Bacterial Fuel Cell for Generating Electricity from Domestic Wastewater

Sreevidya Raman S, Shankar B. S

1. Assistant Professor, Department of Civil Engineering, Cambridge Institute of Technology, Bangalore, Karnataka, India.
email id: sreevidya.civil@cambridge.edu.in

2. Professor and Head, Department of Civil Engineering, Cambridge Institute of Technology, Bangalore, Karnataka, India.
email id: hod.civil@cambridge.edu.in

Corresponding author: Sreevidya Raman S

sreevidya.civil@cambridge.edu.in

Abstract: Bacterial fuel cell (BFC) is an electricity-producing device using wastewater treatment, eco-friendly and low-cost management of energy products. Bacterial fuel cell study demonstrates the electricity generation from wastewater in a single and double chamber bacterial fuel cell. In the present study electricity, generation is analyzed by varying the combination of anode and cathode electrodes. The maximum electricity of 0.6 V was generated in the copper –aluminum electrodes assembly in the double chamber. To achieve maximum efficiency impurity removal in wastewater effluent from bacterial fuel cell, filtration process has been adopted. The physico –chemical parameter reduction is observed at the end of the filtration study. The total solids removal is about 70- 80%; COD and BOD reduction is 40% and 60% respectively.

Keywords: ***Bacterial Fuel Cell, BOD, COD, Filtration, Total Solids.***

Introduction

The biggest challenge the world is facing in the recent decades is energy crisis due to continuous depletion of fossil fuels, increased price of fuels and global warming. The energy-water-food nexus is the biggest challenge in the world [1]. A huge proportion of the total energy load drained by the wastewater treatment sector has been considered as a precious renewable resource, which could be used to address the joint issues of energy generation and wastewater treatment in addition to the recovery of nutrients [2-7].

To quench the world's energy demand, it is important to find alternative energy source which comes under renewable energy. New approaches for electricity and wastewater treatment, which not only reduce cost but also produce useful side products is the order of the day [8]. Although anaerobic treatment methods have the potential to lower treatment costs, they are often only appropriate for high strength wastewater streams that are frequently produced by industry. Conventional anaerobic treatment also results in the production of methane gas, which, if released, can contribute to global warming. Finding ways to make valuable goods from wastewater treatment is one strategy that has been suggested to lower the cost of wastewater treatment. It has been known for several years that bacteria can be used to generate electricity that can be harvested in bacterial fuel cells (BFCs). Bacterial fuel cell technology offers a valuable alternative to energy generation as well as wastewater treatment. Bacterial fuel cell is a promising technology in which wastewater treatment and electricity generation can be accomplished simultaneously without any energy input. The advantages of BFC include degradation of pollutants in wastewater and electricity production. Bacterial Fuel Cell consists of anode (anaerobic chamber) and cathode (aerobic chamber). The anode and cathode are interred connected by a proton exchange membrane. In anaerobic chamber organic matter decomposes by microbes thereby generate electrons and protons, which is further transferred to aerobic chamber by membrane. Microbes as their energy sources utilize organic substrates. In anaerobic condition certain bacteria can transfer electrons to anode. Further these electrons flow from anode to the cathode, which includes current and voltage to produce electricity. The maximum current mainly depends on BFC design, which actually determines the electrochemical losses, activation losses, which, can be lowered by the microbial production of an electron shuttle, type of substrate and its concentration, the genus and the microbial activity, presence and types of membranes, surface area and conductivity of electrodes, ionic strength and the pH value. Bacterial fuel cell is a promising technology by which simultaneous wastewater treatment and electricity generation can be achieved without any energy input. Along with treatment efficiencies, electrical properties of BFC is also studied in terms of power generation and energy produced [9].

Need for the study

1. In addition to solar and wind energy, the biofuels are gaining much importance. Generating bioenergy through burning, vaporizing, and fermenting biomass such as leftover plant material, vegetable waste, wastewater and manure are well-tried methods.

2. Bacterial fuel cell is a new form of renewable energy to generate electricity from waste. Thus, minimizing waste disposal problem globally.

3. BFC is a promising eco-friendly technology to produce eclectic energy.

4. Energy crisis is increasing day by day in the world; BFC technique represents a blooming alternative energy of generating electricity by industrial and domestic wastewater.

5. Nowadays, power density achieved in various types of BFCs operated using mixed cultures is significantly higher than that of those utilizing pure cultures.

6. Increasing attention to bioenergy as alternate source of fuel to replace traditional fuels is spreading worldwide.

Bacterial Fuel Cell Configurations and Principles

Organic substrate in the anode chamber represents the fuel of BFC's. while the bacteria starts degrading the organic , then the electrodes from anode is transferred to cathode chamber in aerobic environment. Protons produced in anode chamber are then passed to the cathode chamber, thus reacting with electron acceptor. The electron flow in an external membrane is responsible for the electricity generation. The required components of BFC are anode in anaerobic compartment in contact with an electron acceptor and cell often made by transparent plastic. Various materials are utilized for large scale prototype. Flow from anode to cathode cell is regulated by cathode exchanging membrane (CEM). A cathode exchanging membrane may be used as a single chamber BFC, adhering to the cathode as ion exchange resins. As far as electrode materials are concerned, a number of materials may be used but, the carbon-based electrodes (graphite plates and carbon clothes) are by far the most commonly adopted ones in waste treatment as a result of their low costs as well as very good performances. Bio cathodes (biofilm-forming bacteria at the cathode) in most cases are advised for any BFC practical utility, both with respect to efficiency as well as reduced costs [9].

Factors affecting the performance of Bacterial Fuel Cells

Chemical and operational aspects significantly influence BFC performance. While estimating an BFC, it is crucial to consider factors such fuel composition, ionic strength, buffer capacity, pH, operational temperature, and flow mode (continuous or in-batch feed mode). The geometry of the cell, the chemical make-up of the electronic acceptor, the distance between the electrodes, their composition, and all of these factors are also very important. The makeup of the microbial communities on the anode and cathode also has a significant impact on how well BFCs work. Although if one or a few numbers of microbial strains populate most laboratory-scale BFCs, a different technique needs to be considered in a scaled, practical application. It is a proven fact that microbial consortia formed by environmental species found in the fuel (such as wastewater) will colonise the electrodes and outcompete any electroactive microbe that had previously been introduced in an BFC, if not completely eliminate it. While endogenous micro flora has been employed in BFCs fed with solid organic wastes, wastewater treatment sludge is typically regarded as a useful source of microorganisms for BFCs handling liquid wastes. Recent studies have shown that when anodic surfaces are chemically modified with nitrogen-containing amines and then placed in microbial cultures, the current generation is greater and occurs more quickly than it would otherwise. The use of photo-reactive semiconductors at the cathode is also being attempted in some cases. The positive outcomes of these new tests, if validated, will create new opportunities for the use of BFCs in practical applications **[9].**

Materials and Methods

Materials: - The experiment set up was simple and involved the use of following:

1. Wastewater.
2. 7 litre containers.
3. Voltmeter.
4. Wires.
5. Nacl salt.
6. Electrodes

Methods

Single chamber bacterial fuel cell

A Single chamber bacterial fuel cell as presented in Figure 1 consists of one chamber of capacity 7 liters, where 5 liters of wastewater is added to chamber. Anode and cathode were immersed in single chamber. Electrodes are connected to the voltmeter with the help of the copper wires. Voltmeter is used to measure the voltage, which was generated during the experiments. After 20 minutes, readings were noted down and tabulated.

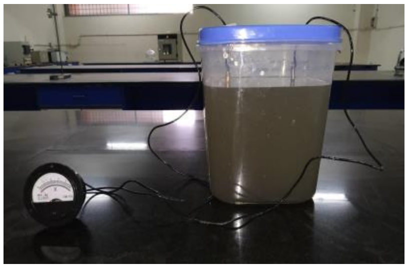

Fig 1: Experimental setup Single chamber bacterial fuel cell

Double chamber bacterial fuel cell

The two half cells were properly cleaned and joined to one another by a salt bridge to keep the contents of the two chambers apart. Leaks in the arrangement were checked. 5L of distilled water and 5L of the wastewater sample were placed in the cathode chamber and the anode chamber, respectively. The electrical connections were created once the electrodes were immersed into their corresponding chambers. Then the potential difference produced is measured periodically after 20 min and the results were tabulated. The setup is presented in Figure 2.

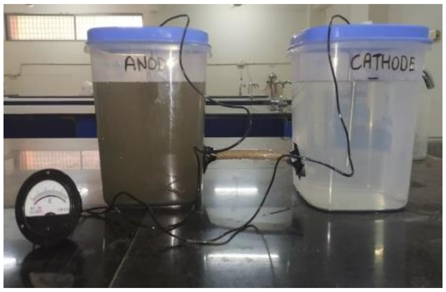

Fig 2: Experimental setup of Double chamber bacterial fuel cell

Filtration Kit

1. Coarse aggregates were sieved on a pan of size of 20mm. the retained aggregates on 20mm was taken for filtration process.
2. Similarly, fine aggregates were sieved of size 1.18mm. The retained fine aggregates were taken for filtration process.
3. Coarse aggregates and fine aggregates were cleaned with water and filled to the kit up to 1/4th of the container.
4. The wastewater allowed to flow in the kit by gravity flow method.
5. The wastewater passes through fine and coarse aggregates media, all the suspended particles gets settle down and wastewater is collected in outlet tank. The setup for filtration process is depicted in Figure 3.

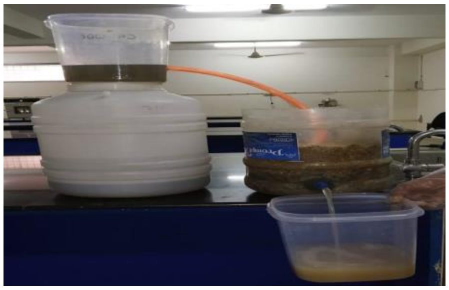

Fig 3: *Filtration process*

Results and Discussion

The analysis results of key physico-chemical parameters have been presented in Tables 1 to 5. As per the results obtained, the double chamber bacterial fuel cell is more efficient than the single chamber**.** The results obtained indicate the reduction in impurities present in wastewater.

Table 1: *Results of pH analysis*

Sample No	Raw Wastewater	After treatment
01	6.5	7.0
02	6.1	7.5
03	7	7.8

Results indicate that the pH value of wastewater is almost in alkaline to neutral condition employing the BFC chamber with filtration process. The obtained pH results indicate less corrosion for the electrode used in the BFC.

Table 2: *Results of Total Solids analysis*

Sample no	Raw Wastewater	After treatment	Units
01	2991	950	mg/L
02	2945	725	mg/L
03	2710	612	mg/L

Total solids is removed by 70-80% after treatment, the production of electricity is also dependent upon the total solids present in the wastewater. If solid present in wastewater is more than degradation, process prolongs, thus affecting the generation of power.

Table 3: Results of Acidity analysis

Sample no	Raw Wastewater	After treatment	Units
01	24	8	mg/L
02	12	3	mg/L
03	09	4	mg/L

The production of electricity in BFC depends on the acidity of the wastewater sample. If the acidity is more the 50 mg/L, the electrodes get corroded but the Wastewater sample used in BFC chamber is not affected by the acidity as the results lies within the limits.

Table 4: *Results of COD analysis*

Sample no	Raw Wastewater	After treatment	Units
01	260	157	mg/L
02	253	154	mg/L
03	241	113	mg/L

The lowest power output was seen at the greatest COD concentration because the anodic reactions in the BFC's anodic chamber depend on the properties of the substrate and the availability of carbon. Colloidal particles may operate as limiting elements and raise internal resistance if they are present in the substrate, which will reduce power density. As the rate of organic loading grows to a specific concentration, power density rises as well. Power density drops when the organic load is higher than the target concentration, but organic load removal rises. A saturated state in the BFC caused by high COD might result in a drop in power density[13].

Table 5: *Results of BOD analysis*

Sample no	Raw Wastewater	After treatment	Units
01	25	12	mg/L
02	19	8	mg/L
03	19	5	mg/L

The BOD measurement in an BFC is based on the proportionality existing between the current efficiency of the cell and the amount of organic matter oxidized which contained in the feedstock used to operate the BFC.

The results indicate the variation of the current generation by the BFC due to the degradation of organic compounds [14].

Electricity generated by bacterial fuel cells

The results of electricity generation using single and double chamber cells are presented in Tables 6 and 7 respectively.

Table 6: *Results of Single chamber bacterial fuel cell*

Trial no	**Electrodes combination**	**Electricity generated**
01	Copper-Copper electrode	0.35v
02	Copper-Aluminum electrode	0.45v
03	Aluminum -Brass electrode	0.4v
04	Copper-Brass electrode	0.35v

Table 7: *Results of Double chamber bacterial fuel cell*

Trial no	**Electrodes used**		**Electricity generated**
	Anode	**Cathode**	
01	Copper	Copper	0.4v
02	Copper	Aluminum	0.6v
03	Aluminum	Brass	0.45v
04	Copper	Brass	0.4v

The maximum power density of 0.6 V for the cell operating with copper and aluminium electrodes with 5L of wastewater, respectively at the anode and cathode chamber. For all the cases, power densities showed an incremental trend with decreasing external resistance and reaches to a peak value. After that, the power densities begin to fall down with increasing current density. Current generation showed a decreasing trend with the increase in, which indicated typical fuel cell behaviour. At higher resistance used, relatively less power density was observed.

Conclusions

A bacterial fuel cell is a device that uses microorganisms as a biocatalyst to oxidize organic materials, converting chemical energy into electrical energy. Nowadays, bacterial fuel cells offer a wide range of possible uses. This research was done in order to identify, test, and quantify the potential created by various electrode combinations. The COD of the wastewater after it was utilized to create current was also examined in this study. The study's findings indicate that current is being created and that the sample's COD is declining. The mix of catalysts supplied determines the current generated; in other words, the current is influenced by the electrodes being utilized. The study also demonstrates that COD of wastewater may be decreased while current is being generated. Future approaches to power production and waste management may make use of technologies that use bacterial metabolisms to break down organic materials into electric current

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References

1. Anand Parkash.; Shaheen Aziz.; Suhail A. Soomro. Utilization of Sewage Sludge for Production of Electricity using Mediated Salt Bridge Based Dual Chamber Microbial Fuel Cell. Journal of Bio processing & Biotechniques , 2016, 5.
2. B.K. Pandey.; V. Mishra.; S. Agrawal. Production of bio-electricity during wastewater treatment using a single chamber microbial fuel cell. International Journal of Engineering, Science and Technology, 2011, 3, 42-77.
3. Booki minet.; Bruce Loga. Continuous Electricity Generation from Domestic Wastewater and Organic Substrates in a Flat Plate Microbial Fuel Cell. Environmental Science and Technology, 2004, 38, 5809-5814.
4. Drisya C M.; Manjunath N T. Dairy Wastewater Treatment and Electricity Generation Using Microbial Fuel Cell. International Research Journal of Engineering and Technology, 2017, 04, 1293-1296
5. Harshal Kawale.; Anil C. Ranveer. Electricity generation from wastewater using a microbial fuel cell by using mixed bacterial culture. Journal of Biochemical Technology, 2017, 7, 1123-1127.
6. Mannarreddy Prabu.; Druga Devi. Electricity Production From Waste Water Using Microbial Fuel Cell. journal of modern biotechnology, 2012, 1, 19–25.
7. Mostafa Ghasemi Wan.; Ramli Wan Daud.; Manal Ismail.; Mostafa Rahimnejad.; Ahmad Fauzi Ismail.; Jun Xing Leong.; Madihah Miskan.; Kien Ben Liew. Effect of pre-treatment and biofouling of proton exchange membrane on microbial fuel cell performance. International journal of hydrogen energy, 2013, 38, 5480-5484.
8. Hong liu.; Ramanathan Ramnarayanan.; Bruce E. Logan. Production of Electricity during Wastewater Treatment Using a Single Chamber Microbial Fuel Cell. Environmental Science and technology, 2004, 38, 2281-2285.
9. R. A. Nastro., Microbial Fuel Cells in Waste Treatment: Recent Advances. International Journal of Performability Engineering, 2014, 10, 367-376.
10. Ravinder Kumar.; Lakhveer Singh.; and A.W. Zularisam. Bioelectricity Generation and Treatment of Sugar Mill Effluent Using a Microbial Fuel Cell. Journal of Clean Energy Technologies, 2016, 4, 249-252.

11. Timothy E. Seiple.; Andre M. Coleman.; Richard L. Skaggs. Bioelectricity Generation and Treatment of Sugar Mill Effluent Using a Microbial Fuel Cell. Journal of Environmental Management, 2017,197 673-680.
12. Zhen he.; Shelley D. Minteer.; Largus T. Angenent. Electricity Generation from Artificial Wastewater Using an Upflow Microbial Fuel Cell. Environmental science & Technology 2005, 39, 5262-5267.
13. Nam J.Y.; Kim H.W.; Lim K.H.; Shin H.S. Effects of organic loading rates on the continuous electricity generation from fermented wastewater using a single-chamber microbial fuel cell. Journal of Bio resource. Technology, 2010, 1, 33-37.
14. Min-Chi Hsieh.; Chiu-Yu Cheng, Man-Hai Liu.; and Ying-Chien Chung. Effects of Operating Parameters on Measurements of Biochemical Oxygen Demand Using a Mediator less Microbial Fuel Cell Biosensor, 2016, 16, 35-40.
15. Ge, Z.; He, Z. Long-term performance of a 200 L modularized microbial fuel cell system treating municipal wastewater: Treatment, energy, and cost. Environ. Sci. Water Res. Technol. 2016, 2, 274–281.
16. Lu, S.; Li, H.; Tan, G.; Wen, F.; Flynn, M.T.; Zhu, X. Resource recovery microbial fuel cells for urine-containing wastewater treatment without external energy consumption. Chem. Eng. J. 2019, 373, 1072–1080.
17. Yan, T.; Ye, Y.; Ma, H.; Zhang, Y.; Guo, W.; Du, B.; Wei, Q.; Wei, D.; Ngo, H.H. A critical review on membrane hybrid system for nutrient recovery from wastewater. Chem. Eng. J. 2018, 348, 143–156.
18. Freguia, S.; Logrieco, M.E.; Monetti, J.; Ledezma, P.; Virdis, B.; Tsujimura, S. Self-powered bioelectrochemical nutrient recovery for fertilizer generation from human urine. Sustainability 2019, 11, 5490.
19. Ye, Y.; Ngo, H.H.; Guo, W.; Chang, S.W.; Nguyen, D.D.; Zhang, X.; Zhang, S.; Luo, G.; Liu, Y. Impacts of hydraulic retention time on a continuous flow mode dual-chamber microbial fuel cell for recovering nutrients from municipal wastewater. Sci. Total Environ. 2020, 734, 139220.
20. Athar, T.; Pandey, A.; Khan, M.; Saqib, Z.A.; Jabeen, M.; Shahid, S.; Hamurcu, M.; Gezgin, S.; Rajput, V.D.; Elinson, M.A. Potential Role of Beneficial Microbes for Sustainable Treatment of Sewage Sludge and Wastewater. In Sustainable Management and Utilization of Sewage Sludge; Springer: Berlin/Heidelberg, Germany, 2022; pp. 71–96.