Journal of Energy Research and Reviews

Volume 13, Issue 2, Page 29-41, 2023; Article no.JENRR.97258
ISSN: 2581-8368

Potential of Electricity Generation and Wastewater Treatment of Organic Brewery Effluent Using Inoculated H-Type Microbial Fuel Cell

Mulu Berhe Desta [a*], Dagmawi Girmay Tebeje [b] and Hagos Mebrahtu Gebrehiwot [b]

[a] Department of Chemistry, College of Natural and Computational Sciences, Mekelle University, Ethiopia.
[b] Department of Chemical Engineering, Ethiopian Institute of Technology-Mekelle, Mekelle University, Ethiopia.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2023/v13i2260

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97258

Original Research Article

Received: 05/01/2023
Accepted: 10/03/2023
Published: 16/03/2023

ABSTRACT

MFCs are bio-electrochemical devices that are capable of transforming chemical energy stored in waste organic matter into direct electrical energy through catalytic activity of microorganisms under anaerobic conditions. Bio-electrochemical systems, such as microbial fuel cells (MFCs), serve as greener alternatives to conventional fuel energy. In recent years, MFCs have drawn science community interest as a method for direct bioelectricity recovery from wastewater while simultaneously treating the wastewater. Moreover; they gain a competitive advantage over other water treatment technologies due to their unique features such as huge energy benefits, less

**Corresponding author: E-mail: mulu.berhe@mu.edu.et;*

environmental impact, good operating stability, and high economic efficiency. Reports reveal that MFCs are the subject of much interest to researchers, and the number of papers on MFCs in wastewater treatment is increasing. The ever-growing demand for green waste management and renewable sources of energy has enthused research efforts all over the world. This study, therefore, investigated the effect of process variables on the bio-electrical performance of H-type microbial fuel cells fueled with brewery wastewater and inoculated with distillery plant waste. From the experimental results, 1150mV maximum voltage output, 92.85%, 91.40%, 68.87%, and 70.10% removal efficiencies of COD, BOD, TN and TP respectively were obtained at 35ºC, pH 7, and 5 days. These results confirmed that brewery wastewater effectively treated would generate a considerable amount of direct bio-electricity. Results also revealed that the MFC provides an alternative insight into an effective treatment of wastewater that can simultaneously generate a direct bio-electricity in a sustainable and eco-friendly manner.

Keywords: Biofilm; electrogenic bacteria; energy recovery; inoculation; microbial fuel cell; renewable energy.

1. INTRODUCTION

Nonrenewable energy sources, such as fossil fuels and nuclear power, are widely used in the world [1]. When it comes to fossil fuels, this source of energy does more damage to the environment and continuous use of fossil fuels emits carbon dioxide, which becomes toxic when there is too much of it in the air. The two major global problems facing human beings are energy shortage and environmental pollution [2]. Therefore, great efforts have long been exerted in a simultaneous response to both the energy consumption and water contamination [3]. The wastewater containing pollutants must be treated before being discharged into the environment [4,5]. At present, wastewater treatment is commonly treated with a conventional aerobic activated sludge reactor, anaerobic digester, membrane filtration, ion exchange, adsorption, coagulation, electrolytic reduction and so on [6]. Nevertheless, the high expenditure of energy and the running cost are the two major restraining factors for the current wastewater treatment technologies [7]. In addition, the presence of a large amount of residual generation can lead to secondary pollution among these technologies, which can be deleterious for the environment and ineffective in catching the energy potential from wastewater [8]. Therefore, it is essential to establish a wastewater treatment technology, which is required to be reliable, sustainable, and cost-effective [9].

Microbial fuel cells (MFCs) are a type of bio-electrochemical fuel cell that requires the presence of active bacteria that function as biocatalyst for bioenergy generation in anodic chambers [10,11]. They are recognized as a future technology with a unique ability to exploit metabolic activities of living microorganisms for simultaneous conversion of chemical energy into electrical energy. This technology holds the promise to offer sustained innovations and continuous development towards many different applications and value-added production that extends beyond electricity generation, such as water desalination, wastewater treatment, heavy metal removal, bio-hydrogen production, volatile fatty acid production and biosensors. Compared with other wastewater treatment technologies, MFCs have the following significant advantages: (1) direct conversion of substrates energy into electricity, (2) low activated sludge generation, (3) being robust and insensitive to environmental factors (e.g., temperature), (4) absence of gas treatment, (5) without any energy input for aeration, and (6) a widespread application in places lacking electrical infrastructures [12,13]. MFCs have proven to have great potential for industrial applications in several types of wastewater treatment [14]. To date, the number of papers on MFCs in wastewater treatment is increasing.

“MFCs are considered as one of the Bio Electrochemical Reactors (BERs), which essentially based on the ability of “electrogenic” or “electroactive” bacteria to exchange electrons with the anode through developing effective anodic biofilm” [15]. The addition of biological organisms responsible for catalyzing electrochemical reactions, gives these systems a level of complexity that is perhaps above that of already complex electrochemical systems (e.g. batteries, fuel cells and supercapacitors). The main differences of MFCs with the conventional low temperature fuel cells (direct methanol fuel cell or proton exchange membrane fuel cell) are: i) “the electrocatalyst is biotic (electroactive

bacteria or proteins) at the anode" [16-18]; ii) "the temperature can range between 15 ℃ and 45 ℃, with close to ambient levels as optimum [19-21]"; iii) "neutral pH working conditions" [22-25]; iv) "utilization of complex biomass (often different types of waste or effluent) as anodic fuel" [26,27]; v) "a promising moderate environmental impact assessed through life cycle analysis" [28,29].

The typical MFCs usually consists: (i) anode—oxidation of organic matter takes place, catalyzed by electroactive bacteria; (ii) cathode—reduction of oxygen or carbon dioxide, a thermodynamically favorable reaction catalyzed in the presence or absence of catalysts; (iii) ion exchange membrane—a proton exchange membrane that favors the passage of protons from anode to cathode through simple diffusion; (iv) electroactive microorganisms—microorganisms with the ability to respire electrodes under anoxic conditions; (v) biofilm—the colonization of bacteria on the surface of the material; (vi) electric circuit—an external load where the electrons are passed through a fixed resistor to regulate the flow of electrons. In the anodic chamber, microbial decomposition (biological oxidation) of organic substrates generate electrons and protons that are transferred to the cathode through the circuit and membrane, respectively (Fig. 1). By transferring electrons from the negative terminal (anode) to the positive terminal (cathode) against a load, an electric current is generated [30]. On the other hand, the generated protons drift over to the cathode through the proton exchange membrane (PEM), which prevents the movement of oxygen into the anode compartment to avoid the inhibition of electricity generation. Instead, the cathode exposed to the oxygen initiates the formation of water [31]. On the cathode surface, the electrons react with the final electron acceptor. Mostly O_2 is applied as electron acceptor because of its abundance in nature. Recently, air-cathodes, based on the gas-diffusion layers, are in use, avoiding forced O_2 provision at the cathode. Commonly used Catholyte include oxygen, ferricyanide, and permanganate [32].

In this work, we report the bio-electrical performance of H-type or dual-chamber microbial fuel cell (DCMFC) fueled with brewery wastewater as an electron donor, inoculated with distillery plant waste from working biogas reactor as a source of microorganisms to run the experiment. The linear effect of process variables such as pH, time, and temperature on the responses has been investigated by keeping other variables constant. Seventeen dual-chamber microbial fuel cells (DCMFCs) were designed as adopted from [33], thirty four polyethylene (PE) cylinders of equal volume (600 ml) and height (20cm) were used. Two PE cylinders were used for one MFC set up in which one was used as a cathode and the other as an anode. A side opening of 2cm diameter at a height of 8cm from the bottom of the bottle and 2mm diameter head opening was made on each cylinder for the insertion of salt bridge and copper wire respectively. The MFCs were operated in a batch mode according to the prescribed experimental conditions for 8 days. The time constraint was fixed based on the decline in power generation (open circuit voltage) [34]. We evaluate the performance of DCMFC using Raya Brewery wastewater (RBWW) for direct bio-electricity generation while treating the wastewater.

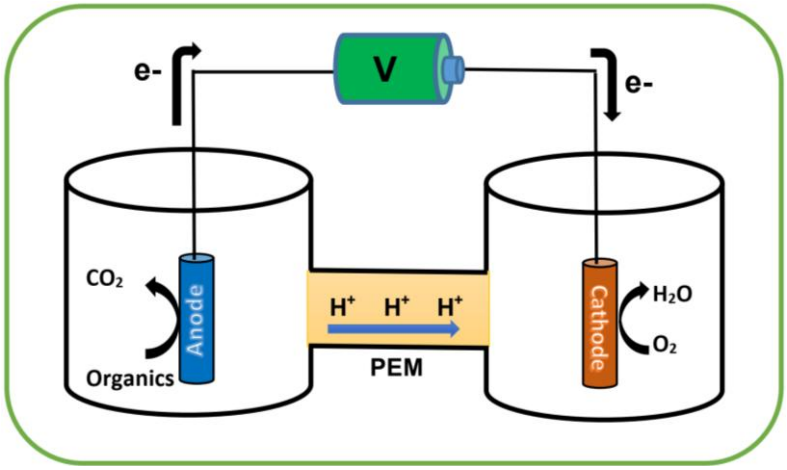

Fig. 1. PEM mediated dual-chamber MFC

The samples were analyzed for the selected significant physicochemical characteristics such as BOD, COD, TN, and TP. The concentration of BOD, COD, TN, and TP in the wastewater was determined according to the standard method [35].

It has been estimated that 4-10 liter of brewery wastewater is generated per liter of beer. "This wastewater is rich in organic content (3000-5000 mg/l of COD), which is approximately nine times concentrated than the domestic wastewater" [36-38]. "Consequently, the wastewater can pose hazard to human beings and the environment if not treated before discharge" [39-41]. However, "most of brewery wastewater treatment technologies are not sustainable to meet the ever-growing waste sanitation needs, basically because they are energy-intensive processes without any return which discourage the investors" [42]. Raya Brewery is one of the largest beer producers in country with an annual production capacity of 600,000 hectoliters of beer. The factory generates a large volume of wastewater, which is about 1250m^3/day. The existing wastewater treatment plant is an up-flow anaerobic sludge blanket reactor (UASBR) with a treatment capacity of 1500 m^3/day and the outlet effluent from this plant is released into the nearby river. "The plant consumes 660 KWh of electricity per 1250m^3 of wastewater, about 50% of the electricity is consumed to supply air for the aeration basins" [43,44].

2. EXPERIMENTAL DETAILS

2.1 MFC Assembly and Operation

Seventeen dual-chamber microbial fuel cells (DCMFCs) were designed as adopted from [36] thirty four PE cylinders of equal volume (600 ml) and height (20cm) were used. The MFCs consists of an anode and cathode, connected by an external circuit and separated in different compartments by a proton exchange membrane (PEM). The MFCs were operated in a batch mode according to the prescribed experimental conditions for about 8 days. The time constraint was fixed based on the decline in power generation (open circuit voltage) [37]. "In the anode section of the microbial fuel cell, the microbes (mixed consortia) oxidize the organic substance in the wastewater as a fuel for growth, consequently producing electrons and protons via redox reactions, by this means a bio-potential difference (biological mediated voltage) enabling power generation" [45]. Protons passed through the salt bridge to the cathode section consisting of a solution of potassium ferricyanide (electron acceptor) and the electrons produced in the anode section flow over the carbon rod electrodes which were linked with the copper wire to complete the circuit. After 24h incubation period, the copper wires were connected to a digital multimeter using alligator clips. The voltage output was measured and recorded as an open circuit voltage.

2.2 Preparation of Anolyte and Catholyte

Raya Brewery wastewater which contains organic matter accessible for the microorganisms was used as a substrate in the anodic chamber. Besides, 50ml of inoculum per anode was taken from a working biogas reactor of Desta Alcohols Distillery plant. "Since, the inoculum contains highly varied bacterial consortia consisting of electrochemically active bacterial strains" [46], it was served as a source of a microorganism to run the experiments. Samples were adjusted at different pH (4, 7, and10) using the prepared standard solution (0.1M HCl, 0.1M NaOH). The anodic chambers of the microbial fuel cells were filled with 410 ml adjusted sample. For the cathode chamber of the microbial fuel cells, 0.1M potassium ferricyanide solution was prepared and the chambers were filled with 460 ml of the solution to serve as a Catholyte (electron acceptor).

2.3 Performance Analysis of the MFC

The wastewater treatment performances of the MCF were measured by the BOD, COD, TN, and TP according to the standard methods [47], before and after each parameter goes through the MFC. The direct bio-electricity generation performance of the MFC was evaluated by measuring the voltage output using advanced digital multimeter (UNI-T UT61B).

2.4 Analysis and Calculation

In every electrical or electronic system, the notion of current density is crucial. The current density determines the power output and efficiency of any circuit. The power density that an MFC can typically generate is low. Therefore, the MFC output voltage and power must be increased for practical uses. So far, several MFCs were simply connected in series or in parallel to overcome the low voltage or power issue. Columbic efficiency is also the efficiency with which electrons are transferred in a system

to carry out an electrochemical reaction. This is an important measure of the microbial fuel cell efficiency as it measures the number of coulombs recovered as electrical current.

The MFC potential was recorded four times a day with the multimeter. The current and the harvested power were calculated from the following formula [48,49].

$$I = \frac{V_{MFC}}{R_{ext}} \quad (1)$$

Where V_{MFC} is the measured voltage, R_{ext} is the external load applied. Current density (mA/m^2) was calculated from the followed equation [50,51]:

$$CD = \frac{I}{A} \quad (2)$$

Where I is the current per mA and A is the projected area of the anode (m^2). The Power density (PD, mW/m^2) was calculated from the followed equation [52]:

$$PD = V_{MFC} \text{ x } CD \quad (3)$$

The Columbic efficiency (CE), describes the efficiency of the MFC in facilitating the electrochemical reactions for charge (electrons) transmission, i.e. the current represented in the recovered fraction electrons versus the complete of oxidation of the substrate. The CE was calculated by the followed equations [53-55]:

$$CE = \frac{C_P}{C_T} x100\% \quad (4)$$

$$C_T = \frac{Fn\Delta cV}{M} \quad (5)$$

Where the C_P is the actual current production collected by the anode during one batch cycle integrated as (C_P = xt) and the C_T is the theoretically available amount of produced coulombs depending on the COD removed in the MFC from the fully oxidation of substrate organic content into CO_2 and water. It was estimated as in formula no.5, where F = faraday's constant (96485 C/mol), n = number of electrons per mole of substrate (4 electrons), Δc is the daily COD removed, V is the inner reactor volume per liter, M = molecular weight of O_2 (32 g/mole).

The COD removal efficiency of the microbial fuel cell was calculated using:

$$\text{Removal efficiency } (\%) = \frac{COD_{influent} - COD_{effluent}}{COD_{influent}} \quad (6)$$

Where, $COD_{influent}$ is initial COD concentration (mg/l) and $COD_{effluent}$ is final COD concentration (mg/ l) in the reactor.

3. RESULTS AND DISCUSSION

3.1 Performance of the Laboratory Scale DCMFC

Table 1 shows the experimentally investigated results of the 17 experimental runs. The results depict that performance of the DCMFC in terms of the voltage output and removal efficiencies for COD, BOD, TN, and TP at each experimental run.

As shown in Table 1, the observed voltage outputs were varied noticeably within the range of 302 mV to 1150 mV. The lowest voltage output (302 mV) was obtained on the 15th run where the experimental conditions were held at an average temperature, lowest pH and longest residence time (35°C, pH 4 and 8 days). On the other hand, the maximum voltage output of (1150 mV) was obtained on the 3rd run, which is the replicate at the experimental conditions at 35°C, pH 7 and in 5 days. This value is higher than what was reported as a maximum voltage output of 750 mV by [56]. Another study by [57] also reported a maximum voltage output of 950 mV, which is still lower than the maximum value obtained in this study. This difference can be result of the type of substrate used in this study: brewery wastewater was used as a substrate that contained higher organic content than soak liquor from the tannery industry and hostel sewage, which were used in the stated studies respectively. On the other hand, the observed value in this study is lower than maximum voltage output of 1480 mV reported by [58]. This difference might be due to reasons such as the type of substrate used, concentration, ionic strength, electrode materials and the difference in the factors and levels used in the process.

The observed removal efficiencies for COD, BOD, TN, and TP were varied within the range of (34.79% to 92.85%), (33.41% to 91.40%), (26% to 68.87%), and (30.12% to 70.10%) respectively. The lowest removal efficiencies for COD, BOD, TN, and TP were 34.79%, 33.41%, 26.00% and 30.12% respectively where the experimental conditions were held at an average temperature, acidic pH and short residence time at 35ºC and pH of 4 for 2 days. On the other hand, the maximum COD, BOD, TN, and TP

removal efficiencies were 92.85%, 91.40%, 68.87% and 70.10% respectively, where the experimental conditions were held at an average value of all the factors considered at35ºC and pH of 7 for 5 days as shown in Table 1.

These results are comparable to other results reported by [59] where brewery wastewater treatment using microalgae had given removal efficiency of 83.1%, 91.4%, 76 %, and 66.1% of COD, BOD, TN and TP respectively. These values confirm that the effectiveness of wastewater treatment using MFC apart from direct bioelectricity generation. Besides, the organic matter reduction was good enough showing that there was biodegradation which in return indicating high voltage output [60,61]. This concept is confirmed in this study as a significant amount of voltage was obtained in parallel with organic load reduction.

3.2 Statistical Analysis of the Experimental Results

The statistical software program used to develop a model equation that describes the significance of the independent variables, interaction effects of the independent variables, and surface plots using the fitted equation obtained from the regression analysis. The suggested model that fits the data for this analysis was a quadratic model. Analysis of variance is a vital tool to check the adequacy of the quadratic model. Checking the adequacy of the fitted model is necessary to confirm that it provides an adequate approximation to the true system and supports the least square regression assumptions. Thus, the adequacy of the fitted model was evaluated from the coefficients of correlation as summarized in Table 2.

Table 1. Three-variable with five responses for the process performance of DCMFC

Run	Factors			Responses				
	Temp (ºC)	pH	Time (Day)	Voltage output (mV)	COD removal (%)	BOD removal (%)	TN removal (%)	TP removal (%)
1	45	7	8	794	91.81	90.41	62.10	69.00
2	35	10	2	767	37.10	35.90	27.00	31.10
3	35	7	5	1150	92.85	91.40	63.20	70.10
4	25	4	5	401	45.10	43.70	31.50	35.20
5	25	7	8	909	90.80	89.40	60.50	67.20
6	35	7	5	1079	90.92	89.52	60.80	67.30
7	25	10	5	798	53.99	52.59	36.10	40.10
8	25	7	2	823	52.82	51.41	35.10	39.20
9	45	4	5	351	45.21	43.81	31.70	35.28
10	45	7	2	952	54.00	52.60	36.19	40.19
11	35	7	5	1110	92.01	90.70	62.20	69.12
12	35	7	5	1106	91.12	89.70	68.87	67.40
13	35	10	8	900	88.10	86.70	57.80	65.10
14	35	4	2	450	34.79	33.41	26.00	30.12
15	35	4	8	302	59.00	57.70	40.10	42.60
16	35	7	5	1109	91.60	90.10	62.04	68.80
17	45	10	5	814	56.96	55.56	39.10	42.10

Table 2. Model fit summary statistics

Parameters	Responses				
	Voltage (V)	COD removal (%)	BOD removal (%)	TN removal (%)	TP removal (%)
Std. Dev.	0.0164	1.01	0.9864	2.62	2.10
Mean	0.8106	68.71	67.33	47.08	51.76
C.V. %	2.02	1.47	1.47	5.56	4.06
R^2	0.9985	0.9991	0.9992	0.9871	0.9926
Adjusted R^2	0.9965	0.9980	0.9981	0.9705	0.9830
Predicted R^2	0.9851	0.9901	0.9909	0.9491	0.9009
Adeq, Precision	63.7724	74.7833	76.4545	19.3369	25.3826

The coefficient of variance (CV), which is the ratio of the standard error of the estimate to the mean value of the observed response is a measure of reproducibility of the model. As a rule, a model can be considered a reasonably adequate model as its CV is less than10% [62]. In this case, the CV is 2.02%, 1.47%, 1.47 %, 5.56%, and 4.06% for voltage output, COD removal, BOD removal, TN removal, and TP removal, respectively which indicates that the developed model is adequate.

The regression coefficient (R^2) shows how much of the difference in the outcome is explained by the model which is useful for checking the adequacy of a model. The regression coefficient value is in a range between 0 and 1, and as it approaches 1.0 it fits well with the experimental data otherwise it indicates the inadequacy of model approximation. So, the model was found to be a highly significant model since the R^2 (0.9985, 0.9991, 0.9992, 0.9871, and 0.9926) value of all the responses is closer to 1.0. This means, 99.85% of the total variation in the voltage output is attributed to the experimental variables studied, or in another term, only 0.15 % of the variation was left unexplained by the model in the case of voltage output. Similarly, the R^2 for other responses such as COD removal, BOD removal, TN removal, and TP removal is 99.91 %, 99.92 %, 98.71 %, and 99.26 % respectively.

The predicted R^2 is the measure of the extent to which this developed model can be used to predict ranges of data this study has not considered, which, therefore, the difference between the predicted R^2 and adjusted R^2 should be less than 0.2 [62]. Accordingly, the obtained predicted R^2 (0.9851, 0.9901, 0.9909, 0.9491, and 0.9009) were in reasonable agreement with their adjusted R^2 (0.9965, 0.9980, 0.9981, 0.99705, and 0.9830) for voltage output, COD removal, BOD removal, TN removal, and TP removal, respectively, because the difference was found less than 0.2. So, the model is adequate to predict the ranges of data this study has not considered since the model had 98.51%, 99.01%, 99.09%, 94.91%, and 90.09% precision in fitting to all ranges of data. Besides, the adequacy of precision measures the signal to disturbance ratio due to random error. A ratio greater than 4 is desirable [62]. In this case, the ratio of all the parameters was found to be greater than 4 which indicates an adequate signal.

3.3 Factors Affecting MFCS Performances

So far, performances of laboratory MFCs are still much lower than the ideal performance. “There may be several possible reasons like Microbe type, fuel biomass type and concentration, ionic strength, pH, temperature, time, electrode materials, proton exchange membrane or salt bridge and operation conditions of anode and cathode that have important effect on MFCs” [63].

Linear effect of process variables such as pH, time, and temperature on the responses has been investigated by keeping other variables constant. The interaction effect of process variables on the responses has been also investigated by two interactive process variables at a fixed third variable. Interaction implies that the effect produced by changing the one-factor levels dependable on the level of the other factor. For the graphical interpretation, the use of three dimensional (3D) response surface plots affected by two interactive variables at a fixed third suggested variable. Thus, in this study, 3D plots were used to show the interactive effect of the variables on the responses and the optimum levels of each variable. Below is the discussion with possible reasons behind the single and interaction effect of process variables on the responses.

3.3.1 Effect of time

Fig. 2 shows the effect of time on the voltage output keeping the temperature and pH at the center point. As shown in the figure the voltage output is slightly affected by time, as time increases from 2 to 5 days the voltage output slightly increases, whereas operating beyond 5 days resulted in a slight decline in voltage output. The best voltage output has been observed on the 5^{th} day. This could be for the reason that the substrate and microbes were in contact for an optimal amount of time which might have favored the system to have an accelerated organic substance degradation by the microbes, so do a release of proton and electrons in the anodic section. “It was reported that the formation of most conductive biofilm over the electrode appears after 3 to 5 days” [64-66]. These studies demonstrated that the maximum voltage output is due to the formation of conductive biofilm which stimulates the oxidation of the organic matter. It is fairly in agreement with the finding of this study.

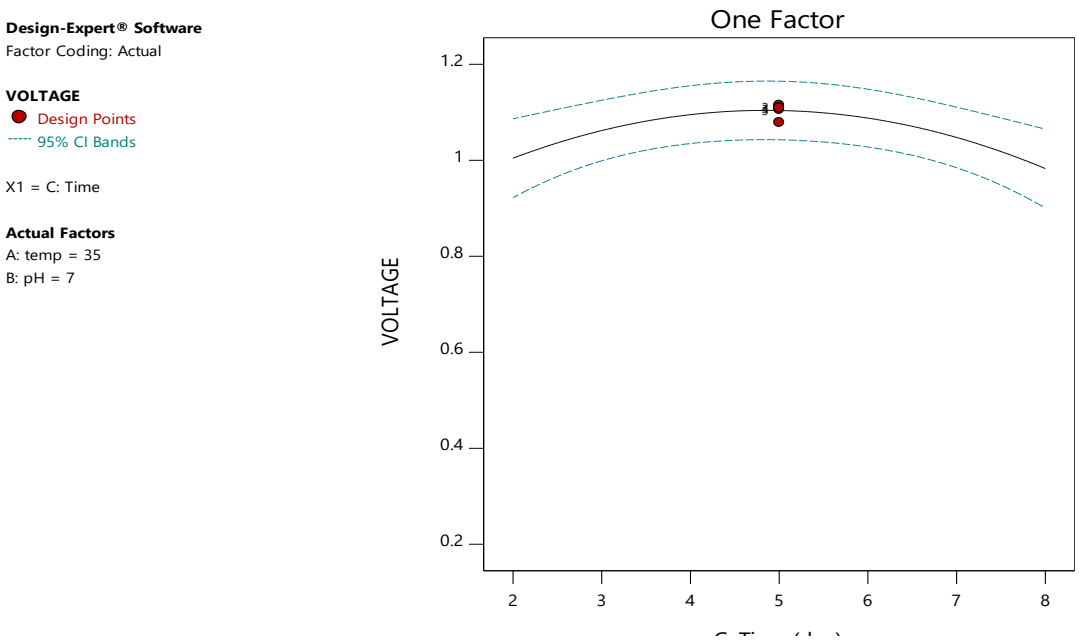

Fig. 2. Effect of time on the voltage output

3.3.2 Effect of pH

"The pH value had a strong effect on MFCs microbial activity which was reflected in the overall MFC performance" [67]. Changes in the pH value also affected the metabolism and absorption of nutrients through influencing the solubility of nutrients, thus affecting the growth rate of microorganisms. "This is because the fact that any microorganism should live in optimal pH value for its proper/optimal microbial growth that can also be inhibited when the pH environment is below or above the appropriate pH value" [68]. Thus, in this study, to investigate the effect of pH on voltage output, the MFC setups were operated under different anodic pH, ranging from 4 to 10. At all pH, the MFC setups started voltage output soon after the incubation period.

Fig. 3 shows the effect of pH on the voltage output holding time and temperature Constant. As shown in Fig. 2, voltage output is sensitive to the changes in pH. Hence, it was observed that a sharp increment in voltage output (302 -1150 mV) was recorded when running from acidic to neutral pH and then decreased gradually to about 850 mV in the basic pH. The best performance was observed when operating at pH 7 as the peak including the highest voltage output (1150 mV). The reason could possibly be the existence of a favorable pH for the microbial metabolic activities which generates proton and electrons. Thus, as the production of electrons increased, so does the voltage output. This is in agreement with the different studies which showed that optimum condition for microbial activity is set at neutral pH. Likewise, "changes in pH tend the microbes to respond accordingly which can pointedly influence the voltage output" [69-72].

The voltage outputs were lower at pH 4 and pH 10, this indicates that the microbial catalytic activity is lower at these pH ranges. Comparatively, the lowest voltage outputs were observed in the acidic pH than in the basic pH. "This is because operating at lower pH inhibiting the metabolic activity resulted from the accumulation of excessive protons and therefore drops the voltage output as reported by" [73,74]. Therefore, it can be concluded that the performance of MFCs towards the voltage output is extremely dependent on pH, and neutral pH exhibit better performance.

3.3.3 Effect of temperature

Fig. 4 shows the effect of temperature on the voltage output keeping the time and pH constant. As shown in the figure the voltage output is slightly affected by temperature, as the temperature increases from 25ºC to 35ºC, the voltage output slightly increases, whereas operating beyond 35ºC resulted in a slight decline in voltage output. The best performance was observed at 35ºC where the maximum

voltage outputs of 1150 mV was recorded. This can be due to the existence of a favorable temperature for the catalytic activity of the microbes. "A report by [75] showed that operating microbial fuel cells at a temperature between 30ºC and 45ºC is optimum to obtain higher voltage outputs", which agrees with the finding in this study. Therefore, it can be concluded that the temperature has insignificant effect on the voltage output but operating at a temperature of 35ºC gives a better result than the other temperature ranges.

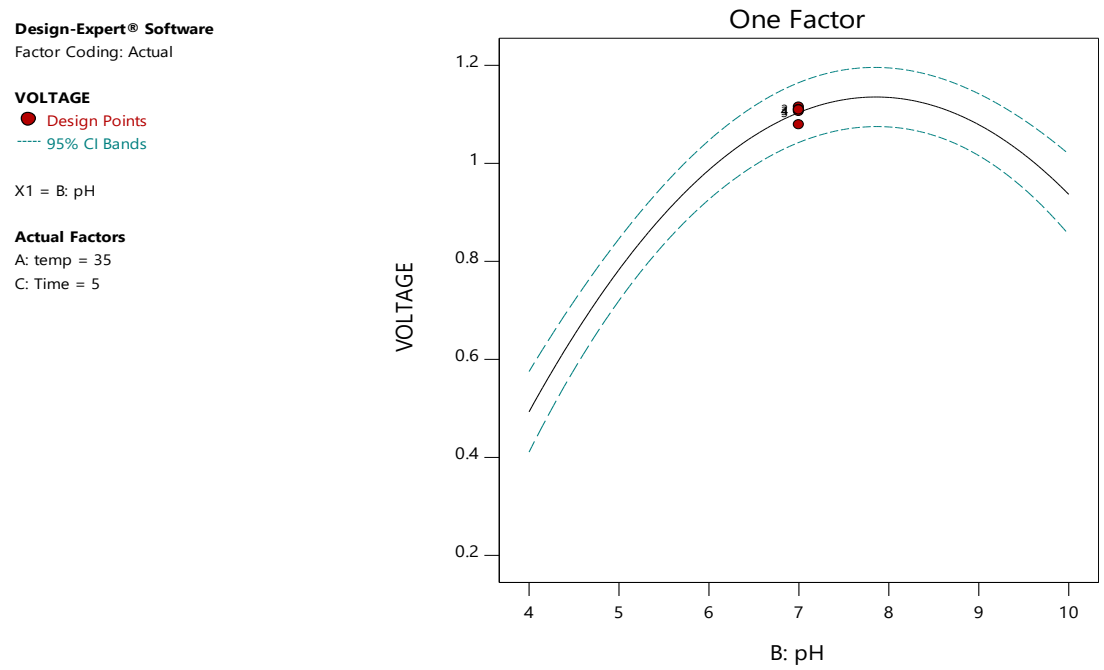

Fig. 3. Effect of pH on the voltage output

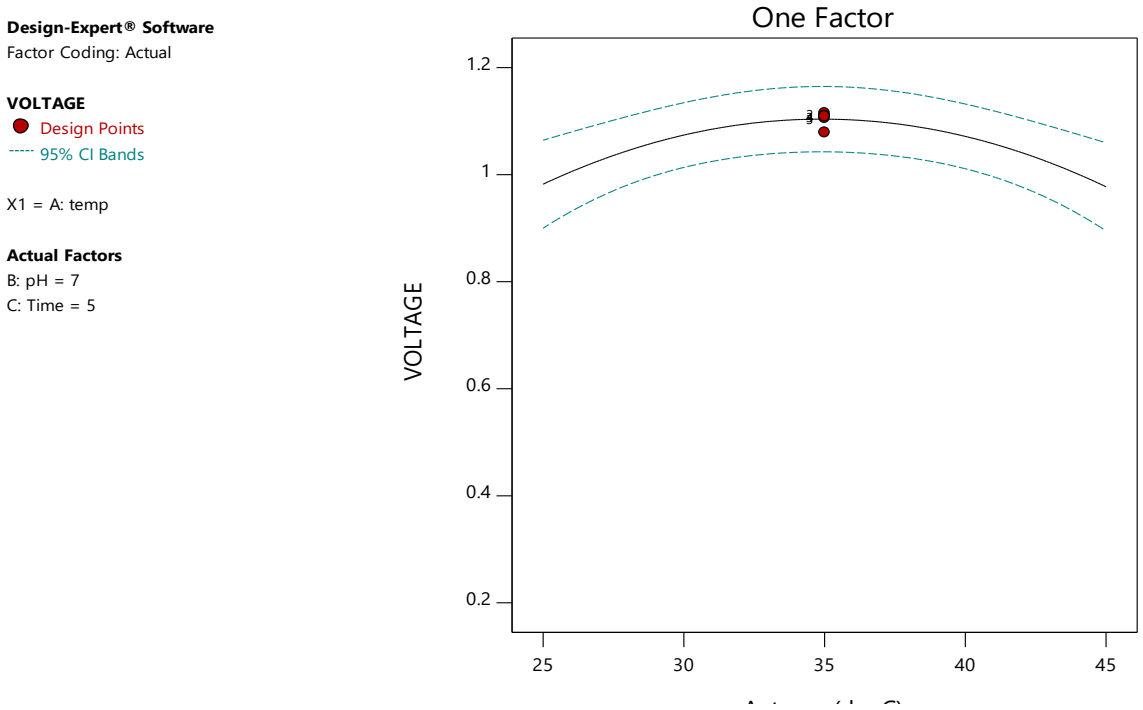

Fig. 4. Effect of temperature on the voltage output

4. CONCLUSION

This study investigated the bio-electrical performance of DCMFC fueled with brewery wastewater as an electron donor and inoculated with distillery plant waste from working biogas reactor as a source of microorganisms to run the experiment. From the experimental results, 1150mV maximum voltage output, 92.85%, 91.40%, 68.87%, and 70.10% removal efficiencies of COD, BOD, TN and TP respectively were obtained at 35ºC, pH 7, and 5 days. These results confirmed that the wastewater has been effectively treated and significant amount of direct bio-electricity is generated. This shows findings supported the hypothesis that bacterial heterogeneity of the anode surface is the main responsible factor for MFCs efficiency. The obtained results were compared with the previous literatures and the current study demonstrated that the potential of well-prepared MFCs to remove organic matter and other pollutants of interest, as well as to produce electricity. Results revealed that DCMFC provides an alternative insight into an effective treatment of wastewater that can simultaneously generate a direct bio-electricity. In this study, the inoculum was used as a source of microorganism. This might influence the voltage output. Thus, the type of microorganism involved in MFCs should be isolated and identified for further investigation. Moreover; further research into novel and economically feasible electrode and membrane materials, the improvement of electrogenicity of the microbes used, and the potential of hybrid MFCs will provide opportunities to launch MFCs from the laboratory to the commercial-scale as a bid to improve the global energy security in an eco-friendly way.

ACKNOWLEDGEMENTS

We are thankful to Mekelle University Department of Chemistry, Department of Chemical engineering and laboratory of Raya Brewery S.C for providing necessary facilities and valuable support throughout the work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kaberger T. Progress of renewable electricity replacing fossil fuels. Global Energy Interconnection. 2018;1:48-52.
2. Teoh TP, Ong SA, Ho LN, Wong YS, Oon YL, Oon YS, Tan SM, Thung WE. Up-flow constructed wetland-microbial fuel cell: Influence of floating plant, aeration and circuit connection on wastewater treatment performance and bioelectricity generation. J. Water Process. Eng. 2020;36:101371.
3. Liu Y, Liu H, Wang C, Hou SX, Yang N. Sustainable energy recovery in wastewater treatment by microbial fuel cells: stable power generation with nitrogen-doped graphene cathode. Environ. Sci. Technol. 2013;47:13889-13895.
4. Kusmayadi A, Leong YK, Yen HW, Huang CY, Dong CD, Chang JS. Microalgae-microbial fuel cell: An integrated process for electricity generation, wastewater treatment, CO_2 sequestration and biomass production. Int. J. Energy Res. 2020;44:9254-9265.
5. Guo YJ, Wang J, Shinde S, Wang X, Li Y, Dai Y, Ren J, Zhang P, Liu X. Simultaneous wastewater treatment and energy harvesting in microbial fuel cells: An update on the biocatalysts. RSC Adv. 2020;10:25874-25887.
6. Gowthami P, Jung HY, Sadhasivam T, Kurkuri MD, Kim SC, Roh SH. A comprehensive review on microbial fuel cell technologies: Processes, utilization, and advanced developments in electrodes and membranes. J. Clean. Prod. 2019;221:598–621.
7. Carlos MC, Hu YL, Xu C, Bassi A. An overview of microbial fuel cell usage in wastewater treatment, resource recovery and energy production. Sci. Total Environ. 2021;754:142429.
8. Crini G, Lichtfouse E. Advantages and disadvantages of techniques used for wastewater treatment. Environ. Chem. Lett. 2019;17:145-155.
9. Tamta P, Rani N, Yadav AK. Enhanced wastewater treatment and electricity generation using stacked constructed wetland microbial fuel cells. Environ. Chem. Lett. 2020;18:871-879.
10. Logan BE, Hamelers B, Rozendal R, Microbial fuel cells: methodology and technology. Environmental Science & Technology. 2006;40:5181-5192.
11. Fadzli FS, Rashid M, Yaqoob AA, Mohamad Ibrahim MN. Electricity generation and heavy metal remediation by utilizing yam (*Dioscorea alata*) waste in

benthic microbial fuel cells (BMFCs). Biochemical Engineering Journal. 2021;172:108067.
12. Do MH, Ngo HH, Guo WS, Liu Y, Chang SW, Nguyen DD, Nghiem LD, Ni BJ. Challenges in the application of microbial fuel cells to wastewater treatment and energy production: A mini review. Sci. Total Environ. 2018; 639: 910-920.
13. Ardakani MN, Gholikandi GB. Microbial fuel cells (MFCs) in integration with anaerobic treatment processes (AnTPs) and membrane bioreactors (MBRs) for simultaneous efficient wastewater/sludge treatment and energy recovery-A state-of-the-art review. Biomass Bioenergy 2020;141:105726.
14. He L, Du P, Chen YZ, Lu HW, Cheng X, Chang B, Wang Z. Advances in microbial fuel cells for wastewater treatment. Renew. Sustain. Energy Rev. 2017;71:388-403.
15. Sharma M, Bajracharya S, Gildemyn S. A critical revisit of the key parameters used to describe microbial electrochemical systems. Electrochimi. Acta. 2014;140:191-208.
16. Borole AP, Reguera G, Ringeisen B, Wang ZW, Feng Y, Hong Kim B. Energy Environ. Sci. 2011;4:4813-4834.
17. Erable B, Dut NM ¸ Ghangrekar MM, Dumas C, Scott K. Biofouling. 2010;26:57-71.
18. Schroeder U, Harnisch F, Biofilms, Electroactive. Encyclopedia of Applied Electrochemistry, Springer, New York. 2014;120-126.
19. Larrosa-Guerrero A, Scott K, Head IM, Mateo F, Ginesta A, Godinez C. Fuel. 2010;89:3985-3994.
20. Tee PF, Abdullah MO, Tan IAW, Amia MAM, Nolasco-Hipolito, Bujang CK. J. Environ. Chem. Eng. 2017;5:178-188.
21. Min B, Roman OB, Angelidaki I. Biotechnol. Lett. 2008;30:1213-1218.
22. Qiang L, Yuan LJ, Ding Q. Huanjing Kexue Xuebao. 2011;32:1524-1528.
23. Ahn Y, Logan BE. Bioresour. Technol. 2013;132:436-439.
24. Ye Y, Zhu X, Logan BE. Electrochim. Acta. 2016;194:441-447.
25. Fan Y, Hu H, Liu H. Environ. Sci. Technol. 2007;41:8154-8158.
26. Pant D, Van Bogaert G, Diels L, Vanbroekhoven K. Bioresour. Technol. 2010;101:1533-1543.
27. Pandey P, Shinde VN, Deopurkar RL, Kale SP, Patil SA, Pant D. Appl. Energy. 2016;168:706-723.
28. Foley JM, Rozendal RA, Hertle CK, Lant PA, Rabaey K. Environ. Sci. Technol. 2010;44:3629-3637.
29. Pant D, Singh A, Van Bogaert G, Alvarez Gallego Y, Diels L, Vanbroekhoven K. Renew. Sustain. Energy Rev. 2011;15:1305-1313.
30. Logan BE, Hamelers B, Rozendal R, Schröder U, Keller J, Freguia S, Aelterman P, Verstraete W, Rabaey K. Microbial Fuel Cells. Methodol. Technol. Environ. Sci. Technol. 2006;40:5181-5192.
31. Shams FA, Mofijur Md, Nafisa I, Tahlil AP, Nazifa R, Awais B, Jiří JK, Mahlia TMI. Insights into the development of microbial fuel cells for generating biohydrogen, bioelectricity, and treating wastewater. J. Energy. 2022;254:124163.
32. Ucar D, Cokgor EU, Sahinkaya E. Evaluation of nitrate and perchlorate reduction using sulfur-based autotrophic and mixotrophic denitrifying processes. Water Sci. Technol. 2015;16:208-218.
33. Enitan AM, Adeyemo J, Kumari S, Swalaha FM, Bux F. Characterization of Brewery Wastewater Composition. 2015;9:1073-1076.
34. Pant D, Van Bogaert G, Diels L, Vanbroekhoven K. A review of the substratesused in microbial fuel cells (MFCs) for sustainable energy production. Bioresource Technology. 2010;101:1533-1543.
35. APHA, AWWA, WEF. Standard methods for examination of water and wastewater. 22nd ed. Washington: American Public Health Association. In Standard Methods; 2012.
Available: https://doi.org/ISBN 978-087553-013-0
36. Parkash A, Aziz S, Nazir I, Soomro SA. Utilization of sewage for voltage generation in dual chamber microbial fuel cell. Sci. Int. (Lahore). 2015;27:5065-5068.
37. Singh K, Dharmendra. Performance of a dual chamber microbial fuel cell using sodium chloride as catholyte. Pollution. 2020;6:79-86.
38. Senthilraja K. Effect of brewery effluent irrigation and sludge application in combination with organic amendments on growth and yield of sesame. International Journal of Current Microbiology and Applied Sciences. 2017;6:965-977.

39. EPA. Ethiopian environmental protection authority; 2011.
Available: http://www.epa.gov.et/default.aspx
40. Kebede TB. Waste water treatment in brewery industry. Review. 2018;6:716-722.
41. Environmental, health, and safety guidelines for breweries; 2007.
Available:https://www.ifc.org/wps/wcm/connect/8afeb6b7-6602-4394-8584-7643035eeb50/Final%2B-%2BBreweries.pdf?MOD=AJPERES&CVID=nPtf7l5
42. Gude VG. Microbial fuel cells for wastewater treatment and energy generation. In Microbial Electrochemical and Fuel Cells: Fundamentals and Applications. 2016; 247-285.
43. Gude, Veera Gnaneswar. Wastewater treatment in microbial fuel cells - An overview. Journal of Cleaner Production. 2016; 122:287-307.
44. Sharda AK, Sharma MP, Kumar S. Performance Evaluation of Brewery Waste Water Treatment Plant. International Journal of Engineering Practical Research. 2013; 2:105-111.
45. Muthukumar M, Sangeetha T. The harnessing of bioenergy from a dual chambered microbial fuel cell (MFC) employing sago-processing wastewater as Catholyte. International Journal of Green Energy. 2014;11:161-172.
46. Kiran V, Gaur B. Microbial fuel cell: Technology for harvesting energy from biomass. Reviews in Chemical Engineering. 2013;29:189-203.
47. APHA, AWWA, WEF. Standard methods for examination of water and wastewater. 22nd ed. Washington: American public health association. In standard methods; 2012.
Available: https://doi.org/ISBN 978-087553-013-0
48. Rahimnejad M, Ghoreyshi AA, Najafpour G, Jafary T. Power generation from organic substrate in batch and continuous flow microbial fuel cell operations. Appl. Energ. 2011;88:3999-4004.
49. Rabaey K, Lissens G, Siciliano SD, Verstraete W. A microbial fuel cell capable of converting glucose to electricity at high rate and efficiency. Biotechnol. Lett. 2003;25:1531-1535.
50. Min B, Cheng S, Logan BE. Electricity generation using membrane and salt bridge microbial fuel cells. Water Res. 2005;39:1575-1586.
51. Liu H, Logan BE. Electricity generation using an air-cathode single chamber microbial fuel cell in the presence and absence of a proton exchange membrane. Environ. Sci. Technol. 2004;38:4040-4046.
52. Catal T, Li K, Bermek H, Liu H. Electricity production from twelve monosaccharides using microbial fuel cells. J. Power Sources. 2008;175:196-200.
53. Heilmann J, Logan BE. Production of electricity from proteins using a microbial fuel cell. Water Environ. Res. 2006;78:531-537.
54. Ringeisen BR, Ray R, Little B. A miniature microbial fuel cell operating with an aerobic anode chamber. J. Power Sources. 2007;165:591-597.
55. Ieropoulos IA, Greenman J, Melhuish C, Hart J. Comparative study of three types of microbial fuel cell. Enzyme Microb. Technol. 2005;37:238-245.
56. Rajeswari S, Vidhya S, Navanietha Krishnaraj R, Saravanan P, Sundarapandiyan S, Maruthamuthu S, Ponmariappan S, Vijayan M. Utilization of soak liquor in microbial fuel cell. Fuel, 2016;181:148-156.
57. Nair R, Renganathan K, Barathi S, Venkatraman K. Concentrations using hostel sewage waste as substrate. 2013;2:326-330.
58. Parkash A, Aziz S, Nazir I, Soomro SA. Utilization of Sewage for Voltage Generation in Dual Chamber Microbial Fuel Cell. Sci. Int. (Lahore). 2015;27:5065-5068.
59. Choi HJ. Parametric study of brewery wastewater effluent treatment using *Chlorella vulgaris* microalgae. Environmental Engineering Research. 2016;21:401-408.
60. Flimban SGA, Ismail IMI, Kim T, Oh SE. Overview of recent advancements in the microbial fuel cell from fundamentals to applications: Design, major elements, and scalability. Energies. 2019;12: 3390.
61. Khan MD, Khan N, Sultana S, Khan MZ, Sabir S, Azam A. Microbial fuel cell: Waste minimization and energy generation. In Modern Age Environmental Problems and their Remediation. 2018;40:129-146.
62. Montgomery DC. Design and Analysis of Experiments, fifth edition. Quality and

Reliability Engineering International. 2012; 18:697.
63. Oh ST, Kim JR, Premier GC, Lee TH, Kim C, Sloan WT. Sustainable wastewater treatment: How might microbial fuel cells contribute. Biotechnology Advances. 2010;28:871-881.
64. Jiang Q, Xing D, Sun R, Zhang L, Feng Y, Ren N. Anode biofilm communities and the performance of microbial fuel cells with different reactor configurations. RSC Advances. 2016;6: 85149-85155.
65. Liu Y, Climent V, Berná A, Feliu JM. Effect of temperature on the catalytic ability of electrochemically active biofilm as anode catalyst in microbial fuel cells. Electro-analysis. 2011;23:387-394.
66. Mei X, Xing D, Yang Y, Liu Q, Zhou H, Guo C, Ren N. Adaptation of microbial community of the anode biofilm in microbial fuel cells to temperature. Bioelectrochemistry. 2017; 117:29-33.
67. Vilajeliu-Pons A, Puig S, Rovira A. Effect of hydrodynamics on MFC microbial community. In: 2nd european international society for microbial electrochemistry and technology meeting. Alcalá de Henares, Spain; 2014.
68. Rago L, Baeza JA, Guisasola A. Increased performance of hydrogen production in microbial electrolysis cells under alkaline conditions. Bioelectrochemistry. 2016;109:57-62.
69. Kumar R, Singh L, Wahid ZA, Din MFM. Exoelectrogens in microbial fuel cells toward bioelectricity generation: A review. International Journal of Energy Research. 2015;39:1048-1067.
70. Kumar R, Singh L, Zularisam AW. Exoelectrogens: Recent advances in molecular drivers involved in extracellular electron transfer and strategies used to improve it for microbial fuel cell applications. Renewable and Sustainable Energy Reviews. 2016;56:1322-1336.
71. Sultana R, Adhikary NC, Kalita MC, Talukdar NC, Khan MR. Study of the Efficiency of a Double-chambered Microbial Fuel Cell using Citrobacter sp. International Journal of Scientific Research in Biological Sciences. 2019; 6:1-9.
72. Venkata Mohan S, Velvizhi G, Annie Modestra J, Srikanth S. Microbial fuel cell: Critical factors regulating bio-catalyzed electrochemical process and recent advancements. Renewable and Sustainable Energy Reviews. 2014; 40:779-797.
73. Bermek H, Catal T, Akan SS, Ulutaş MS, Kumru M, Özgüven M, Liu H, Özçelik B, Akarsubaşı AT. Olive mill wastewater treatment in single-chamber aircathode microbial fuel cells. World Journal of Microbiology and Biotechnology. 2014; 30:1177-1185.
74. Shaheen Aziz AP. Utilization of sewage sludge for production of electricity using mediated salt bridge based dual chamber microbial fuel cell. Journal of Bioprocessing & Biotechniques. 2015; 5:2155-9821.
75. Yong XY, Feng J, Chen YL, Shi DY, Xu YS, Zhou J, Wang SY, Xu L, Yong YC, Sun YM, Shi CL, OuYang PK, Zheng, T. Enhancement of bioelectricity generation by cofactor manipulation in microbial fuel cell. Biosensors and Bioelectronics. 2014; 56:19-25.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/97258