Study of The Effect of pH on The Performance of Microbial Fuel Cell for Generation of Bioelectricity

Md. Abdul Halim
Department of Chemical Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh
Md. Owaleur Rahman
Department of Chemical Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh
Md. Ibrahim
Department of Chemical Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh
Rituparna Kundu
Department of Chemical Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh
Biplob Biswas (bk.biswas@just.edu.bd)
Jashore University of Science and Technology https://orcid.org/0000-0002-0883-5681

Research

Keywords: Microbial fuel cell, Bioelectricity, Current density, Power density, Wastewater

Posted Date: January 22nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-151072/v1

Study of the effect of pH on the performance of microbial fuel cell for generation of bioelectricity

Md. Abdul Halim, Md. Owaleur Rahman, Md. Ibrahim, Rituparna Kundu, Biplob Kumar Biswas*

Department of Chemical Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh

*Corresponding email: biplobbiswas2009@gmail.com

Abstract

Background: Day by day microbial fuel cell (MFC) technology is becoming a thought-provoking topic to the researcher because for its simultaneous utilization e.g. electricity production and wastewater treatment. Since wastewater is an important source of electrolyte for MFC, the key tenacity of this study was to investigate the outcome of pH happening various (Municipal, Bhairab river and Hospital) wastewaters used as electrolyte in dual chamber MFC.

Findings: The lab-scale experiment was conducted in batch mode, where zinc plate ($0.0027m^2$) as anode and copper plate ($0.0027m^2$) as cathode. In this study a single electrolyte (any one of earlier mentioned three electrolytes) was used in five dual-chambers MFC where the pH of the electrolyte was 6, 7, 8, 9 and 10. The MFC was worked on a temperature ranged from 27°C to 34°C. Maximum outputs were found in terms of current density (1288.9mAm^{-2}), voltage (1132 mV) and power density (1459.02 mWm^{-2}) were obtained at pH 8 by using Bhairab river water as an electrolyte in MFC chamber. A substantial amount of COD removal (94%) was also achieved in the same MFC chamber at the same pH (i.e. pH 8). However, the optimum operating pH for MFC containing municipal wastewater and hospital wastewater was found to be 8 and 9, respectively.

Conclusion: The results suggest that various wastewaters may act as feasible feedstocks for bioelectricity generation in MFC. The results also show that COD can be removed from wastewater that suggest a treatment possibility of wastewater .

Keywords: Microbial fuel cell, Bioelectricity, Current density, Power density, Wastewater.

Introduction

In contemporary years, utilization of energy in the whole world has been increased enormously (Rahimnejad et al. 2015). Energy comes from various sources such as renewable as well as non-renewable. All non-renewable (fossil) based energy has a negative impact on environment by producing greenhouse gases (Feng et al. 2018). However, for the sake of adversative effect (global heating and contamination) on the environment, the accumulation of fossil energies as a vigor source desires to be abridged (Slate et al. 2019). Considering cost effectiveness and environmental problems, an environmental friendly renewable energy source is very urgent. Microbial fuel cell is imminent system, which provides a potential renewable energy source that might help achieving energy security. MFC can produce energy (electricity) by decomposing the carbon-based substance existing in the electrolyte whereas various wastewaters as well as industrial effluents can be used. Since effluents and wastewaters are causing environmental pollution very much, their treatment is required indeed to improve the environmental condition from pollution. Apart from the classical wastewater treatment, MFC is reported to be used for wastewater management (Gotovtsev et al. 2016). In developed countries 1-3% electricity for domestic consumption comes from sewage wastewater treatment plants (Maktabifard et al. 2018). At a same time MFC generate electricity and treat wastewater too (Mustakeem 2015; Dong et al. 2015). Variety of knowledge from engineering, biology and chemistry is required for the assembly and finest procedure of microbial fuel cells (Mansoorian et al. 2014; Rajeswari et al. 2016). The most three key materials of MFC are electrode, membrane, and electrolyte which, determine the performance of the MFCs. In MFC bio-electrochemical both half-cell reactions occurs on the outward of the anode and cathode. However, better yield optimization and improvement of electrode of MFC are still thought-provoking research topic worldwide (Li et al. 2017). Ion exchange membrane (IEMs) particular cation exchange membrane (CEM) is very effective on large-scale with greater depth of electrolyte (Ge and He 2016; Liang et al. 2018). Though, the MFC can extravagances numerous cations, such for example Na^+, Ca^{2+}, K^+, and ${NH_4}^+$ present in the electrolyte (wastewater), which contest by protons that attribute to the minus charged functional groups in the CEM (Rozendal et al. 2006), which can reduce in electrical energy creation subsequently long-standing process (Ge and He 2016; Liang et al. 2018). Bacteria can help to increase the output of MFC and reject mediator from anode chamber (Reshetilov et al. 2017). Literature shows that, electrolytes like chemical based industrial wastewater (Venkata Mohan et al. 2008), dairy wastewater (Porwal et al. 2015), soak liquor (Sawasdee and Pisutpaisal 2016), dye factory wastewater (Kalathil et al. 2012; Patade et al. 2016), starch treating wastewater (Quan et al. 2014), leachate (Damiano et al. 2014), sugar mill sewage (Kumar et al. 2016), Domestic wastewater (Asai et al. 2017), Poultry dropping wastewater (Oyiwona et al. 2018), rice bran (Takahashi et al. 2016) beside through new spreads in the usage of various substrates (Pandey et al. 2016) can be treated by MFC. Beside wastewater MFC can usage clean mixtures such as acetate or butyrate (Hidalgo et al. 2016), alcohol, fatty acid, monosaccharide sugar (Asensio et al. 2016), sucrose and glucose as electrolyte. To improve the output of MFC, recently researchers did several studies to the practice of MFC through membrane (Ghasemi et al. 2015), short of membrane (Logan et al. 2007), using moderator, short of moderator (Sevda and Sreekrishnan 2012) also using bio-cathodes (Gonzalez del Campo et al. 2014). Various operating parameters such as pH (Jadhav and Ghangrekar 2009), anode and cathode ingredients (Scott et al. 2008), the space among the electrodes (Hong et al. 2009a), external resistance (Hong et al. 2009a), temperature (Hong et al. 2009a), conductivity (Hong et al. 2009b), also carbon-based substance of the deposit (Wang et al. 2012) distresses the generated outputs of the microbial fuel cell.

The foremost interest of our experiment is to examine the effect of initial pH of various wastewaters obtained from Jashore on the output of MFC and to find the most favorable value of pH at which the system works best. To achieve that several experiments on municipal wastewater, bhairab river water and hospital wastewater were conducted by using zinc plate as anode, copper plate as cathode, and salt bridge as proton exchange membrane.

Materials and Methods

In this section, design and construction procedures of MFC are discussed with detailed description of construction materials. The reactor configuration and operation of the whole processes (micro-organism inoculation, electrolyte collection, salt bridge and electrode preparation, data collection and performance analysis) are also discussed.

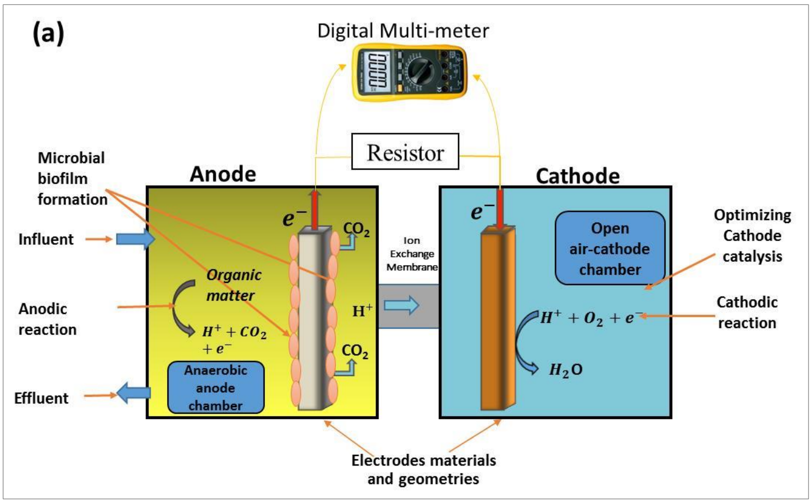
Materials collection and cell construction

Various materials were used for this research work. Each material has its specific function. However, the coordinated function of these materials is to construct microbial fuel cell and to operate it optimally. The name and its operation of the used ingredients are given in the Table 1.

Table 1 Name and function of ingredients used in microbial fuel cell.

Name	**Function**
Zinc plate and Copper plate	Anode and Cathode
Glass	Body of MFC
PVC pipe, Potassium sulphate salt, Agar-agar and Surgical cloth	Constituents for salt bridge
Waste water	Electrolyte
Digital Multimeter	Collecting data

Zinc and Copper plates (for anode and cathode) were purchased from local scientific shop at Jashore, Bangladesh. All other items were purchased from local shops. To construct the main body (the chamber) of the MFC, locally available window glass was used. The volume of each chamber was 0.005 m^3 (length 0.25 m, width 0.10 m and height 0.20 m) where there were three intros; single designed for adding, second for deletion of electrolyte as well as rest one for the connection with former compartment. The two chambers were connected using an agar salt bridge with a length and diameter of 4.0 cm and 0.5 cm, separately. For the preparation of salt bridge 0.1M salt solution of 5 gm agar was prepared in which several pieces of surgical cloths were kept for 2-3 h. A small PVC tube approximately 4.0 cm long was packed by the surgical cloths immersed the agar-salt resolutions. All joints of MFC were enclosed using M-seal (K1 Mart, India) to avert the outflow. The prepared microbial fuel cell (MFC) is shown in Fig. 1.



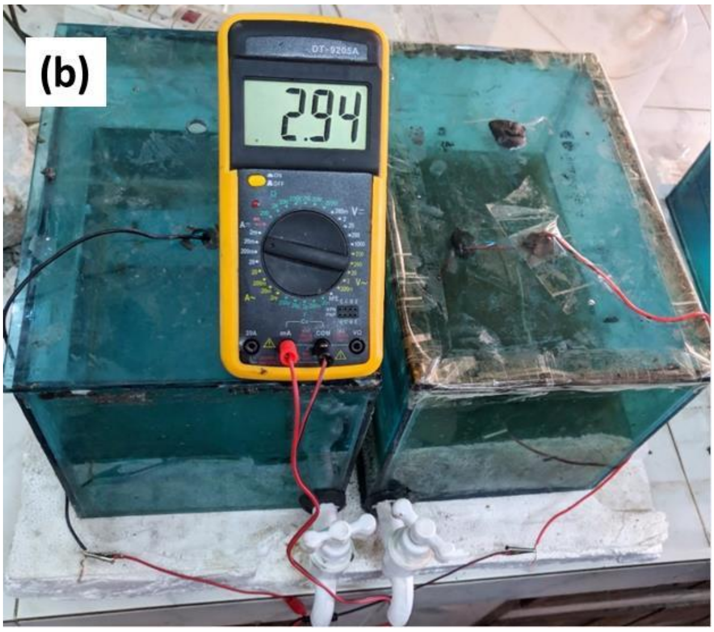


Fig. 1(a) Schematic diagram and **(b)** constructed MFC for the experiment.

Microbe inoculation and electrolyte collection

Locally available microorganisms (*Escherichia coli, Anabaena, Rhodospirillum* and some cyanobacteria) were used in all experiment. At first organic rich bottom feeders were collected from the local pond, which was then cultured for proper growth of micro-organisms. It was done by mixing 1.5 ($^{w}/_{w}$%) cow dung and 0.2($^{w}/_{w}$%) sugar with bottom feeders.

The mixture was kept in an anaerobic condition for 48 h. After inoculation these microbes were used in anode chamber for the experiment. The untreated raw wastewaters (collected from Municipal drain, Bhairab River and Jashore General Hospital) were used in anode chamber. For first experiment we collected wastewater from municipal drain where the water flow rate was 225 ml·s^{-1}. In second experiment we collected wastewater from Bhairab River at 150 cm depth from the surface. In third experiment we collected wastewater from Jashore General Hospital pipeline where the water flow rate was 195 ml·s^{-1}. The average chemical compositions of these wastewaters throughout the experiment are abridged in Table 2. The average COD concentration of the raw municipal wastewater was 784 mg·L^{-1}, Bhairab river water was 832 mg·L^{-1} and hospital wastewater was 842 mg·L^{-1}.

(a) Municipal drainage

(b) Bhairab river

Fig. 2 Sources of wastewater used as electrolyte.

Table 2: The average chemical composition of various wastewaters in Jashore, Bangladesh.

Parameter	Municipal wastewater (mg·L^{-1})	Bhairab river water (mg·L^{-1})	Hospital wastewater (mg·L^{-1})
HCO_3^-	347.4	354.8	294.6
Cl^-	395.8	565.6	835.3
Ca^{2+}	32.4	38.6	56.6

Mg^{2+}	26.7	32.3	18.7
Na^{+}	17.3	21.9	19.9
NO_3^-	4.42	3.24	13.18
SO_4^{2-}	82.3	87.5	127.5
PO_4^{2-}	6.25	5.8	3.9

Collection of data and its analysis

To monitor the effect of electrode materials, data was collected manually by using a digital multi-meter (DT-9205A, China) at a fixed interval of 20 min. The average values of voltage and current were calculated as follows:

$$Average\ voltage = {Total\ voltage}/{Number\ of\ count} \quad (1)$$

$$Average\ current = {Total\ current}/{Number\ of\ count} \quad (2)$$

Founded on the documented electrical energy (voltage, current and power) current density (I_{anode}, $A\cdot m^{-2}$) as well as power density (P_{anode}, $W\cdot m^{-2}$) were determined as follows:

$$\text{Current density}, \mathrm{I_{anode}} = \mathrm{I}/\mathrm{A} \quad (3)$$

$$\text{Power density}, \mathrm{P_{anode}} = \mathrm{P}/\mathrm{A} \quad (4)$$

where, I is current (A), P is the power (W), and A is the external area (m^2) of the anode.

Calculation of COD removal

Chemical Oxygen Demand (COD) specifies the quantity of oxygen (O_2) that can be consumed by reactions in a measured solution. The carbon-based substance existing in the water sample is dissolved by potassium dichromate ($K_2Cr_2O_7$) in the attendance of sulfuric acid (H_2SO_4), silver sulfate (Ag_2SO_4) and mercury sulfate ($HgSO_4$) to harvest carbon dioxide (CO_2) and water (H_2O). COD can be calculated by using Equation 5.

$$\mathrm{COD} = \frac{8 \times 1000 \times \mathrm{DF} \times \mathrm{M} \times (\mathrm{V_B} - \mathrm{V_S})}{\text{Volume of sample (in ml)}} \tag{5}$$

where, DF stands for the Dilution Factor, M stands for the Molarity of standardized Ferrous Ammonium Sulfate $(NH_4)_2Fe(SO_4)_2.6H_2O$ solution, V_B stands for the Volume used up in titration through blank preparation, V_S stands for the Volume used up in titration through sample preparation.

To calculate the removal percentage of COD we used the Equation 6.

$$\text{COD removal efficiency (\%)} = \frac{COD_{in} - COD_{out}}{COD_{in}} \times 100 \tag{6}$$

Where, subscript *in* and *out* indicates influent and effluent fluid, respectively.

Results and discussion

Parameters such as pH (Jadhav and Ghangrekar 2009), electrode constituents (Scott et al. 2008), the space among the electrodes (Hong et al. 2009a), external resistance (Hong et al. 2009a), temperature (Hong et al. 2009a), conductivity (Hong et al. 2009b), also biological matter of the residue (Wang et al. 2012) are reported to affect the power production of the microbial fuel cell. The performance of MFCs increased for long term operation when electro-genic biofilm formed on the electrode surface. The pH of electrolytes acting a vigorous character in bioreactor performance (Gil et al. 2003). Likewise, electrolyte pH acting a vigorous key role in MFC's power output. Acidic pH lower than 6 drastically reduces the power generated from MFC (Gil et al. 2003). It means, low-slung pH situations exposed a contrary consequence on the electro-chemically lively bacteriological inhabitants, which in chance clues to an extreme fall in power generation. So, pH strongly influences the output of MFC for both in batch feed and continuous feed way of action. A perfect pH variety for favored fuel cell arrangement was quantified to be in the mid of 7–8 (Liu and Ramnarayanan 2004). This section mainly discussed the effect of pH on various locally available wastewaters for the output of microbial fuel cells.

Effect of pH while using municipal wastewater as electrolyte

In microbial fuel cell operation, pH is considered to be an important parameter that may affect the generation of electricity. A series of experiments were conducted by varying the pH (from pH 6 to pH 10) of the electrolyte (municipal wastewater in this case) while the other parameters such as operating temperature, volume of the electrolyte, materials of electrodes, surface area of electrodes etc. were kept constant. The results are depicted in Fig. 3 (a, b and c). As shown in Fig. 3(a), it was obvious that pH 8 gave highest output (in the form of voltage) all through the experimental period (1 – 15 days) compared to other experimented pH. The voltage gradually increased up to day 4 and then it started to decline. The highest value of voltage (1125 mV) was obtained at day 4 for the process operated at pH 8. On the other hand, current density increases up to day 3 for all tested pH as shown in Fig. 3 b. Then it starts decreasing gradually. However, the maximum value of current density was found to be 1155.6 mAm^{-2} for pH 8 at day 3. Like voltage and current density the supreme power density was obtained at pH 8 which is 1245.7 mWm^{-2}, where the other top values are 1008.7 mWm^{-2}, 1066.8 mWm^{-2}, 990.9 mWm^{-2} and 837.8 mWm^{-2} for pH 6, 7, 9 and 10, respectively as shown in Fig. 3 (c). It is obvious from Fig. 3(a, b and c) that voltage, current density and power density increases for first several days and then starts to decrease gradually. The increase in extent of current density, voltage and power density in initial days happens because (Abhilasha 2013) shows that microbial inoculation enabled higher current yield. In this experiment it takes three to four days for complete inoculation of bacteria. Again the decrease in extent may happen owing to the fact that with time a biofilm may form on the exterior of the anode. However after 15 days of operation, cumulative yields for voltage, current density and power density were tabulated in Table 3 from where it is obvious that pH 8 showed highest values.

Table 3: Cumulative yield obtained from municipal wastewater for various pH in 15 days using microbial fuel cell (MFC).

Operating pH	Measurement	Cumulative value
6	Voltage (mV)	12497
	Current density (mAm^{-2})	11014.8
	Power density (mWm^{-2})	9518.8
7	Voltage(mV)	12847
	Current density (mAm^{-2})	11918.5
	Power density (mWm^{-2})	10551.1
8	Voltage (mV)	13577
	Current density (mAm^{-2})	13574.1
	Power density (mWm^{-2})	12676.2
9	Voltage (mV)	12050
	Current density (mAm^{-2})	11151.8
	Power density (mWm^{-2})	9298.1
10	Voltage (mV)	11455
	Current density (mAm^{-2})	9829.6
	Power density (mWm^{-2})	7830.4

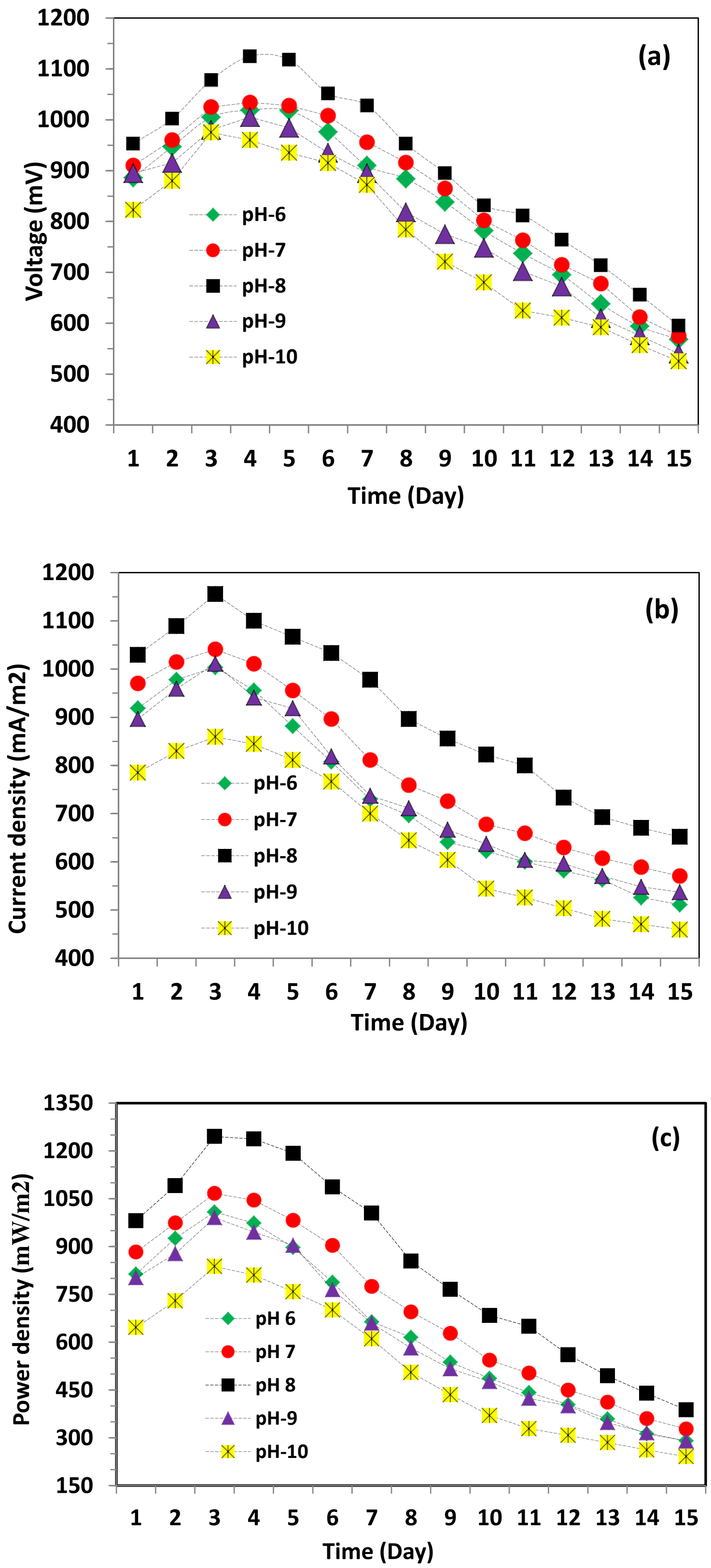


Figure 3: Effect of various pH on the **(a)** generated voltage, **(b)** current density and **(c)** power density from double chamber MFC for municipal wastewater.

For comparison with other reported values, a comparative statement has been tabulated in Table 4. It is apparent that the present study gives better result in terms of extent of voltage, current density and power density compared to many other reported values.

Table 4: Comparative statement with related published research findings.

pH	Electrode	Electrolyte	Voltage	Current/ Current density	Power/ Power density	Reference
8	Zinc and copper	Municipal wastewater	1125 mV	1155.6 mAm^{-2}	1245.7 mWm^{-2}	Present study
	copper boride alloy	Municipal wastewater		3500 mAm^{-2}	3055 mWm^{-2}	Paweł and Barbara 2019
6.9	carbon paper and magnesium oxide	Sugar industry wastewater	1420 m V	23.66 mA	5.1 mWm^{-2}	Omprakash 2019
7	graphite felt		445 mV			Zhang et al. 2011
6–7	graphite felt			400 µA		Biffinger et al. 2008

graphite felt		223.8 mAm^{-2}		He et al. 2008
graphite rod	urban wastewater		18 mWm^{-2}	Sebastia et al. 2010

This findings is very much resemble with (Jadhav and Ghangrekar 2009), who express that highest current is obtained between pH of 6.5 and 8, but this values were lesser at pH of 9 plus pH under 7. The main reason behind this, at higher pH than optimum value affects the growth of bacteria, which decrease he generated voltage (Sebastia et al. 2010).

COD removal is an important parameter for microbial fuel cell. (Zinadini et al. 2017) indicates that high COD deletion and columbic efficiency (CE) improve significantly the productivity of MFCs. The initial COD of municipal waste water in Jashore municipality was 538 ppm. In this experiment the COD removal were over 86%, 89%, 91%, 88% and 86% for the electrolyte having initial pH 6, 7, 8, 9 and 10, respectively.

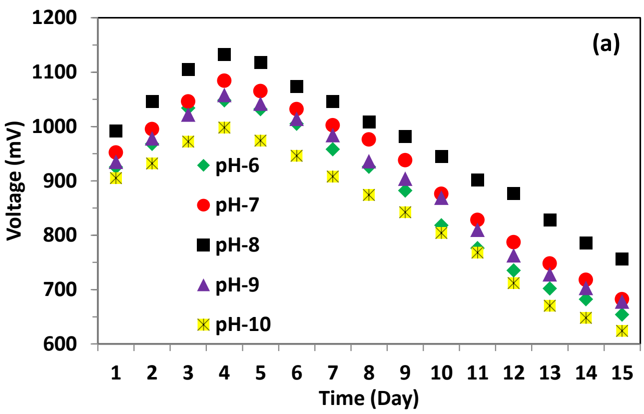
Effect of pH while using Bhairab river water as electrolyte

A series of experiments were conducted by varying the pH (from pH 6 to pH 10) of the electrolyte (Bhairab river water in this case) while the other parameters such as operating temperature, volume of the electrolyte, materials of electrodes, surface area of electrodes etc. were kept constant. Water collected at 150 cm depth from the surface of the river water. The results are depicted in Fig. 4(a), 4(b) and 4(c). As shown in Fig. 4(a), it was obvious that pH 8 gave highest output (in the form of voltage) all through the experimental period (1 – 15 days) compared to other experimented pH. The voltage gradually increased up to day 4 and then it started to decline. The highest value of voltage (1132 mV) was obtained at day 4 for the process operated at pH 8. It is also seen in (Fig. 4a) that, in operation period pH 8 gives the best result in all time. The yield from pH 7 is better than the other three. Obtained voltage from pH 6 and pH 9 are approximately the same, but for higher pH (10) the yield is lower than the others. Like voltage, current density (Fig. 4b) spike in first four days goes a maximum value of 1144.4mAm^{-2}, 1174.1mAm^{-2}, 1288.9mAm^{-2}, 1181.5mAm^{-2}, and 1122.2mAm^{-2} for pH 6, 7, 8, 9 and 10, respectively, and then current density decreased in a similar way to voltage. In this experiment the maximum current density obtained for pH 8. Similar to voltage and current density the supreme power density obtained for pH 8 which is 1459.02 mWm^{-2}, where the other top values are 1199.4 mWm^{-2}, 1272.7 mWm^{-2}, 1250 mWm^{-2} and 1120 mWm^{-2} for pH 6, 7, 9 and 10, correspondingly which is shown in Fig. 4c. It shows that for maximum output pH 8 is better than the other, so, it can be said that, when Bhairab river water is used as electrolyte pH 7 to pH 8 produce the better yield. Variation of pH from this value the outlet will be declined. The total obtained values are shown in Table 5.

Table 5: Cumulative yield obtained from Bhairab river water for various pH in 15 days using microbial fuel cell (MFC).

Operating pH	Measurement	Cumulative value
6	Voltage (mV)	13145
	Current density (mAm^{-2})	12566.7
	Power density (mWm^{-2})	11435.4

7	Voltage (mV)	13729
	Current density (mAm^{-2})	13274.1
	Power density (mWm^{-2})	12526.3
8	Voltage (mV)	14597
	Current density (mAm^{-2})	15322.2
	Power density (mWm^{-2})	15233.5
9	Voltage (mV)	13424
	Current density (mAm^{-2})	13740.7
	Power density (mWm^{-2})	12644.02
10	Voltage (mV)	12577
	Current density (mAm^{-2})	12966.7
	Power density (mWm^{-2})	11202.7



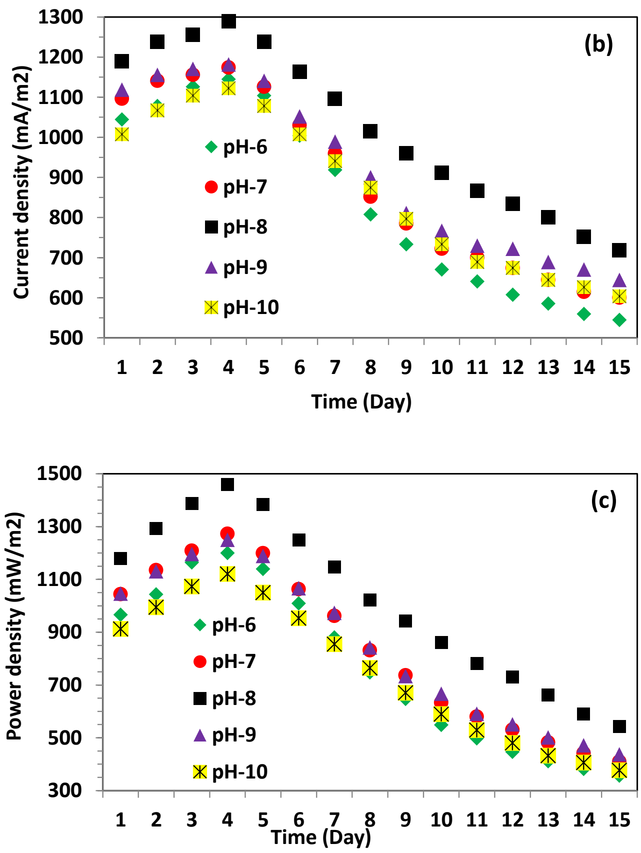


Figure- 4: Effect of various pH on the **(a)** generated voltage, **(b)** current density, **(c)** power density from double chamber MFC for bhairab river wastewater.

For comparison with other reported values, a comparative statement has been tabulated in Table 6. It is apparent that the present study gives better result in terms of extent of voltage, current density and power density compared to many other reported values.

Table 6: Comparative statement with related published research findings.

pH	Electrode	Electrolyte	Voltage	Current density	Power density	Reference
8.0	Zinc and copper	Bhairab river water	1132 mV	1288.9 mAm^{-2}	1459.02 mWm^{-2}	This study

6	graphite rods and PbO_2 graphite	River water	937mV	382 ($\mu A/cm^2$)	86 ($\mu W/cm^2$)	Dhiraj et al. 2020
6.5 to 7.5	Carbon cloth	Domestic wastewater			120 mWm^{-2}	Li and Chen 2018
6.7	Hybrid with stainless steel and plain graphite	Musi river water	mV	62.23 mAm^{-2}	15.56 mWm^{-2}	Venkata et al. 2009

In fifteen days operation the COD removal were over 88%, 90%, 94%, 91% and 89% for the electrolyte having initial pH 6, 7, 8, 9 and 10 respectively. COD removal rates of (Zhang et al. 2011) were 85%, 86%, 83%, and 88% at initial pH (4, 5, 6, and 7) respectively. We got all the maximum findings at pH 8. (Zhang et al. 2011) also said that, on anode surface biofilms formed by both long and short rod-shaped biomass bacteria. But acidic medium the thickness of biofilm is less than the neutral medium. So, biofilms can break at pH ≤5, which can drop down into the inner portion of the electrode, resulting in decries the generated electricity. (Behera et al. 2010) identified that; slightly alkaline anodic pH (7.5) is favorable for better electricity generation and COD removal. (Gil et al. 2003) said that at higher pH more than 10 power generations decreased for low proton transfer.

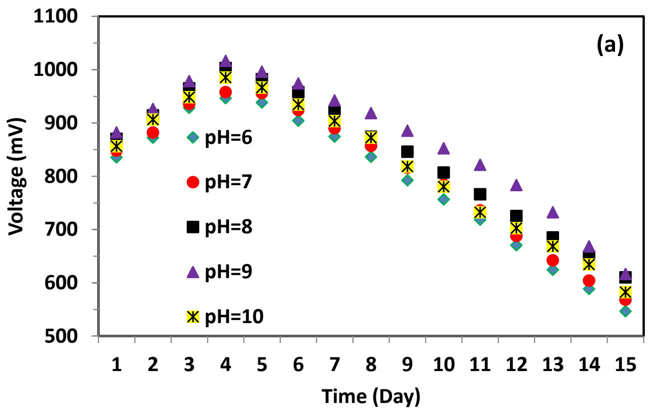
Effect of pH while using Jashore General Hospital wastewater as electrolyte

To examine the consequence of pH on the output of microbial fuel cell, several experiments were done by using Jashore General Hospital wastewater as electrolyte. The experiment performed at room temperature and Zinc plate used as an anode and Cupper plate used as a cathode. In this experiment, the only variable was the initial pH (6 to 10) of electrolyte. Whereas, the other operating conditions (temperature, volume, electrolyte, and electrode) are the same. Here the Jashore General Hospital wastewater was collected from the outlet of hospital pipeline. The results are depicted in Fig. 5a, 5b and 5c. As shown in Fig. 5a, it was obvious that pH 9 gave highest output (in the form of voltage) all through the experimental period (1-15 days) compared to other experimented pH. The voltage gradually increased up to day 4 and then it started to decline. The highest value of voltage (1016 mV) was obtained at day 4 for the process operated at pH 9. Again, in current density it increases up to day 4 for all tested pH as shown in Fig. 5b. Then it starts decreasing gradually. However, the maximum value of current density was found to be 1007.41 mAm^{-2} for pH 9 at day 4. Like voltage and current density the extreme power density was obtained at pH 9 which is 1023.53 mWm^{-2}, where the other top values are 767.31 mWm^{-2}, 830.27 mWm^{-2}, 980.71 mWm^{-2} and 886.5 mWm^{-2} for pH 6, 7, 8 and 10, respectively as shown in Fig. 5c. All the figures show that, for Jashore General Hospital wastewater as electrolyte pH 9 is better than the other. Where, (Parkash 2018) got pick output at pH 8.5. Variation of pH from this value the outlet will be declined. The total obtained values are shown in Table 7.

Table 7 Cumulative yield obtained from Jashore General Hospital wastewater for various pH in 15 days using microbial fuel cell (MFC).

Operating pH	Measurement	Cumulative value
6	Voltage (mV)	11827
	Current density (mAm^{-2})	8529.63
	Power density (mWm^{-2})	7072.72

7	Voltage (mV)	12089
	Current density (mAm^{-2})	8977.78
	Power density (mWm^{-2})	7597.98
8	Voltage (mV)	12575
	Current density (mAm^{-2})	10370.37
	Power density (mWm^{-2})	9039.91
9	Voltage (mV)	12989
	Current density (mAm^{-2})	10874.07
	Power density (mWm^{-2})	9732.85
10	Voltage (mV)	12286
	Current density (mAm^{-2})	9477.78
	Power density (mWm^{-2})	8119.42



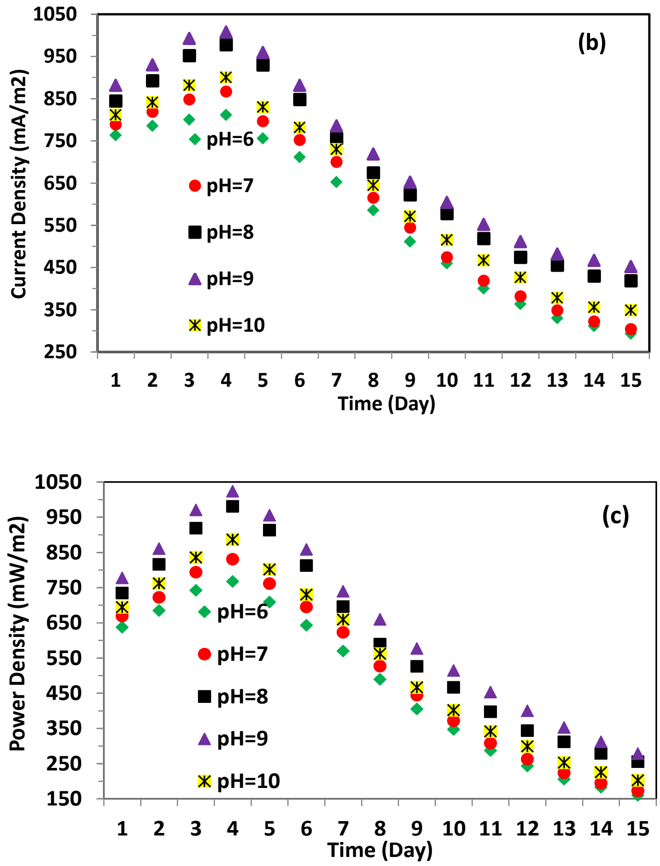


Fig. 5 Effect of various pH on the **(a)** generated voltage, **(b)** current density, **(c)** power density from double chamber MFC for Jashore General Hospital wastewater.

For comparison with other reported values, a comparative statement has been tabulated in Table 8. It is apparent that the present study gives better result in terms of extent of voltage, current density and power density compared to many other reported values.

Table 8 Comparative statement with related published research findings.

pH	Electrode	Electrolyte	Voltage	Current density	Power density	Reference
8.0	Zinc and copper	Jashore General	1016 mV	1007.41 mAm^{-2}	1023.53 mWm^{-2}	This experiment

		Hospital wastewater				
7.5	Graphite granules and graphite rod	Hospital wastewater			140±10 mWm^{-2}	Aelterman et al. 2006
9.0	Graphite felt and carbon cloth		439.7 ± 0.1 mV	231.3±1.1 mAm^{-2}	107.1±1.0 mWm^{-2}	He et al. 2008
9.5	Graphite rod and air-cathode	Urban wastewater			18.0 mWm^{-2}	Sebastia et al. 2010

COD removal is very significant to treat wastewater. Higher COD removal means the process is more applicable for wastewater treatment. In fifteen days operation the COD removal were over 78%, 83%, 86%, 88% and 84% for the electrolyte having initial pH 6, 7, 8, 9 and 10 respectively.

Conclusion

Initial pH greatly affects the output of microbial fuel cell along with COD removal from wastewater. In every experiment initially the productivity (voltage, current density and power density) increased then after a certain period these values gradually decreased with time. The main reason behind this anodic microbe took time for their proper growth, after complete inoculation the growth of microbes is decreased. The optimum pH for municipal waste water of Jashore and bhairab river water is 8.0, where the maximum voltage, current density and power density were 1125 mV, 1155.6 mAm^{-2}, 1245.7 mWm^{-2} and 1132 mV, 1288.9mAm^{-2}, 1459.02 mWm^{-2} respectively. But for hospital wastewater the top results obtained at pH 9 these were 1016 mV, 1007.41 mAm^{-2} and 1023.53 mWm^{-2}. The maximum COD removal was 91%, 94% and 88% from municipal, bhairab river and hospital wastewater respectively. At lower pH anodic biofilm will break which result the lower output.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All data generated through experiments and analyzed during this study are included in this article.

Competing interests

The authors declare that they have no competing interests.

Funding

Not applicable.

Authors' contributions

MAH conceptualized the methodology, wrote original draft, MOR gave general advice, MI designed and conducted the experiments, RK designed and conducted the experiments, and BKB laid the guideline, edited and reviewed the manuscript. All authors read and approved the final manuscript.

Acknowledgement

Not applicable.

Authors' information

Department of Chemical Engineering, Jashore University of Science and Technology, Jashore-7408, Bangladesh.

References

Abhilasha SM (2013) Inoculum selection to enhance performance of a microbial fuel cell for electricity generation during wastewater treatment. Environ Technol 34:1957-1964. https://doi.org/10.1080/09593330.2013.808674

Aelterman P, Rabaey K, Clauwaert P, Verstraete W (2006) Microbial fuel cells for wastewater treatment. Water Sci Technol 54(8):9-15. https://doi.org/10.2166/wst.2006.702

Asai Y, Miyahara M, Kouzuma A, and Watanabe K, (2017), Comparative evaluation of wastewater-treatment microbial fuel cells in terms of organics removal, waste-sludge production, and electricity generation, Bioresour Bioprocess, 4(1), https://doi.org/10.1186/s40643-017-0163-7

Asensio Y, Fernandez-Marchante CM, Lobato J, Canizares P, Rodrigo MA (2016) Influence of the fuel and dosage on the performance of double-compartment microbial fuel cells. Water Res 99:16–23. https://doi.org/10.1016/j.watres.2016.04.028

Behera M, Jana PS, More TT, Ghangrekar MM (2010) Rice mill wastewater treatment in microbial fuel cells fabricated using proton exchange membrane and earthen pot at different pH. Bioelectrochem 79:228–233. https://doi.org/10.1016/j.bioelechem.2010.06.002

Biffinger JC, Little B, Pietron J, Ray R, Ringeisen BR (2008) Aerobic Miniature Microbial Fuel Cells. NRL Review 141–142

Damiano L, Jambeck JR, Ringelberg DB (2014) Municipal solid waste landfill leachate treatment and electricity production using microbial fuel cells. Appl Biochem Biotechnol 173:472–485. https://doi.org/10.1007/s12010-014-0854-x

Dhiraj C, Vijay J, Harish KD, and Datta K (2020) Influence of microbial fuel cell employed with porous anode on the voltage generation, COD, chloride content and total dissolved solids. Water Sci Technol. https://doi.org/10.2166/wst.2020.380

Dong Y, Feng Y, Qu Y, Du Y, Zhou X, Liu J (2015) A combined system of microbial fuel cell and intermittently aerated biological filter for energy self-sufficient wastewater treatment. Sci Rep 5:1–8. https://doi.org/10.1038/srep1 8070

Feng T, Zhou W, Wu S, Niu Z, Cheng P, Xiong X, Li G (2018) Simulations of summertime fossil fuel CO2 in the Guanzhong basin. Sci Total Environ 624:1163-70. https://doi.org/10.1016/j.scitotenv.2017.12.021

Ge Z, He Z (2016) Long-term performance of a 200 liter modularized microbial fuel cell system treating municipal wastewater: treatment, energy, and cost. Environ Sci Water Res Technol 2:274–281. https://doi.org/10.1039/c6ew00020g

Ghasemi M, Halakoo E, Sedighi M, Alam J, Sadeqzadeh M (2015) Performance comparison of three common proton exchange membranes for sustainable bioenergy production in microbial fuel cell. Procedia CIRP 26:162–166. https://doi.org/10.1016/j.procir.2014.07.169

Gil GC, Chang IS, Kim BH, Kim M, Jang JK, Park HS, Kim HJ (2003) Operational parameters affecting the performance of a mediator-less microbial fuel cell. Biosens Bioelectron 18(4):327–334. https://doi.org/10.1016/s0956-5663(02)00110-0

Gonzalez del Campo A, Perez JF, Cañizares P, Rodrigo MA, Fernandez FJ, Lobato J (2014) Study of a photosynthetic MFC for energy recovery from synthetic industrial fruit juice wastewater. Int J Hydrog Energy 39:21828–21836. https://doi.org/10.1016/j.ijhydene.2014.07.055

Gotovtsev P, Dyakov A (2016) Biotechnology and Internet of Things for green smart city application 2016 IEEE 3rd World Forum on Internet of Things (WF-IoT) 542–6.

He Z, Huang Y, Manohar AK, Mansfeld F (2008) Bioelectrochemistry Effect of electrolyte pH on the rate of the anodic and cathodic reactions in an air-cathode microbial fuel cell. Bioelectrochemistry 74(1):78–82. https://doi.org/10.1016/j.bioelechem.2008.07.007

Hidalgo D, Tommasi T, Velayutham K, Ruggeri B (2016) Long term testing of microbial fuel cells: comparison of different anode materials. Bioresour Technol, 219:37–44. https://doi.org/10.1016/j.biort ech.2016.07.084

Hong SW, Chang IS, Choi YS, Chung TH (2009) Experimental evaluation of influential factors for electricity harvesting from sediment using microbial fuel cell. Bioresour Technol 100 (12):3029–3035. https://doi.org/10.1016/j.biortech.2009.01

Hong SW, Chang IS, Choi YS, Kim BH, Chung TH (2009) Responses from freshwater sediment during electricity generation using microbial fuel cells. Bioprocess Biosyst Eng 32(3):389–395. https://doi.org/10.1007/s00449-008-0258-9

Jadhav G, Ghangrekar M (2009) Performance of microbial fuel cell subjected to variation in pH, temperature, external load and substrate concentration. Bioresour Technol 100(2):717-723. https://doi.org/10.1016/j.biortech.2008.07.041

Kalathil S, Lee J, Cho MH (2012) Efficient decolorization of real dye wastewater and bioelectricity generation using a novel single chamber biocathode-microbial fuel cell. Bioresour Technol 119:22–27. https://doi.org/10.1016/j.biort ech.2012.05.059

Kumar R, Singh L, Zularisam AW (2016) Exoelectrogens: recent advances in molecular drivers involved in extracellular electron transfer and strategies used to improve it for microbial fuel cell applications. Renew Sustain Energy Rev 56:1322–1336. https://doi.org/10.1016/j.rser.2015.12.029

Li S, Chen G (2018) Factors Affecting the Effectiveness of Bioelectrochemical System Applications: Data Synthesis and Meta-Analysis. Batteries 4(3):34. https://doi.org/10.3390/batteries4030034

Li S, Cheng C, Thomas A (2017) Carbon-based microbial-fuel cell electrodes: from conductive supports to active catalysts. Adv Mater 29:1602547. https://doi.org/10.1002/adma.201602547

Liang P, Duan R, Jiang Y, Zhang X, Qiu Y, Huang X (2018) One-year operation of 1000-L modularized microbial fuel cell for municipal wastewater treatment. Water Res 141:1–8. https://doi.org/10.1016/j.watres.2018.04.066

Liu H, Ramnarayanan R (2004) Production of Electricity during Wastewater Treatment Using a Single Chamber Microbial Fuel Cell. Environ Sci Technol 38(7):2281–2285. https://doi.org/10.1021/es034923g

Logan B, Cheng S, Watson V, Estadt G (2007) Graphite fiber brush anodes for increased power production in air-cathode microbial fuel cells. Environ Sci Technol 41:3341–3346. https://doi.org/10.1021/es062644y

Maktabifard M, Zaborowska E, Makinia J (2018) Achieving energy neutrality in wastewater treatment plants through energy savings and enhancing renewable energy production. Rev Environ Sci Biotechnol 17:655–689. https://doi.org/10.1007/s11157-018-9478-x

Mansoorian HJ, Mahvi AH, Jafari AJ, Khanjani N (2014) Evaluation of dairy industry wastewater treatment and simultaneous bioelectricity generation in a catalyst-less and mediator-less membrane microbial fuel cell. J SAUDI CHEM SOC 20:88–100. https://doi.org/10.1016/j.jscs.2014.08.002

Mustakeem (2015) Electrode materials for microbial fuel cells: nanomaterial approach. Mater Renew Sustain Energy 4:1–11. https://doi.org/10.1007/s4024 3-015-0063-8

Omprakash S (2019) Sustainable and clean treatment of industrial wastewater with microbial fuel cell. Engineering. https://doi.org/10.1016/j.rineng.2019.100053

Oyiwona1G E, Ogbonna J C, Anyanwu C U and Okabe S, (2018), Electricity generation potential of poultry droppings wastewater in microbial fuel cell using rice husk charcoal electrodes, Bioresour Bioprocess, 5(1), https://doi.org/10.1186/s40643-018-0201-0

Pandey P, Shinde VN, Deopurkar RL, Kale SP, Patil SA, Pant D (2016) Recent advances in the use of different substrates in microbial fuel cells toward wastewater treatment and simultaneous energy recovery. Appl Energy 168:706–723. https://doi.org/10.1016/j.apene rgy.2016.01.056

Parkash A (2018) Effects of various parameters on bioenergy generation in microbial fuel cell. MOJ Proteomics Bioinform 7(3):177–178. https://doi.org/10.15406/mojpb.2018.07.00229

Patade S, Silveira K, Babu A, Mhatre Y, Saini V, Rajput R, Mathew J, Birmole R (2016) Bioremediation of dye effluent waste through an optimised microbial fuel cell. Int J Adv Res Biol Sci 3:214–226

Paweł PW, Barbara W (2019) Wastewater Treatment and Electricity Production in a Microbial Fuel Cell with Cu–B Alloy as the Cathode Catalyst. Catalysts 9:572. https://doi.org/10.3390/catal9070572

Porwal HJ, Mane AV, Velhal SG (2015) Biodegradation of dairy effluent by using microbial isolates obtained from activated sludge. Water Resour Ind 9:1–15. https://doi.org/10.1016/j.wri.2014.11.002

Puig S, Serra M, Coma M, Cabré M, Balaguer M, Colprim J (2010) Effect of pH on nutrient dynamics and electricity production using microbial fuel cells. Bioresour Technol 101: 9594-9. https://doi.org/10.1016/j.biortech.2010.07.082.

Quan X, Tao K, Mei Y, Jiang X (2014) Power generation from cassava alcohol wastewater: effects of pretreatment and anode aeration. Bioprocess Biosyst Eng 37:2325–2332. https://doi.org/10.1007/s0044 9-014-1210-9

Rahimnejad M, Adhami A, Darvari S, Zirepour A, Oh SE (2015) Microbial fuel cell as new technology for bioelectricity generation: a review. Alex Eng J 54:745–756. https://doi.org/10.1016/j. aej.2015.03.031

Rajeswari S, Vidhya S, Navanietha Krishnaraj R, Saravanan P, Sundarapandiyan S, Maruthamuthu S, Ponmariappan S, Vijayan M (2016) Utilization of soak liquor in microbial fuel cell. Fuel 181:148–156. https://doi.org/10.1016/j.fuel.2016.04.121

Reshetilov A, Plekhanova Yu, Tarasov S, Arlyapov V, Kolesov V, Gutorov M, Gotovtsev P, Vasilov R (2017) Effect of some carbon nanomaterials on ethanol oxidation by Gluconobacteroxydans bacterial cells. Appl Biochem and Microbiol 53:123-9. https://doi.org/10.1134/S0003683817010161

Rozendal RA, Hamelers HVM, Buisman CJN (2006) Effects of membrane cation transport on pH and microbial fuel cell performance. Environ Sci Technol 40:5206–5211. https://doi.org/10.1021/es060387r

Sawasdee V, Pisutpaisal N (2016) Simultaneous pollution treatment and electricity generation of tannery wastewater in air-cathode single chamber MFC. Int J Hydrog Energy 41:15632–15637. https://doi.org/10.1016/j.ijhyd ene.2016.04.179

Scott K, Cotlarciuc I, Head I, Katuri KP, Hall D, Lakeman JB, Browning D (2008) Fuel cell power generation from marine sediments: investigation of cathode materials. J Chem Technol Biotechnol 83(9):1244–1254. https://doi.org/10.1002/jctb.1937

Sevda S, Sreekrishnan TR (2012) Effect of salt concentration and mediators in salt bridge microbial fuel cell for electricity generation from synthetic wastewater. J Environ Sci Health A Tox Hazard Subst Environ Eng 47:878–886. https://doi.org/10.1080/10934529.2012.665004

Slate AJ, Whitehead KA, Brownson DAC, Banks CE (2019) Microbial fuel cells: an overview of current technology. Renew Sustain Energy Rev 101:60–81. https://doi.org/10.1016/j.rser.2018.09.044

Takahashi S, Miyahara M, Kouzuma A, and Watanabe K, (2016), Electricity generation from rice bran in microbial fuel cells, Bioresour Bioprocess, 3:50. https://doi.org/10.1186/s40643-016-0129-1

Venkata Mohan S, Mohanakrishna G, Reddy BP, Saravanan R, Sarma PN (2008) Bioelectricity generation from chemical wastewater treatment in mediatorless (anode) microbial fuel cell (MFC) using selectively enriched hydrogen producing mixed culture under acidophilic microenvironment. Biochem Eng J 39:121–130. https://doi.org/10.1016/j.bej.2007.08.023

Venkata Mohan S, Srikanth S, Raghuvulu S, Mohanakrishna G, Kumar AK, Sarma PN, (2009) Evaluation of the potential of various aquatic eco-systems inharnessing bioelectricity through benthic fuel cell: effect of electrode assembly and water characteristics. Bioresource Technol 100:2240–2246. https://doi.org/10.1016/j.biortech.2008.10.020

Wang A, Cheng H, Ren N, Cui D, Lin N, Wu W (2012) Sediment microbial fuel cell with floating biocathode for organic removal and energy recovery. Front Environ Sci Eng In China 6(4):569–574. https://doi.org/10.1007/s11783-011-0335-1

Zhang L, Li C, Ding L, Xu K, Ren H (2011) Influences of initial pH on performance and anodic microbes of fed-batch microbial fuel cells. J Chem Technol Biotechnol 86(9):1226-1232. https://doi.org/10.1002/jctb.2641

Zinadini S, Zinatizadeh AA, Rahimi M, Vatanpour V, Rahimi Z (2017) High power generation and COD removal in a microbial fuel cell operated by a novel sulfonated PES/PES blend proton exchange membrane. Energy 125:427–438. https://doi.org/10.1016/j.energy.2017.02.146

Figures

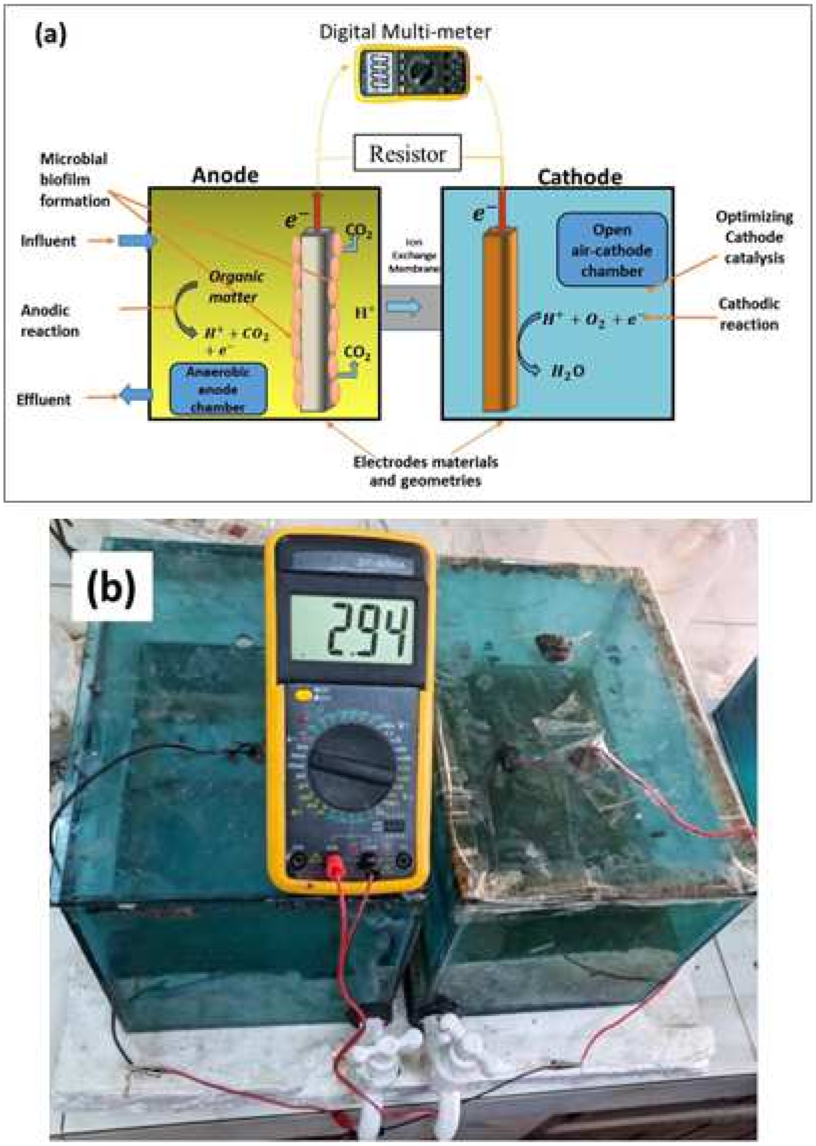


Figure 1

(a) Schematic diagram and (b) constructed MFC for the experiment.

(a) Municipal drainage　　(b) Bhairab river

Figure 2

Sources of wastewater used as electrolyte.

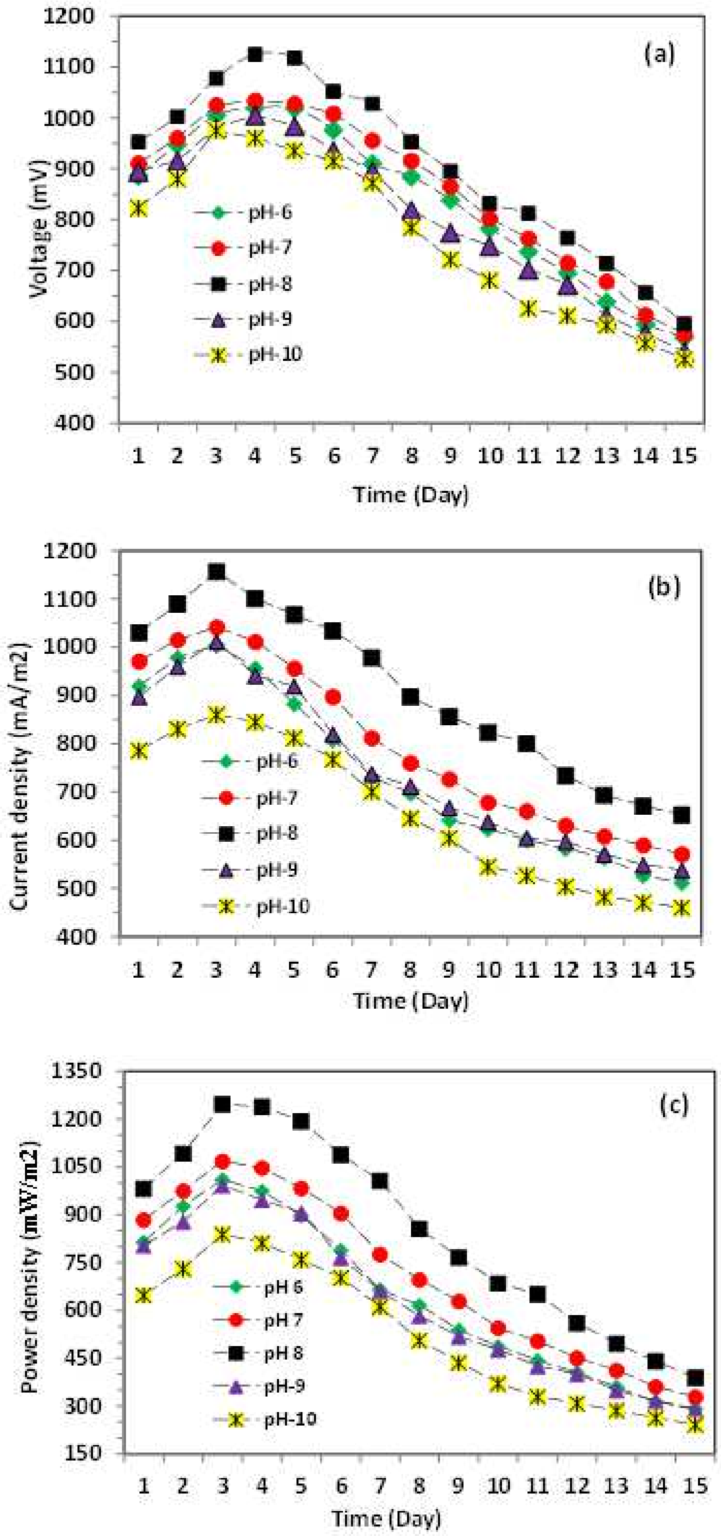


Figure 3

Effect of various pH on the (a) generated voltage, (b) current density and (c) power density from double chamber MFC for municipal wastewater.

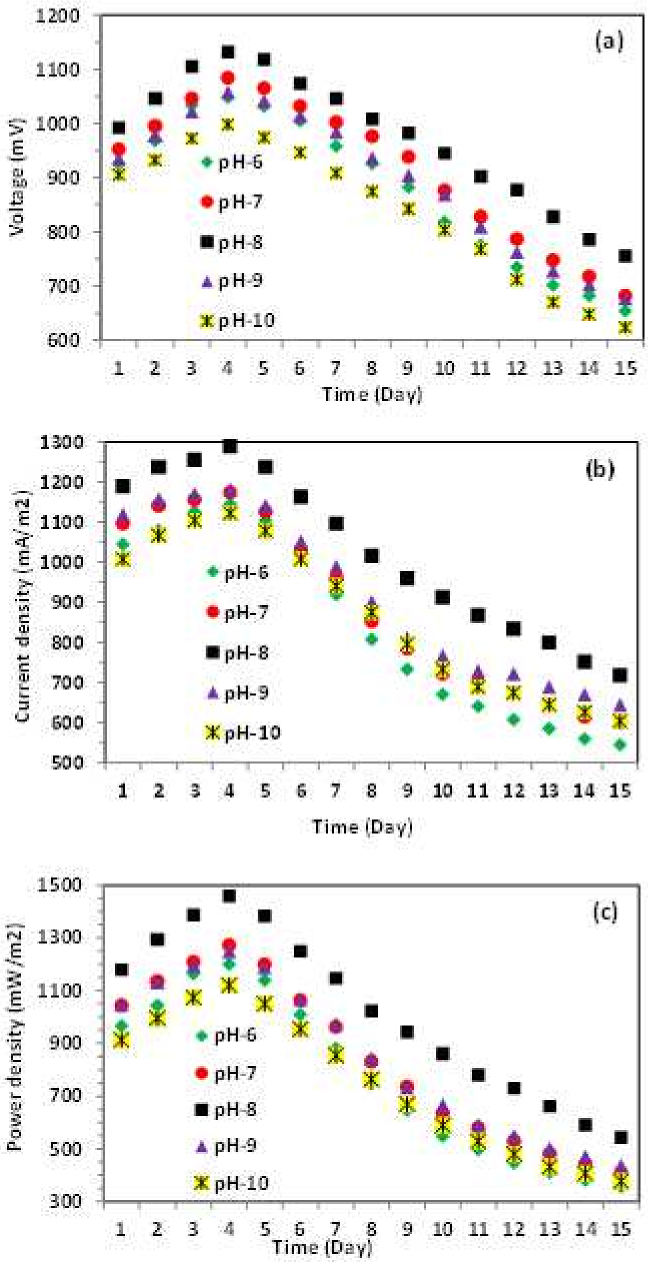


Figure 4

Effect of various pH on the (a) generated voltage, (b) current density, (c) power density from double chamber MFC for bhairab river wastewater.

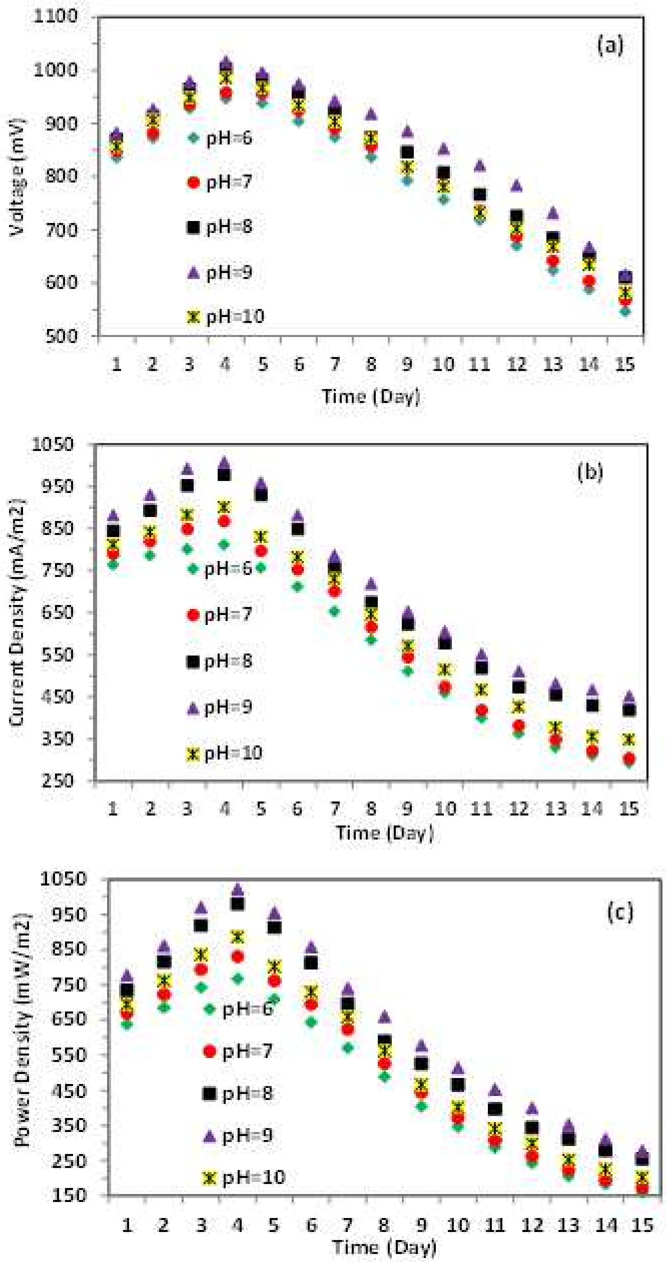


Figure 5

Effect of various pH on the (a) generated voltage, (b) current density, (c) power density from double chamber MFC for Jashore General Hospital wastewater.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Graphicalabstract.docx