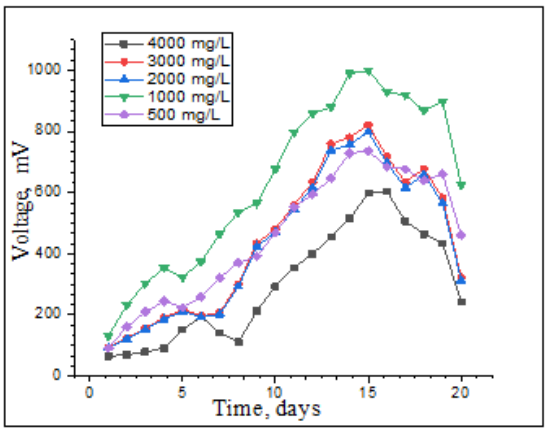

Figure 4. *Voltage generation at 0.3 M $KMnO_4$.*

As it is shown in (Figure 4) the maximum peak values of voltage generation were obtained on the 15th day at 0.5 M KMnO4. The results were 631, 843, 885, 1060 and 828 mV (4000, 3000, 2000, 1000 and 500 mg/L COD) respectively. Clearly illustrated that the maximum voltage generation (1060 mV) was found at 0.5 M $KMnO_4$ and 1000 mg/L COD concentration. Nevertheless, the minimum voltage (631 mV) was recorded at 4000 mg/L COD) because the microbial activity and growth were influenced by high COD concentration [7]. Voltages generation with 3000, 2000 and 500 mg/L COD at 0.5 M $KMnO_4$ were found between 631 and 1060 mV ranges (Figure 5).

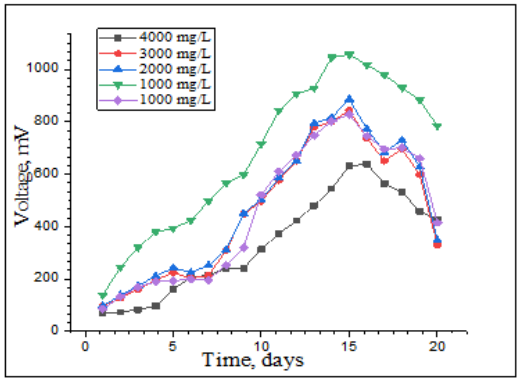

Figure 5. *Voltage generation at 0.5 M $KMnO_4$.*

Maximum peak values of voltage generation rate in (Figure 5) were obtained on 15th day at 0.8 M $KMnO_4$ were 621, 757, 802, 1012, 655 mV (4000, 3000, 2000, 1000 and 500 mg/L COD) respectively. As shown in Fig 8, the maximum voltage generation (1012 mV) was recorded at 0.8 M $KMnO_4$ and 1000 mg/L COD concentration. Conversely, the minimum voltages were found at 4000 and 500 mg/L COD because the microbial activity and growth was influenced with high COD concentration and substrate depletion in low COD concentration. Voltages generation for 3000 and 2000 mg/L COD at 0.8 M $KMnO_4$ were found to be between 621 and 1012 mV (Figure 6).

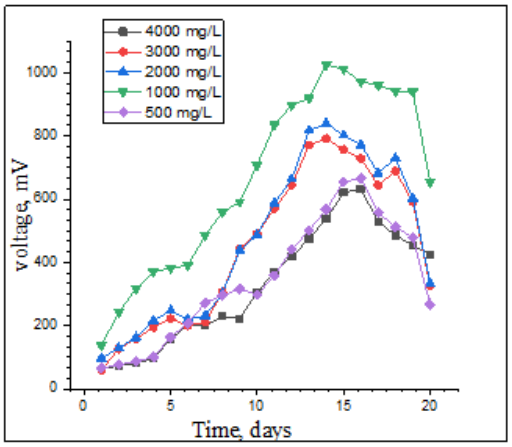

Figure 6. *Voltage generation rate at 0.8 M $KMnO_4$.*

Generally, (Figure 6) Showed voltage generation for all substrate COD concentration for up to 20 days of the experiment. In MFC voltage production, different trends were investigated from 5 to 10 days and 12 to 20 days of output voltages in the above Figures. The initial voltage generation was lower due to the low microbial activity in the brewery wastewater because they did not adopt the new environment in the MFC. The increasing trends were observed between 5-15 days in all the experiments. When the oxidation reaction time became longer the voltage generation was increased because of higher biological activity and the maximum voltages were obtained on 15th days. After 15 days the voltage output declined due to the organic content of waste depleting and the declination of microbial activity [8].

However, the voltage generation at 0.5 M $KMnO_4$ and 1000 mg/L COD concentration was 1060 mV which is the highest value among other voltage generations. The previous studies found that the maximum voltage generation of the MFC ranging from 500 to 800 mV, nevertheless, the voltage results from the present study have greater voltage as compared to the previous studies. There is a significant difference in voltage generation at different COD concentration and $KMnO_4$ concentration ($p<0.05$) (Figure 7).

The effects of final electron acceptors in MFC voltage generation. The impact of final electron acceptors in MFC voltage generation at a different molar concentration of potassium permanganate and air was tested in the cathode chamber with different COD concentrations of brewery wastewater in the anode chamber. The COD concentration 1000 mg/L was selected to compare the effects of final electron acceptors on MFC performance because of which provides a maximum voltage at each concentration of $KMnO_4$ and air.

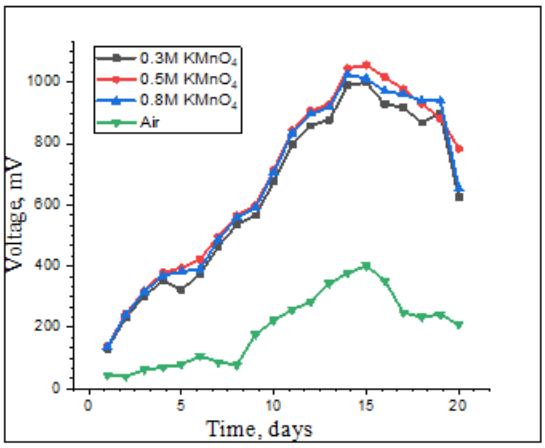

Figure 7. *Effects of final electron acceptors.*

The voltage generation results at different electron acceptors. Without potassium permanganate, air (oxygen) as an electron acceptor the highest voltage was generated 402 mV. However, when permanganate of potash was an electron acceptor, the maximum voltages were 1012 mV, 1060 mV, 999 mV at (0.3 M, 0.5 M, 0.8 M $KMnO_4$) respectively. This confirms that the effects of different types final electron acceptors on voltage generation so that potassium permanganate has a considerable

influence on voltage generation than oxygen did on it. As it can be seen in (Figure 7), the 0.5 M $KMnO_4$ provided the maximum voltage generation (1060 mV) as compared with the other potassium permanganate concentrations of voltage generations [9]. At low concentrations (0.5 M), the voltage output increased with increasing Potassium permanganate, however, at high concentrations (0.8 M) the voltage output decreased with increasing concentration. Due to the extrusion of potassium permanganate through PEM to anode chamber, osmotic pressure inhibited the movement of protons to the cathode chamber, decreasing the biodegradation of sucrose or short-chain fatty acids.

Statistical analysis of voltage generation

Statistics SPSS as described in (Table 4). The statistic basis univariate generalized linear model, Which analyzes statistics such as the significance of each factor, the interaction effect between factors and also the overall interaction effect of factors on the target. As shown in (Table 4). All The parameres and their interaction affect the target voltage generation significantly.

Table 4: *Univarate statistical analysis of voltage generation.*

Source	Type III sum of squares	df	Mean square	Sig.
Corrected model	173893.577	8	21736.7	0
Intercept	1797164	1	1797164	0
COD concn	166335.6	2	83167.82	0
$MKMnO_4$	6917.6662		3458.833	0
COD concn $MKMnO_4$	640.279	4	160.07	0
Error	0	0	.	
Total	1971057	9		
Corrected total	173893.6	8		

Polarization and power density curve

The Open Circuit Voltage (OCV) for the MFC system was very high (1060 mV) with 1000 mg/L, which could have translated to higher power density. According to this for polarization and power density curves on 1000 mg/L COD with different final electron acceptors. (Figure 10) shows the results found when oxygen was used as a final electron acceptor. The maximum voltage was observed prior to polarization and the maximum surface power density of 266.23 mW/m^2 was observed at a current density of 0.6 mA/cm^2. The maximum power transferred by the microbial fuel cell usually occurs when the external load (resistance) equals to the internal resistance. Thus, the internal resistances at maximum power were determined to be 200 Ω. The maximum surface power density observed for the present MFC system is consistent with results obtained in previous studies (Figure 8).

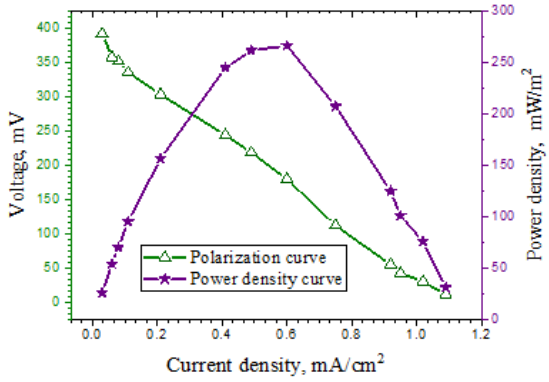

Figure 8. *Polarization and power density curve using 1000 mg COD/L with oxygen as a final electron acceptor.*

As it can be seen clearly in (Figure 8) with oxygen as a final electron acceptor, when the ohmic resistance was increased from 200 Ω to 5 kΩ, the power density was decreased from 266.23 to 26.11 mW/m^2. Current also decreased consistently with the increase of the resistance from 0.6 to 0.03 mA/cm^2 at an external resistor of 5 kΩ. The previous studies had found similar results on power density and current density. However, the present study has slightly higher values [10].

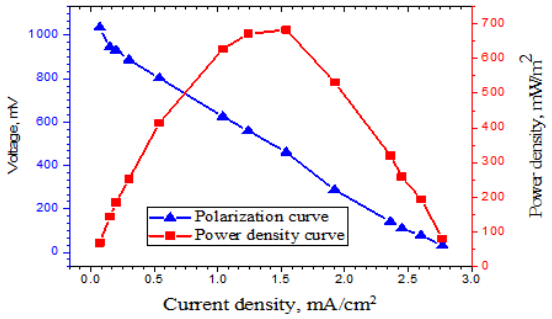

Figure 9. *Polarization and power density curve using 1000 mg COD/L with $KMnO_4$ as a final electron acceptor.*

When $KMnO_4$ (Figure 9) as a final electron acceptor maximum open circuit voltages observed before polarization and the maximum surface power density and current density observation were 682.83 mW/m^2 and 1.54 mA/cm^2. The maximum power transferred by the microbial fuel cell usually occurs when the external load (resistance) just equals the internal resistance.Thus, the internal resistances at maximum power were determined to be 200 Ω. The maximum surface power density observed for the present MFC system is consistent with results obtained in previous studies.

As it can be seen clearly in (Figure 9) with 0.5 M $KMnO_4$ as a final electron acceptor, when the ohmic resistance was increased from 200 Ω to 5 kΩ, the power density was decreased from 682.83 m^2 W/m to 69.14. Current also decreased consistently with the increase of the resistance from 1.54 to 0.07 mA/cm^2 at an external resistor of 5 kΩ. This is in agreement with previous studies.

In (Figures 4, 6 and 7), in different electron acceptors, the type of final electron acceptor in the cathode chamber has created a large difference in the power generation in MFC [11]. When potassium permanganate is 0.5 M the maximum power density was 682.83 mW/m^2 and with oxygen as a final electron acceptor, the maximum power density was 266.23 mW/m^2. This clearly indicates that the maximum power density and current density affected by the type of final electron acceptor in the MFC.

This study shows that potassium permanganate as final electron acceptor provided higher power density than oxygen produced because $KMnO_4$ has a higher rate of proton transfer or it increased the forward reaction. In the other way (Figures 6 and 7) the current and power density showed decreasing trend with increasing in resistance which demonstrated a similar trend with the previous studies, which indicated a typical fuel cell behavior [12].

It is evident from the experimental data that the voltage–current density curve can be roughly divided into three stages: Activation polarization, ohmic loss and concentration polarization. At the first stage, the current was relatively low, activation resistance caused by reaction kinetics played a dominant role, which caused a rapid voltage decrease.

As current increased, the polarization curve showed a linear relationship between voltage and current, which is called ohmic polarization, resulted from ionic resistance and electronic resistance. In this phase, there was also non-ohmic polarization; when external resistance was equal to internal resistance (200 Ω), power density reached the maximum of 682.83 mW/m^2 and 266.23 mW/m^2 for each 0.5 M $KMnO_4$ and air as final electron acceptors respectively. With the continued increase of current density, concentration diffusion became observable.

COD removal efficiency (Ƞ) and Columbic Efficiency (CE) of MFC: As it can be seen in (Figure 10) the columbic and COD removal efficiency are clearly illustrated. The COD reduction efficiency of the MFC using 0.5 M of $KMnO_4$ was found ranging 45-67% and with air was found ranging 21-35%. The removal efficiency of $KMnO_4$ final electron acceptor was obtained higher than the removal efficiency of air as final electron acceptor as it can be shown in (Figure 10). The figure demonstrated that COD removal efficiency of MFC using KMnO4 was increased when brewery wastewater concentration was from 500 to 3000 mg/L. The low COD removal was possibly due to less availability of biodegradable substrate in wastewater (500 mg/L) samples than that of high strength (1000, 2000 and 3000 mg/L) wastewater leading to competitive inhibition in microorganisms. The more the sustainability of microorganisms in their stationary phase, the higher is the removal of COD [13]. However, when concentration was from 3000 to 4000 mg/L COD, its removal efficiency was decreased. This due to the high COD concentration limits the function of microbes present in brewery wastewaters in metabolizing the carbon source as electron donors. Similarly, previous studies had found comparable removal efficiency trends.

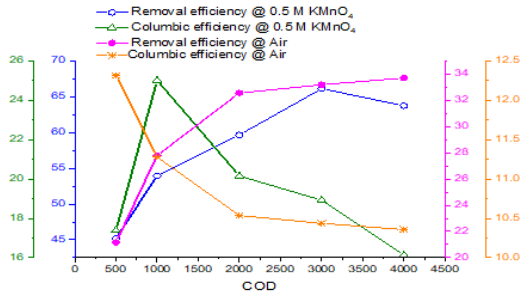

Figure 10. *Columbic and COD removal efficiency of MFC with and without $KMnO_4$.*

The maximum COD removal efficiency of MFC using potassium permanganate concentration was found 66.3%, however, MFC with air was found 34.13%. The reason why the removal efficiency of MFC with $KMnO_4$ is higher than the MFC with air is due to $KMnO_4$ helps increase the rate of the forward reaction of biodegradation.

As it is illustrated in (Figures 3 and 9), when the COD concentration was from 500 to 1000 mg/L the columbic efficiency was increased from 17 to 25%. However, when the concentration is increasing above 1000 mg/L COD the columbic efficiency was drop down 25 to 16% because the COD concentration became strong it hinders the microbial activity. The columbic efficiency of the MFC was investigated when oxygen was used as the final electron acceptor in the cathode was demonstrated in (Figures 3 and 9). The columbic efficiency of using oxygen showed decreasing trends from 12% to 10% when the COD concentration was increased. These results indicated that the performance of MFC at 0.5 $MKMnO_4$ provided higher COD removal efficiency and columbic efficiency than Air used in the cathode [14]. The maximum columbic efficiency of $KMnO_4$ in MFC was 25% and the columbic efficiency using oxygen was 12% at 1000 mg/L COD. This depicted that potassium permanganate electron acceptor provided the maximum columbic efficiency than the columbic efficiency obtained when oxygen used as electron acceptor that was 12% in the MFC.

Conclusion

The present study used the potential of MFC to produce electricity and COD Removal efficiency from dashen brewery effluent as a case study , the result expressed in terms of voltage, current density and power density. Potasium Permanganate ($KMnO_4$) and air were used as final electron acceptors within the cathode chamber and also the results were compared with varying the COD concentration of substrate for twenty days of redox reaction method. During this study, at numerous concentration of $KMnO_4$ (0.3, 0.5 and 0.8 M) the voltages generated (999, 1060 and 1012 mV) were found severally at one thousand mg/L COD within the fifteenth day. This experiment showed that the utmost voltage is obtained at 0.5 M $KMnO_4$ that was 1060 mV the utmost voltage generated in $KMnO_4$ (1060 mV) is far larger than that generated in

oxygen electrolyte (401 mV), that indicates that permanganate is a wonderful electrode Electron acceptor for the Dual MFCs.

The maximum power density (682.83 mW/m^2) and current density (1.54 mA/cm^2) were obtained at 0.5 M $KMnO_4$ and one thousand mg/L COD with 200 Ω external resistor. Maximum power density (266.23 mW/m^2) and current density (0.6 mA/cm^2) were obtained using oxygen as a final electron acceptor. So the utmost power density of the system with potassium permanganate was beyond that with aerated catholyte.

The COD reduction efficiency of the MFC using 0.5 M of $KMnO_4$ was found ranging 45-67 attempt with air was found ranging 21-35%. The utmost COD removal efficiency of MFC using permanganate of potash concentration was found sixty six. The explanation why the removal efficiency of of MFC with $KMnO_4$ is beyond the MFC with air .This is because of $KMnO_4$ helps increasing the rate of the biodegradation forward reaction by microbes. The utmost columbic efficiency of $KMnO_4$ in MFC was twenty fifth percent and therefore the columbic efficiency using oxygen was 12% system at one thousand mg/L COD. This revealed that permanganate of potash electron acceptor provided the utmost columbic efficiency than the columbic efficiency obtained when oxygen used as electron-acceptor that was 12% system within the MFC.

References

1. Logan BE, Liu H, Cheng S. Power generation in fed-batch microbial fuel cells as a function of ionic strength, temperature, and reactor configuration. Environ Sci Technol. 2005;39:5488-93.
2. Voeikova TA, Emelyanova LK, Novikova LM, et al. Intensification of bioelectricity generation in microbial fuel cells using Shewanella oneidensis MR-1 mutants with increased reducing activity. Microbiol. 2013;82:410-14.
3. Amenorfenyo DK, Huang X, Zhang Y, et al. Microalgae brewery wastewater treatment: Potentials, benefits and the challenges. Int J Environ Res Public Health. 2019;16:1910.
4. Guo K, Hassett DJ, Gu TY. Microbial fuel cells: Electricity generation from organic wastes by microbes. Semantic Scholar. 2012.
5. Feng Y, Wang X, Logan BE, et al. Brewery wastewater treatment using air-cathode microbial fuel cells. Appl Microbiol Biotechnol. 2008;78:873-80.
6. Feng C, Sharma SCD, Yu CP. Microbial fuel cells for wastewater treatment. Biotechnol Biomimetics Civ Eng. 2015; 411-437.
7. Linke L, Lijuan Z, Yau SF. Evaluation of the performance of zero-electrolyte-discharge microbial fuel cell based on the type of substrate. RSC Adv. 2017; 7:4070-4077.
8. Patel SK. Performance evaluation of effluent treatment plant of textile wet processing industry: A case study of narol textile cluster, Ahmedabad. Ind J Environ Prot. 2013; 33:1002-1008.
9. AI-Mamun A, Lefebvre O, Baawain MS, et al. A sandwiched denitrifying biocathode in a microbial fuel cell for electricity generation and waste minimization. Int J Environ Sci Technol. 2016;13:1055-64.
10. Islam MA, Ethiraj B, Cheng CK, et al. Electrogenic and antimethanogenic properties of bacillus cereus for enhanced power generation in anaerobic sludge-driven microbial fuel cells. Energy Fuels. 2017; 31:6132-39.
11. Othman I, Anuar AN, Ujang Z, et al. Livestock wastewater treatment using aerobic granular sludge. Bioresour Technol. 2013;133:630-34.
12. Akaluka CK, Orji JC, Braide W, et al. Abattoir wastewater treatment and energy recovery using a ferricyanide-catholyte microbial fuel cell. Int Lett Nat Sci. 2016;55:68-76.
13. You S, Zhao Q, Zhang J, et al. A microbial fuel cell using permanganate as the cathodic electron acceptor. J Power Sources. 2006;162:1409-15.
14. Qing W, Wu Y, Zhao Li, et al. Electricity gener brew wastewater treat from Seq anode-cathode microb fuel cell. J Zhejiang Univ Sci B. 2010; 11:87-93.

*Correspondence to

Dr. Tegen Dagnew

Department of Chemical and Food Engineering

Bahir Dar University

Bahir Dar

Ethiopia

E-mail: tegi1246@gmail.com