Materials Today: Proceedings 57 (2022) 1781–1788

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Sustainable technology for modern era effluent treatment: Microbial fuel cell

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ARTICLE INFO

Article history:
Available online 12 January 2022

Keywords:
Microbial Fuel Cell
Wastewater treatment
Sustainable
Microbes
Break-even point
Corncob bed

ABSTRACT

Wastewater generated from allied industry contains high organic load and the treatment is primary carried out using biological methods. Sustainable wastewater treatment is considered the most advanced and cost-effective solution for the high organically polluted industrial waste stream. However normal treatment plants are associated with the recovery of energy that seems to be a potential approach for waste treatment and conservation. On the other hand, Microbial Fuel Cell (MFC) represent a new bio-electrochemical system for generation of electricity directly from biodegradable organic compound. This enables us to harness the power of organic compounds through the action of microbes. In the current scenario, Industrial wastewater is a potential hazard to the natural water body. The waste water contains many organic matter, which is toxic to the various life forms of the system. Industrial waste water has a complex mixture of chemicals whose behaviour alter towards biological systems. Treatment of waste water is therefore over riding process. This study is designed to treat waste water with the generation of bioelectricity and minimising the parameter of the waste water before it been released into a water source. Primary treatment of waste water is done with the help of corn cobbed to eliminate primary treatment of wastewater and the addition of substrate in the MFC. In the current study efficiency of Microbial Fuel Cell (MFC) in eliminating contaminate and generation of bioelectricity was determined, its break-even point was analysed and 15 L model was constructed for the operational analysis and to put into effect on a large industrial scale. From the experiment, we found that MFC is an effective method for waste water treatment with the generation of bio-electricity.

Selection and peer-review under responsibility of the scientific committee of the International Chemical Engineering Conference 2021 (100 Glorious Years of Chemical Engineering & Technology).

1. Introduction

Wastewater treatment was the revolution in the world of treatment of effluent discharge from the industries. But in Modern era the wastewater treatment is outdated due to modern era is moving toward a sustainable energy. So we need new technology for a modern era that would have less consumption of electricity with the treatment of effluent [1]. So Microbial Fuel Cell is the new technology that generate the electricity as well as treat the effluent simultaneously [2].

Microbial Fuel Cells (MFCs) is new-fangled methodology in the field of energy production and wastewater treatment over other conventional method. It is a considerable interest for power generation and waste water treatment as it can directly convert chemical energy stored in the organic matter to electricity[3]. The need is to innovate new methods to generate energy in the form of electricity with amalgamation of waste water treatment, this is aided by electron transport chain of microbes. Apart from this, current wastewater treatment processes are energy intensive as they required huge amount of power input for aeration, sludge treatment and various other processes. Microbial fuel cell (MFC) that uses an active microorganism as a biocatalyst in an anaerobic anode compartment for production of bioelectricity [4].

Microbial Fuel Cell is a bio-electrochemical cell which is used in the secondary waste water treatment process. A MFC comprises of

Abbreviations: MFC, Microbial Fuel Cell; COD, Chemical Oxygen Demand; BOD, Biochemical Oxygen Demand.

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https://doi.org/10.1016/j.matpr.2021.12.476
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Chemical Engineering Conference 2021 (100 Glorious Years of Chemical Engineering & Technology).

Table 1
Material used.

Component	Material
Reactor	High Density Poly Ethylene (HDPE) Container
Anode	Graphite
Cathode	Platinum coated Titanium
Membrane	Nafion-117
Wire	Copper
Multimeter	Digital 81-USB multimeter

Table 2
Costing components.

Material	Cost	Duration
Plastic container	900	Till the working life
Bacteria and management	200	1 month
Electrode	4500(for 6 units)	Life time
Cathode	17,110	Life time
Nafion membrane	35,518	6 months
Measuring instruments	5000	One time investments

Table 3
Break-even analysis.

FIXED CAPITAL		COST WORKING CAPITAL COST	
MATERIAL	COST	MATERIAL	COST
Plastic container	900	Nafion membrane	71,036
Electrode	4500	Bacteria and management	2400
Cathode	17,110		
Measuring instruments	5000		
TOTAL	27,510		73,436
GRAND TOTAL	100,946		

Table 4
Revenue.

Cost of 1 unit in Gujarat	8.32
1unit equals	1 KWh
48.3085 Rs.	In 1 day
100,946 in how many days	2090 (by simple unitary days)
	Thus **5.72** years

two chambers, that is, anodic and cathodic chamber containing the anode and cathode, respectively. Proton transfer is done with the help of membrane. Membrane is used to separate the anode and cathode chamber (diameter 15 mm, Nafion™) (Fig. 1). MFC relies on the unique micro-organism called Electroactive micro-organism that can degrade the organic matters with diverse metabolic pathways and pass the released electrons onto the anodic electrode which are transported from the anode to cathode[5]. Breeding process of microorganisms take place on the anode side. At anode Electrochemical Active Bacteria (EAB) is converted into Electroactive Biofilm. Quality of anode is the important parameter of the microbial fuel cell [6]. Membrane being the heart of the MFC will divide anode and cathode chamber. Microbial cultures can be involved in the processes of oxidation and reduction[7].Electron transfer can take place through an external circuit and proton transfer take place through a membrane. According to literature, without membrane there will be a reduction of Columbic Efficiency (CE) and an increase in the oxygen level. In the cathode, an oxygen reduction reaction occurs. Performance of cathode judge the high current generation Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig. 7, Fig. 8, [8].

In the current industrial uses, there are various effluent treatment techniques, such as Chemical treatment, aerobic treatment, anaerobic digestion and membrane filtration. But Microbial Fuel Cell (MFC) is considered as a modern and sustainable technology process with the dual purpose of pollutant removal and energy recovery [9]. There are multiple aim for the Microbial Fuel Cell but the main three aim are the treatment of the effluent, bioelectricity and biofuel(Methane) generation. Material plays a pivotal role in the MFC. The material like Cathode (Platinum), Anode(Graphite), membrane (Nafion) and a reactor. Microbes is the key component of the MFC. The microbes like geobacter, shewanella, pseudomonas, lactobacilus, klebsiela, mixed culture etc. are used. Redox reaction is carried out by the microbes. The biomass conversion to an electricity is the based composition of the microbial community. Uses of microbial consortium as the bioactivators and the effluent as the feedstock is an economically viable option to upgrade MFC in the existing effluent treatment units which will have dual benefits viz., treatment of the wastewater as well as bioenergy generation[10,11]. In the generation of methane, the overall efficiency of the bioelectricity will be less due to decrease in the columbic efficiency. Different microbes have the different columbic efficiency. The most important group of the microbes should be electrochemical active for the electron transfer chain to the anode also known as exoelectrogens[12]. Electrochemically inactive microbes are also useful because it help in the degrade of complex substrate to simple one [13,14].

Most studies on MFCs have been conducted using simple substrates such as glucose or acetate at anode. The use of substrate in the form of pure substrate allows for the efficient production of electricity at a high columbic efficiency [15]. During the breeding process the microorganism use substrates as the oxidising agents.

A natural substrate, Corncobis an optimistic material which can be used as adsorbent for removal purpose due to the abundance, cheap and simple handling. A corncobis available worldwide, especially in Asian countries and European countries. Therefore, the usage of corncob for wastewater treatment not only helps dispose of corncob in a green way but also it helps to generate electricity production. According to research corn have fair amount of starch. Therefore, we are using corn-starch adsorbent bed for the primary treatment of wastewater.

For the enhancement between electron and proton transfer, ferricyanide is used as a substrate on the cathode. Due to its good performance, ferricyanide ($K_3[Fe(CN)_6]$) as an overall good performer in MFC [16]. Due to low over potential properties of ferricynide, the cathode working is close to its open circuit potential. Anode material should have a large surface area for the betterment performance of the cell [17]. The electrochemical reaction in an MFC involves the metabolic pathway, except operational and design parameters, biological factor also play pivotal role in the performance of the cell [18]. Materials in the anode should be chemically stable, conductive and biocompatible in the reactor solution. Non-corrosive metals are used at anode side like stainless steel [19], but some metals like copper is not used due to the toxicity of even trace copper ions to bacteria. There are different processes for a Microbial Fuel Cell with a biocatalysed anode and a chemical cathode that involve a complex interplay between electrochemistry, microbiology, material science, transport phenomena and environment biotechnology [20].

MFC is widely used for the studying the different electro-gens properties of the microbial communities. And help in the understanding the transfer of electron to solid substrate. MFC was designed for the uses of power generation during waste water treatment that help in the economical manner and also drive toward the sustainable environment [21]. Organic pollutants have a specific metabolic process in the MFC with the operating condition that alter the dependence of the MFC. The two positive side of the MFC is: First bacteria are promoted to use for the degradation of pollutant. Secondly the electrodes will adsorb the pollutant during the process with the surface enrichment. During the process MFC has to increase the COD removal rate. That is governed by the

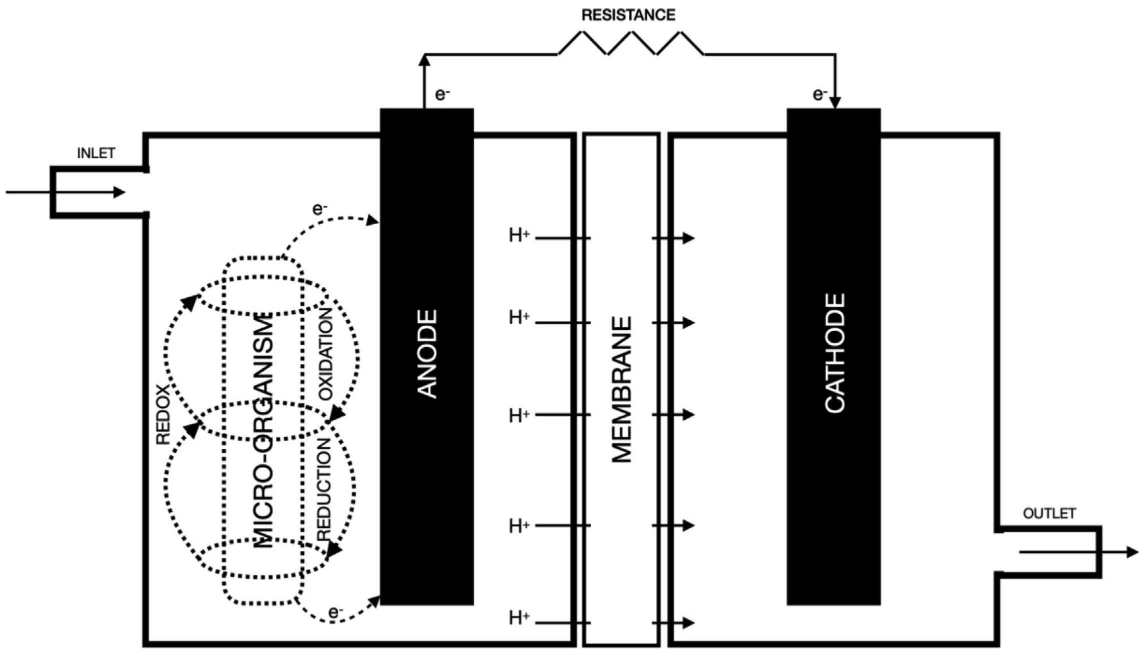

Fig. 1. Microbal Fuel Cell (MFC).

Fig. 2. Graphite.

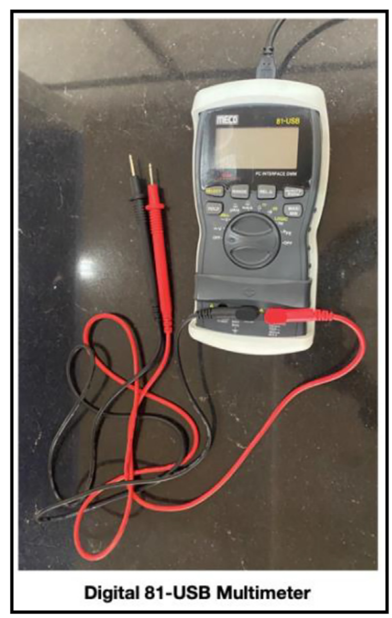

Fig. 3. USB multimeter.

influencing factors like microbial communities, different electrodes material and the concentration of the substrate [22]. Maximum power output with the highest removal rate is a quite difficult to achieve during the process [23].

2. Material and method

2.1. Material used (Table 1)

2.1.1. Cell set-up and process

In the construction of the Microbial Fuel Cell (MFC) High-Density Poly Ethylene (HDPE) container is used as the reactor. The reactor is divided into two chambers- one is an anode and another is a cathode. The chamber is separated by the Proton exchange membrane which will be placed between the wooden frames for Fix-up. Graphite is been used as the anode side. And Platinum coated Titanium cathode is been used. Nafion-117 is used as the Proton Exchange Membrane. Cathode and anode are be con-

Fig. 4. Platinium coated titanium.

Fig. 5. Nafion.

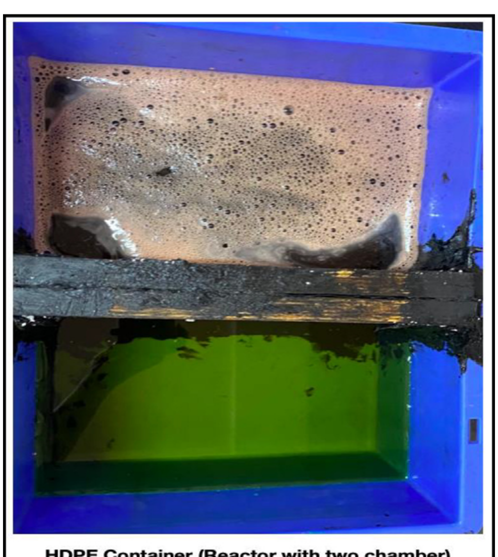

Fig. 6. Reactor with two chamber.

Fig. 7. Corncob bed.

nected with the wire for use in the external circuit. The overall volume of the reactor is 15 L with the division of 7.5 L in each chamber. Microbes are introduced to the anode side with effluent. Microbes like Aeromonas Formiican, Aeromonas spp., Citrobacter spp., Ps. Acidovorans, Ps. putida, Pseudomonas aeruginosa, Klebsielaoxytoca or Lactobacillus plantarum can be used during the process.

Mainly, the corncobs were rinsed with distilled water to remove residual impurities like low density dust particles, foreign particles present on its surface and then dried at 110 °C for 5 to 6 h with the help of hot convection air oven to remove moisture. Finally, the corncobs were ground and screened to achieve required particles with size in the range from 0.5 to 2.0 mm. The fixed bed column is prepared by using glass column of 3.5 cm inner diameter and 30 cm of height. The above mentioned dried and sieved corncobs are filled in the column for further process. Primarily untreated wastewater is introduced into the column and kept for overnight. After that, effluent is sent into anodic chamber where it is mixed with microbes. Tap water is introduced to the cathode side. As we know the separation is done by the membrane. The whole process has to observe on the duration of the 6 days. Initial sophisticated instrumental analysis like Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Solid Dissolved (TSD), Total Suspended Solid (TSS) & pH are being performed and interpreted. After completion of anode and cathode setup, the wire is connected to the digital multimeter to record the generation of current and the particular process of time through the software of the multimeter.

At the starting of the process of the cell, the generation of current is gradually increasing. Due to microbes present in the anode chamber, a redox reaction takes place where the substrate is added to satisfy the requirement of the oxygen demand. The electron is transferred to the cathode through the external circuit and the transfer of proton takes place by the membrane. After reaching a certain current reading it starts to decrease in the generation of the current. Then the final parameters are measured and recorded.

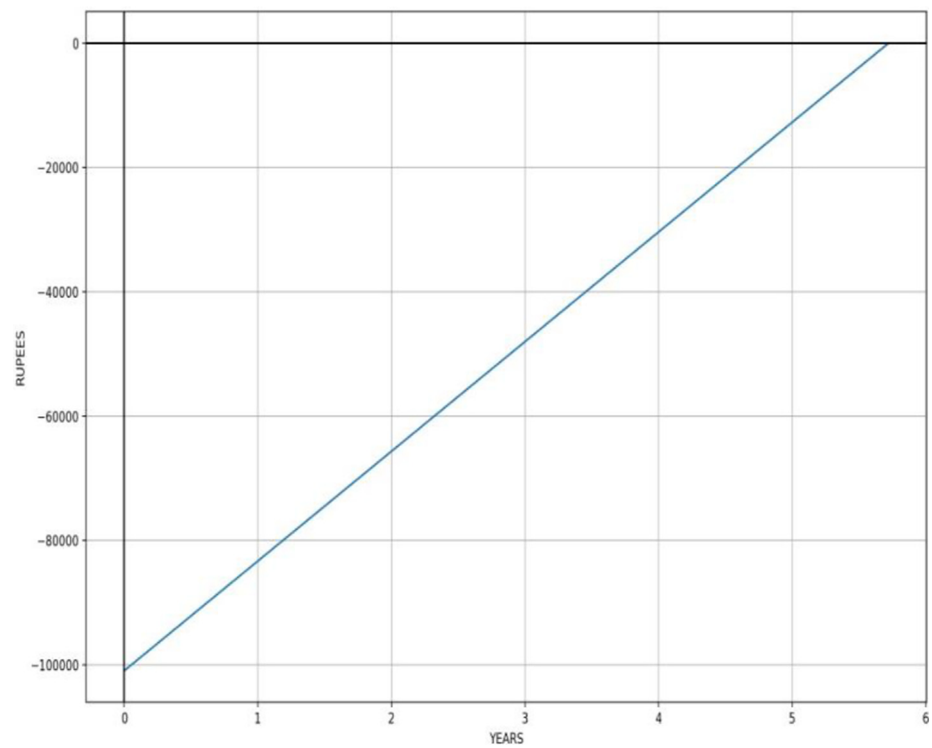

Fig. 8. Break-point analysis.

3. Break-even analysis

Break-even analysis is an economic analysis method used to identify the time required to reach no profit and no loss condition. This helps us to analyze how we can implement project successfully and coherently obtain profits from the same. To do this we must deduce the inputs we make and output that are generated, this is all plotted on a graph with X axis being the time period and Y-axis being the cost that is inputted. The negative part or left side denotes the construction phase and, the origin of the graph will be the time when the construction is finished and it starts to generate the revenue. When this graph will touch the X-axis. The break-even is reached.

This method does not include the time value of money and is the only drawback of this method, but to be incorporated for an ETP plant this is the best suitable method and is used here. Primarily the bifurcation of the cost input is made which is classified on the basis of working capital cost and fixed capital cost. Working capital is the cost incurred when the plant is working and it is to be inputted for normal functioning of the plant. Fixed capital includes the cost which is only incurred one time that is at the time of installation and need not to be incurred again and again. As tabulated all the cost were included as the maximum basis and was INR 1,00,946.(Table 3)

The average power produced by the cell in a day was found to be 5. 80963KWh, which was equated with the cost of single unit in Gujarat, India. And was found to be INR 8.32 per unit (KWh). Hence it produced INR. 48.3085 in a single day thus by unitary method we require 5.72 years for the Break-even(Table 4) to reach for a 10 L model and when this will be implemented on a large scale break even can be reached sooner.

The existing technology costs around of INR 88,350 for 10 L model, including the cost of container, microbes, pump, electricity, diffusers and surface aerators, etc.

Again it also helps in the comparison with the existing technology that is aeration tank technically (with the percentage reduction of BOD, COD data also MFC is far better than aeration tank) and Economically it generates no revenue and is a sink of absorbing the money with constant and heavy investment, with no break-even whatsoever but on the other hand MFC is a boon economically.

4. Result and discussion

Throughout the process, samples were taken at definite interval of 24 h to check different parameters i.e. pH, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Chemical Oxygen Demand(COD), Biological Oxygen Demand(BOD).The values of various parameters like pH, color, temperature, dissolved oxygen, COD, BOD, TSS, TDS before and after the treatment of sample are as shown in Table 5.

4.1. Effect on pH, COD & BOD

pH-meter was used to determine pH of the wastewater sample. This experiment was done under the pH range of 6–9. Variation in pH was measured after taking samples at definite interval of time of 24 h and are plotted in the Fig. 9. Graph shows that pH has reduced substantially. Substrate i.e. starch which is used as a food to microorganism leads to the acidic nature of the sample. Substrate breaks down into carbon and hydrogen bond and turn them

Table.5
Effect of Microbial Fuel Cell on various parameters is as follows.

Parameter	Untreated Effluent	Treated Effluent
Colour	Dark Brown	Reddish
pH	8.4	7.3
BOD	405	201
COD	1893	1223
TSS	108	82
TDS	17,600	13,200

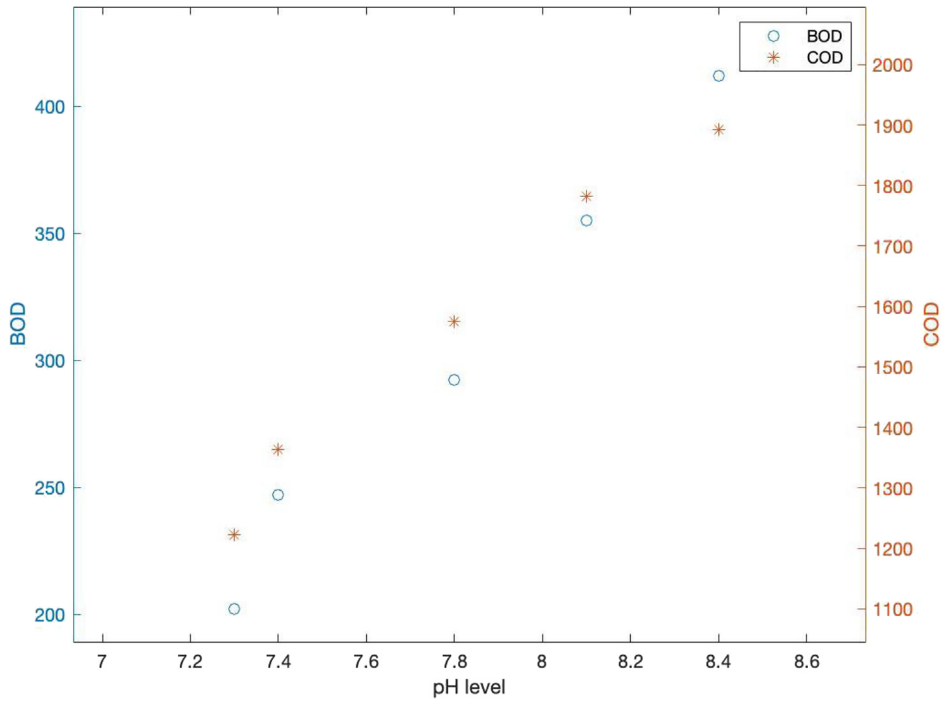

Fig. 9. pH BOD COD values during treatment days.

into simpler compounds which in-turn becomes bio-degradable substituents.

The quality of oxygen required for the oxidation of organic matter to produce CO_2 with the by-product water, is generally known as COD, but under acidic conditions the organic compound can act as an oxidizing agent. For the preservation of sample, H_2SO_4 is used, thereafter the sample was processed for COD amount determination. Monetarization of MFC was continued to determine the potential of the cell as a treatment unit. COD of the waste water sample at different time intervals are presented in the Fig. 9. Results show that COD of the waste water has decreased from an initial of 1893 mg/l to 1223 mg/l.

During the life cycle of microbes, the amount of oxygen desired by the microbes to convert the organic compound to CO_2 and water is known as BOD. BOD of the waste water sample at different time intervals are presented in the Fig. 9.The BOD of the waste water sample has decreased from 412 mg/l to 202 mg/l.

4.2. Effect on total suspended solids & total dissolved solids

Changes in TSS of the wastewater sample because of MFC are shown in Fig. 10. Experimental data represent that the amount of TSS has reduced with time. Biodegradable substrate in wastewater sample leading to competitive inhibition in microorganism is the

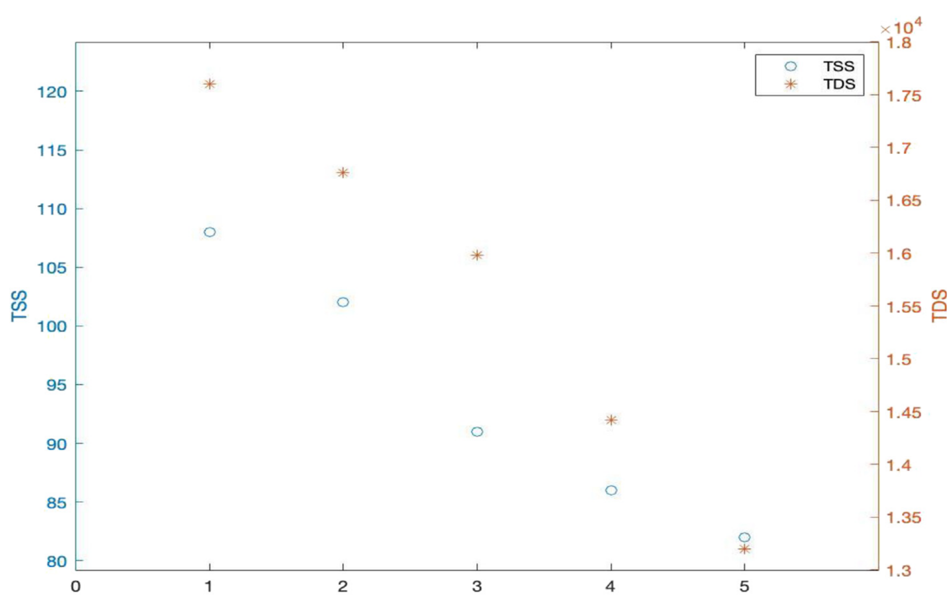

Fig. 10. TSS TDS parameters Vs No of Days.

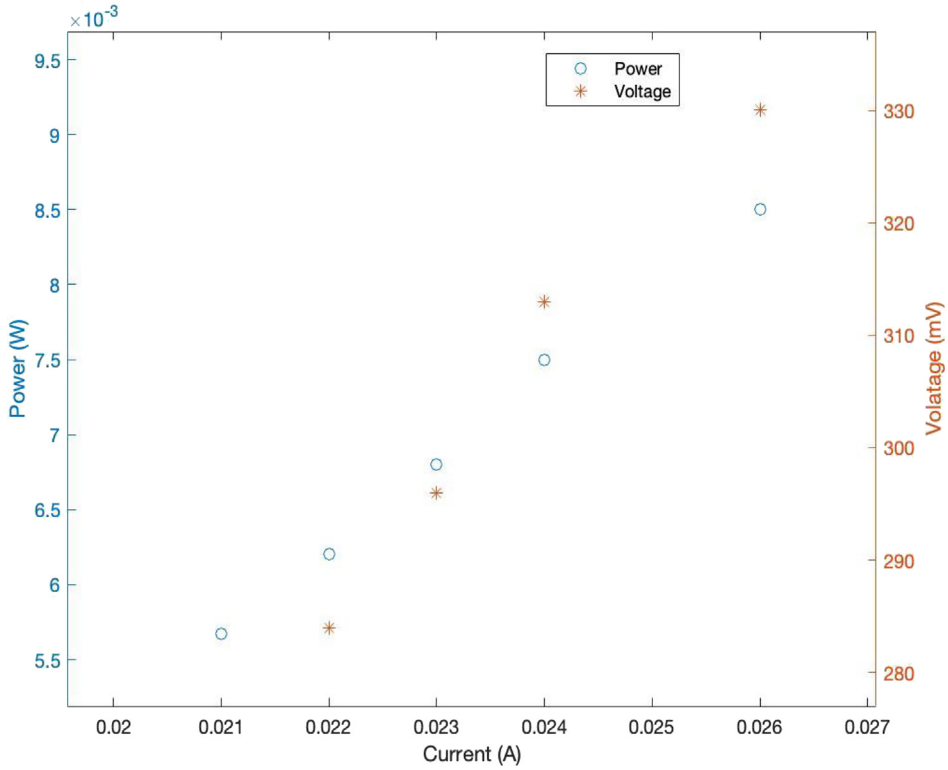

Fig. 11. Electrodes polarization during treatment cycle.

reason for the decrease of TSS. The TSS of the waste water sample has decreased from 108 mg/lit to 92 mg/lit.

The variation in TDS of the wastewater sample because of MFC are shown in Fig. 10.Decrease in the graph of TDS is shown by the experimental data taken during the 6 days operation. The TDS of the waste water sample has decreased from 17,600 mg/lit to 13200 mg/lit.

4.3. Electricity generation

After the addition of a pure substrate into the form of starch from corncob, cell voltage increased gradually to 270–330 mV, and then decreased to about 210 mV. After the reaction, cell current increased gradually to 0.009–0.026 A, and then gradually decreased to about 0.008 A. The higher MFC power in our study may have resulted from using platinum coating on the cathode: such a coating accelerate the cathode reaction [24]**.** The data for the same is presented in Fig. 11.

As per literature survey the micro-organism needs glucose, sucrose, methanol, or acetate as a substrate for growth. Here we utilized corncob bed as a source of carbohydrate. So, there is no need to add extra substrate during treatment. In the first batch of the MFC we had used Pseudomonas aeruginosa, Klebsielaoxytoca & Lactobacillus plantarum as a micro-organism in the ratio of 4:4:2. In the second batch we have alter the micro-organism and had used Citrobacter spp., Ps. Acidovorans & Ps. Putida in the equal ratio. The result of the study suggest that first batch has more efficient micro-organism and showed higher COD removal compared to second batch. As the first batch has both gram-positive bacteria and gram-negative bacteria whereas the second batch has only gram-negative bacteria.

5. Conclusion

It was observed that MFC technology does have very good potential in waste water treatment coupled with electricity production. As a function of microbes present in the wastewater for the metabolizing the carbon origin as electron donors, COD is removed. Our data also shown that MFC has pivotal role in achieving the COD removal efficiency of 35.39% and in generation of 330 mV or 0.026 A. According to our calculation the payback period of MFC will be around 5.72 years. The study exemplify that MFC system is able to treat industry wastewater efficiently. MFC system may provide a new method to offset wastewater treatment plant for operating cost, making wastewater treatment more affordable in developing and developed nations. At the same time, it may also open new path to develop the new system for sustainable energy production. Further developments can be done by changing different mixed culture or by customizing design of MFC which may improve the efficiency of MFC in terms of waste water treatment and electricity production.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

Authors thank Student Start-up & Innovation Policy (SSIP), Government of Gujarat for providing grant of 1,89,290/- for this project. Our sincere thanks to UPL University of Sustainable Technology for providing lab facilities.

To be presented in International Chemical Engineering Conference on “100 Glorious Years of Chemical Engineering & Technology” from September 17 to 19, 2021, organized by Department of

Chemical Engineering at Dr B R Ambedkar NIT Jalandhar, Punjab, India (Organizing Chairman: Dr. Raj Kumar Arya & Organizing secretary : Dr. Anurag Kumar Tiwari).

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