PROGRESS IN ENGINEERING APPLICATION AND TECHNOLOGY
e-ISSN: 2773-5303

PEAT

Vol. 6 No. 2 (2025) 171-183
https://publisher.uthm.edu.my/periodicals/index.php/peat

The Dirt Powered Fuel Cell (DPFC)

Muhammad Naim Ramli[1], Norain Sahari[1]*

[1] *Department of Electrical Engineering Technology/Faculty of Engineering Technology/Unit Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: norains@uthm.edu.my
DOI: https://doi.org/10.30880/peat.2025.06.02.019

Article Info

Received: 26 June 2025
Accepted: 11 August 2025
Available online: 30 October 2025

Keywords

Dirt Powered Fuel Cell (DPFC), Microbial Fuell Cells (MFC), Chambers, Electrodes and Materials Configuration, Series-Parallel DPFC

Abstract

The Dirt Powered Fuel Cell (DPFC) project explores soil-based microbial fuel cells using electroactive microbes to generate electricity sustainably. Responding to the challenge of improving clean energy technology, the study investigates how electrode configurations (packed vs. planar) and materials (graphite, carbon cloth, aluminium mesh) impact performance. The objectives were to optimize electrode design for maximum electricity output and develop a system capable of powering a DC load. The methodology involved constructing three test chambers which are Chambers A, B, and C with varying materials and configurations, monitoring voltage, current density, and power density over four days. Quantitative findings revealed that Chamber C, with a planar electrode arrangement combining carbon cloth and aluminium mesh, achieved the highest metrics voltage of 602 mV, the current density of 2.95 mA/m^2 and power density of 1,777 µW/m^2. Finally, a series-parallel assembly of 24 such fuel cells produced 8 V at 50 mA, sufficient to light a 5 V bulb and indicate practical viability. The study concludes that judicious selection of electrode materials and configurations substantially enhances DPFC output, demonstrating its promise as an eco-friendly small-scale energy source.

1. Introduction

The Dirt Powered Fuel Cell (DPFC) also known as Microbial fuel cells (MFCs) is innovative bio-electrochemical devices that convert chemical energy into electrical energy by utilizing the metabolic activities of microorganisms. These systems are gaining attention as a sustainable energy technology due to their ability to use organic matter and renewable substrates for electricity generation. In the fundamentals of Microbial Fuel Cells (MFCs), J. Dziegielowski et al. highlights that the MFC systems use electrogenic bacteria to convert the chemical energy of organic substrates into electrical energy, simultaneously degrading the pollutants [1]. Naaz et al. have highlighted within MFCs, electrodes and bacteria work together to form biofilms on the anodic surface that speed up the conversion of complex organic materials into valuable energy through microbial metabolism [2]. In working principle of MFCs, G. Palanisamy et al. has examined a traditional MFCs consists of an anaerobic anode chamber and an aerobic cathode chamber that is either open to the air or submerged in aerated solutions [3]. These compartments are partitioned by a proton exchange membrane, which lets protons pass from the anode to the cathode. An external circuit connects the anode and cathode terminals, allowing electrons to move more freely. Electrons and protons produced by the catalytic oxidation of the substrates in the anode chamber react with the oxygen in the cathodic chamber to form water [3].

There are factors that influence output generation from MFCs such as types of soil, materials and types of electrode, and also electrode configurations. For example, in the research by Prasad et al. has studied that the

type of soil that they used on their research on electricity generation is using soil in microbial fuel cells (MFCs), which is sediment or soil serves as a natural and abundant source of electroactive microorganisms [14]. These microbes metabolize organic matter present in the soil, releasing electrons that are captured by an anode and transferred through an external circuit to the cathode, completing the electron flow and generating electricity. The various electrode materials have been studied to enhance electricity generation and system efficiency. Carbon-based materials, such as graphite fiber, carbon felt, and carbon cloth, are widely used due to their high conductivity, biocompatibility, and resistance to corrosion [15-19]. These materials provide a large surface area for microbial adhesion, making them ideal for long-term applications, though their higher cost can be a limitation. Metal-based electrodes like copper and zinc have demonstrated promising performance in terms of power density and open-circuit voltage. Wei et al. has examined three electrode configurations used in Microbial Fuel Cells (MFCs) which are planar, packed, and brush structures, each offering distinct advantages based on surface area and bacterial adhesion [13]. Planar structures, made from materials like carbon paper, graphite plates, and carbon cloth, provide smooth surfaces suitable for biomass measurements but suffer from limited specific surface areas, impacting bacterial growth and energy generation. Packed structures, utilizing granular or irregularly shaped carbon materials like graphite granules or carbon felt, significantly increase the surface area, enhancing bacterial adhesion and electron transfer. However, they are prone to clogging and dead zones, affecting current collection efficiency over time.

Based on the reviewed studies, several research gaps are identified in the development of microbial fuel cells (MFCs). For soil types Prasad et al. have shown that soil and sediment act as natural sources of electroactive microorganisms, there is limited comparative analysis on how different soil types such as clay, loamy, or sandy soils that affect microbial activity and electricity generation, as well as insufficient investigation into variables like pH, moisture, and nutrient content. Regarding electrode materials, although carbon-based and metal electrodes have been explored for their conductivity and biocompatibility, there is a lack of long-term performance evaluations, studies on hybrid electrodes, and the use of sustainable or low-cost local materials. In terms of electrode configurations, the research by Wei et al. highlighted the strengths of planar, packed, and brush structures and a comprehensive comparison under identical conditions, development of adaptive or modular configurations, and analysis of real-world scalability and maintenance challenges remain underexplored.

There are several challenges in order to achieve the optimal output generation from MFCs regarding on their types of soil, materials and types of electrode, and also electrode configurations. Understanding how different electrode configurations specifically packed versus planar that affect electricity output, which packed electrodes offering greater surface area for microbial attachment and electron transfer, while planar electrodes provide simplicity and scalability. Additionally, the choice of electrode materials plays a vital role, as factors such as conductivity, biocompatibility, and durability directly impact MFC performance. Although carbon-based materials are commonly used, metals like stainless steel and aluminum present more affordable alternatives, yet their effectiveness in various configurations, especially in soil-based systems, has not been thoroughly examined. Compounding these issues is the absence of a standardized evaluation framework, which makes it difficult to compare designs and materials across studies due to inconsistencies in testing conditions and measurement methods. Comprehensive research is therefore essential to identify optimal configurations and materials for enhancing the efficiency and scalability of MFCs. Therefore, this project to investigates the fundamental principles of Dirt Powered Fuel Cell (DPFC), focusing on the impact of electrode materials and electrode configurations such as packed and planar on electricity output. Secondly, to investigate the performance of DPFC under varying electrode configurations to identify the optimal combination for enhanced power generation efficiency and to develop a functional DPFC system that capable of powering a load especially DC load such as a bulb by designing an appropriate connection method which series-parallel for effective energy utilization.

2. Methodology

2.1 Flowchart of The System

This flowchart shows the working and testing process of a Dirt Powered Fuel Cell (DPFC) system. It begins with a DPFC setup based on black soil, where microbial reactions occur of oxidation at the anode and reduction at the cathode is producing a DC electrical output. The system then compares planar and packed electrode configurations to determine which yields optimal electricity, with planar configuration selected for its better performance. The DPFC units are then connected in a series-parallel configuration to optimize both voltage and current output. This output is passed through a DC-DC booster to step up the voltage to a usable level. If the booster functions correctly, the output is directed to a rechargeable battery for energy storage. The stored

Progress in Engineering Application and Technology Vol. 6 No. 2 (2025) p. 171-183

energy is then used to power electrical loads, such as DC bulbs. If the rechargeable battery is unable to power the load, troubleshooting is required at either the booster or battery output stage. If successful, the system operates effectively, completing the energy conversion and delivery cycle. In Fig. 1 shows the flowchart of the system in DPFC.

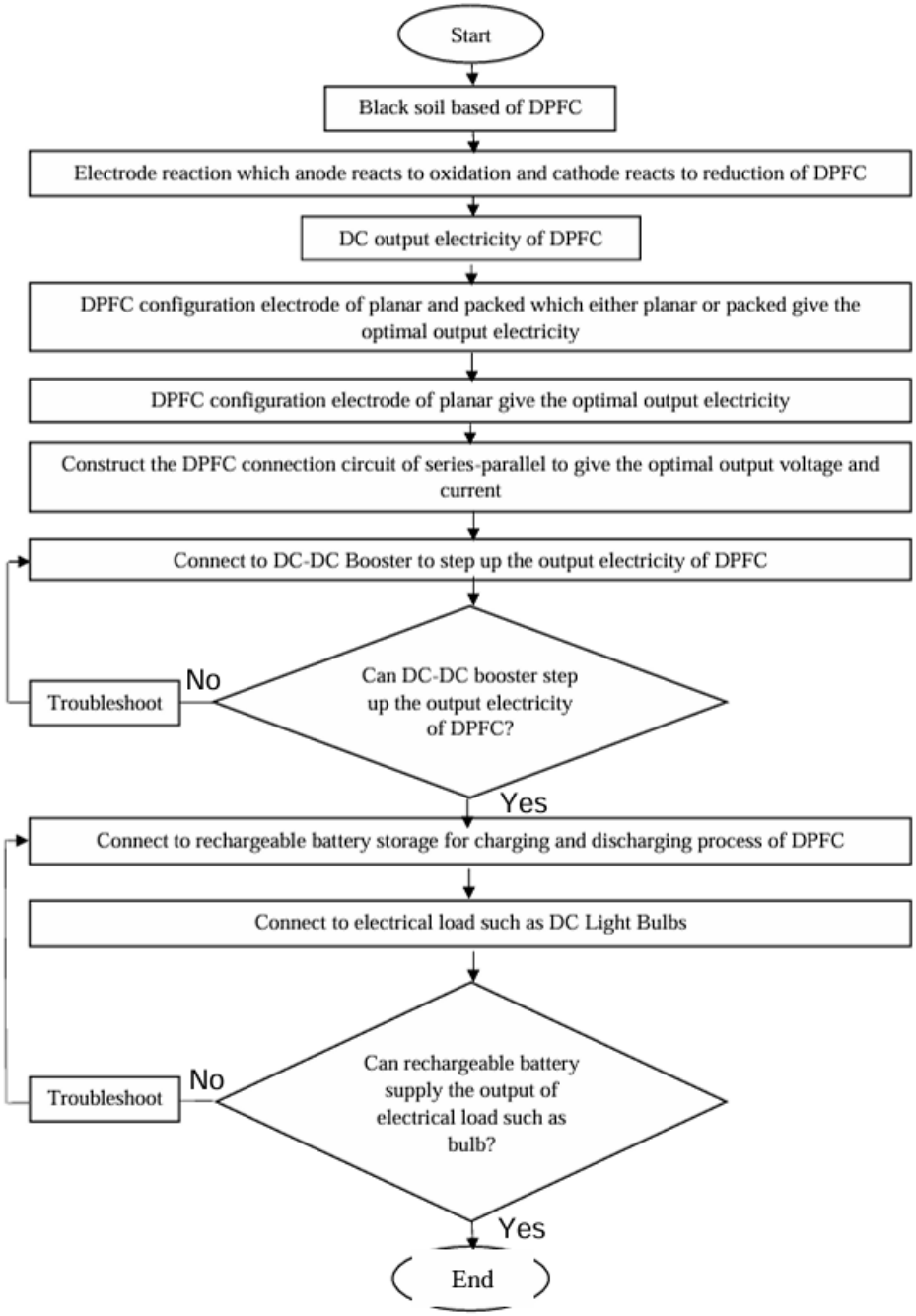


Fig. 1 *The flowchart of the system in DPFC*

2.2 Hardware Implementation of DPFC

In this project, the circuit designed for the DPFC divided in two stages. In Fig. 2 shows the early of hardware implementation of DPFC which for the DPFC electrode configurations of planar and packed. Fig. 3 shows the top view (a), side view (b) and front view (c) of the final stage of hardware implementation of DPFC for the DPFC connection circuit of series-parallel.

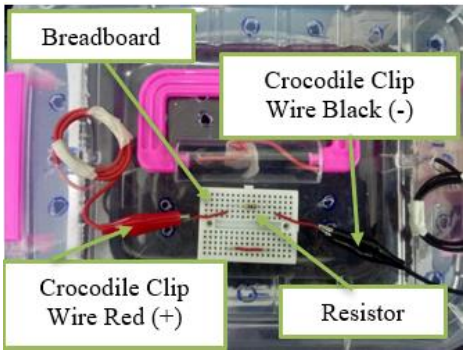
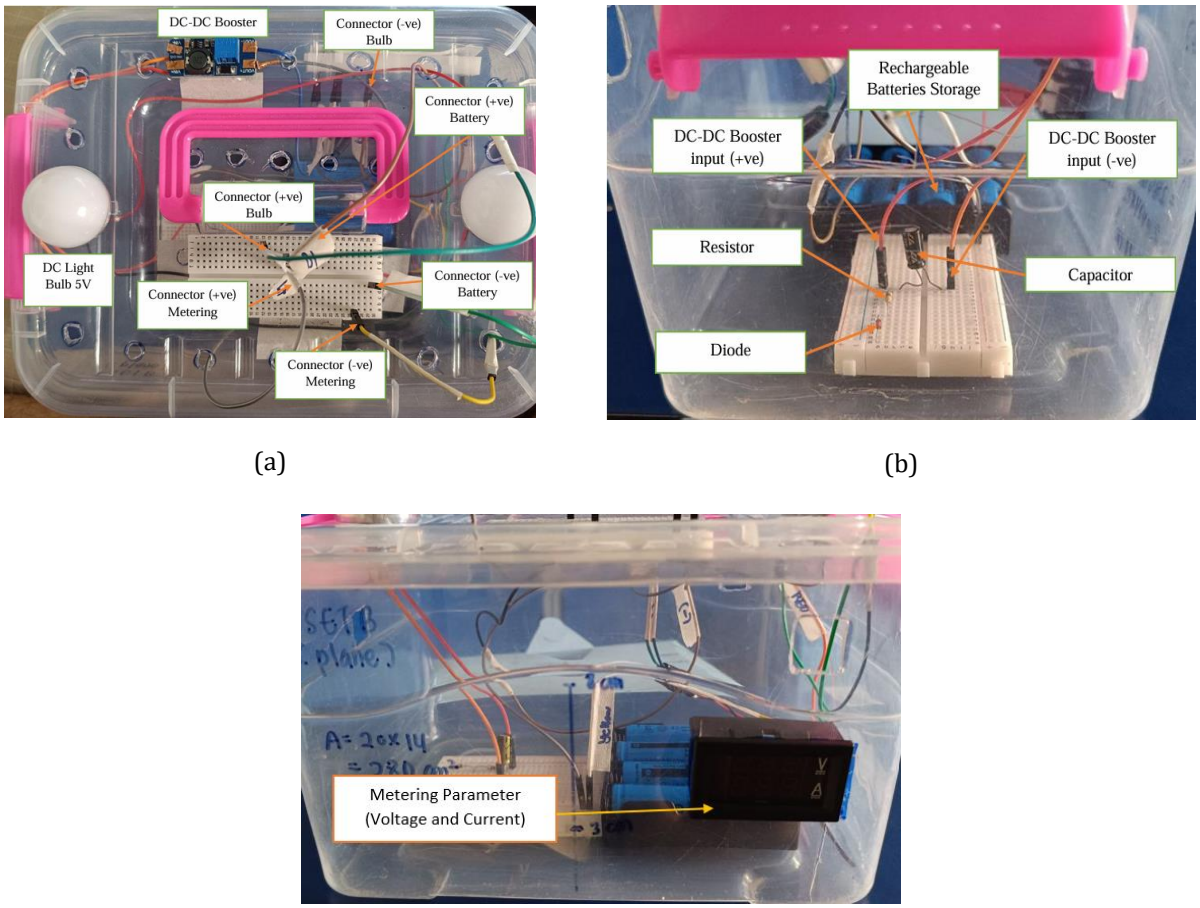


Fig. 2 *The early stage of hardware implementation of DPFC*



(a) (b)

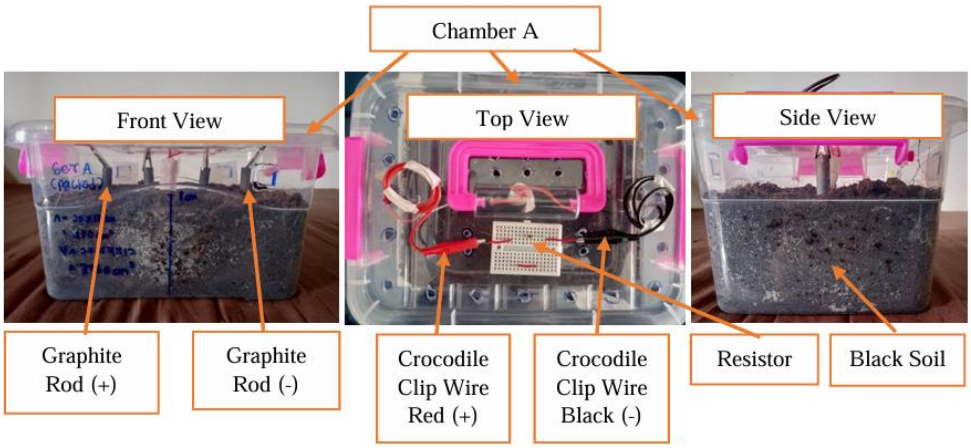
(c)

Fig. 3 *The final stage of hardware implementation of DPFC (a) Top view (b) Side view (c) Front view*

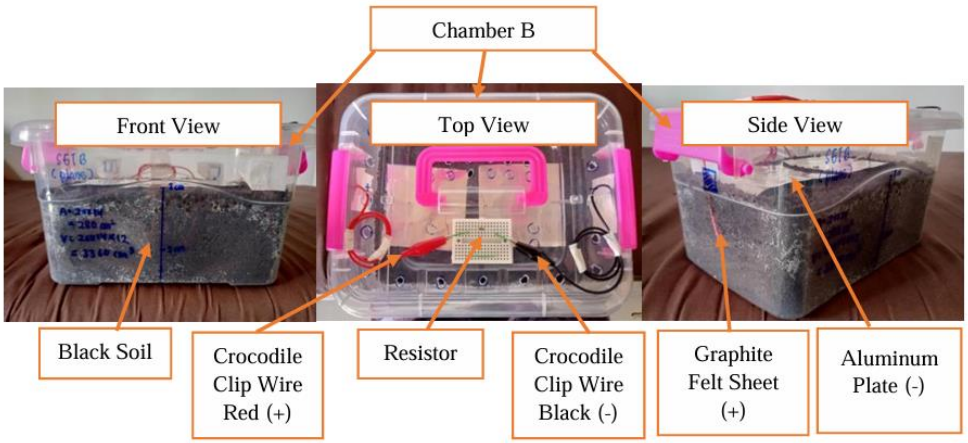
2.3 Experimental Setup of DPFC

In experimental setup for Chamber A is packed electrode configuration while Chamber B and Chamber C both are planar electrode configurations. There are 2 anode and 2 cathode electrodes are been used in Chamber A, B and C which both electrodes are connected in series connection. These experimental setups are to identify either the packed electrode or the planar electrode configurations of Chamber A, B & C shows the optimal output of electricity generation. Chamber A, the material and types of electrode that been used are graphite rod in both anode and cathode electrodes. Chamber B, the materials and types of electrode that been used are graphite felt sheet in anode electrodes and aluminum plate in cathode electrodes. Chamber C, the materials and types of electrode that been used are carbon cloth mesh in anode electrodes and aluminum mesh in cathode electrodes. In Fig.4 shows the experimental setups of DPFC for Chamber A (a), Chamber B (b) and Chamber C (c).

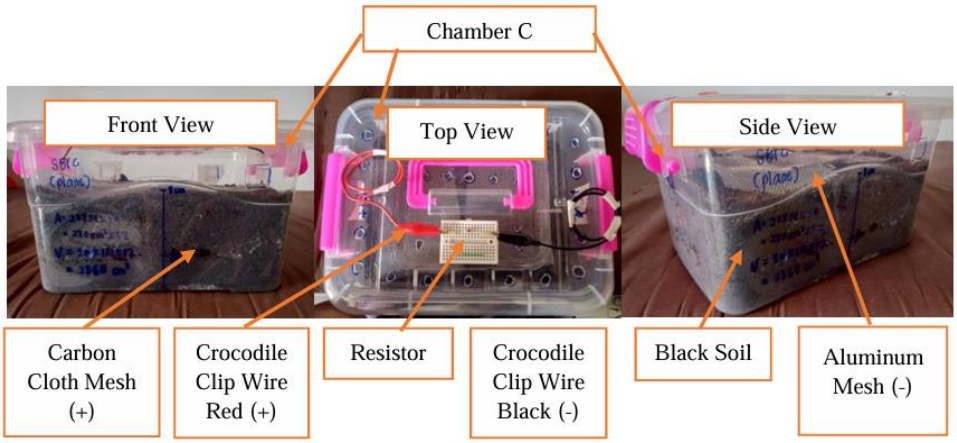
Progress in Engineering Application and Technology Vol. 6 No. 2 (2025) p. 171-183



(a)



(b)



(c)

Fig. 4 *The experimental setups of chamber (a) Chamber A (b) Chamber B (c) Chamber C*

2.4 Implementation Setup of Series-Parallel DPFC

The implementation setup of series-parallel DPFC is based on the experimental setups of Chamber A, Chamber B and Chamber C which each of the chamber gave the optimal output electricity. As the results, Chamber C is

giving the best optimum of output electricity in DPFC. Therefore, the electrode configurations, materials and types of electrode for series-parallel DPFC are based on experimental setup of Chamber C. The implementation setup of series-parallel DPFC also can power up or distribute its electricity to electrical load especially in DC load such as bulbs in order to achieve the objectives of the project. Fig. 5 shows the schematic circuit diagram of the power management system DPFC which to supply the electrical DC load. In Fig.6 shows the construction of single fuel cells of DPFC while Fig. 7 represent as a series connection of 12 fuel cells of DPFC. In Fig. 8 shows that the complete circuit of series-parallel connection of DPFC which divided into 2 set (Set A and Set B) that represented a series connection of 12 fuel cells of DPFC.

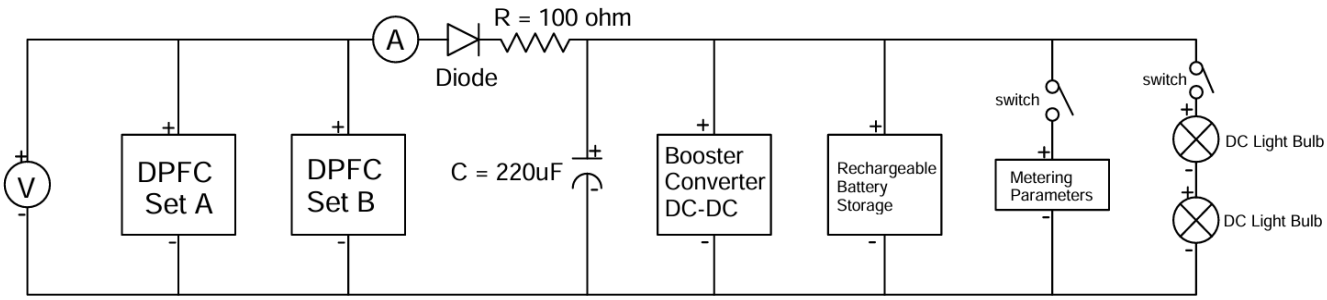


Fig. 5 *The schematic diagram of the power management system of DPFC*

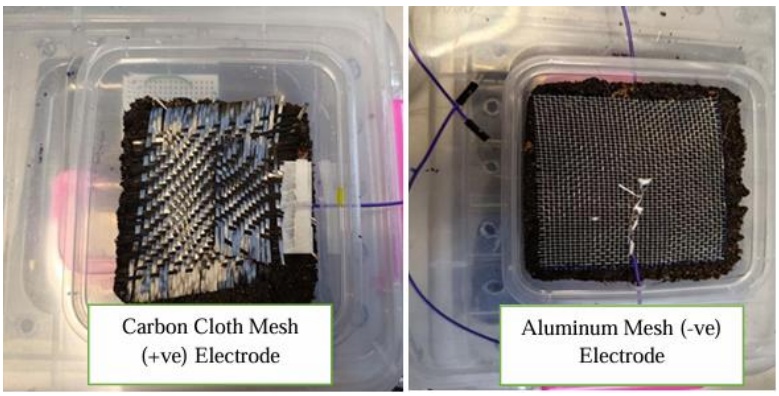


Fig. 6 *The construction of single fuel cells of DPFC*

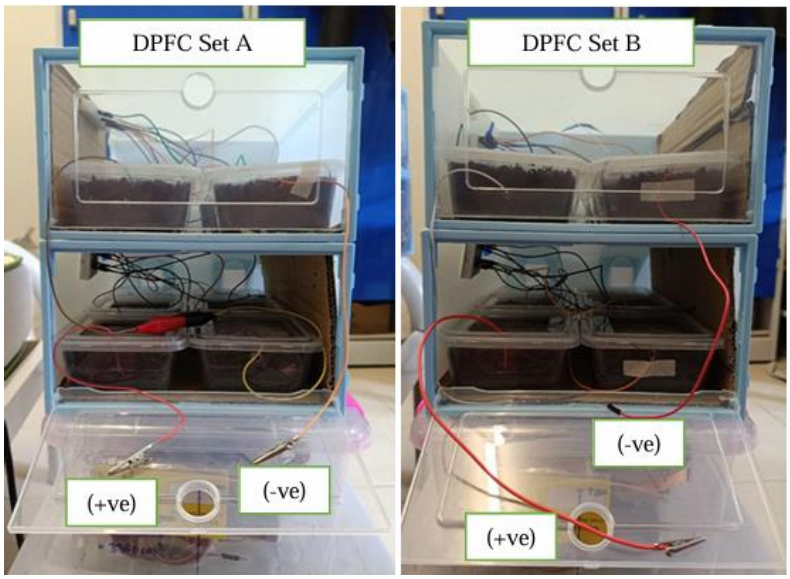


Fig. 7 *The series connection of 12 fuel cells of DPFC for Set A and Set B*

Progress in Engineering Application and Technology Vol. 6 No. 2 (2025) p. 171-183

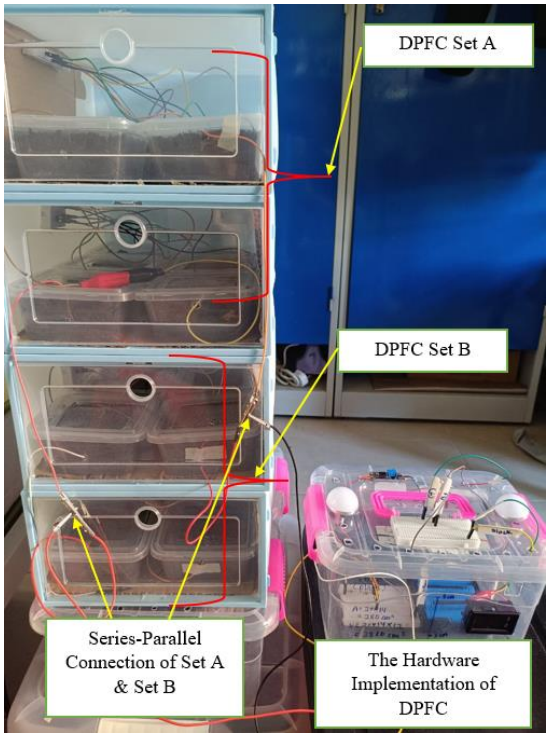


Fig. 8 *The complete circuit of series-parallel connection of DPFC*

3. Results and Discussion

3.1 Outcome Results of Experimental Setup of DPFC

The initial results of the project have been discussed in details with various of data collection and analysis based on voltage, current density and power density of DPFC. The data collection has been collected within 4 days as the initial results of analysis. Table 1 shows the data collection of voltage of DPFC that has been collected in Chamber A, Chamber B and Chamber C within 4 days. Fig. 9 shows the graph of voltage (mV) versus time (Day). In Table 2 shows the data collection of current density of DPFC that has been collected in Chamber A, B and C within 4 days. Fig. 10 shows the graph of current density (mA/m^2) versus time (Day). Table 3 shows the data collection of power density of DPFC that has been collected in Chamber A, B and C within 4 days. Fig. 11 shows the graph of current density (μW/m^2) versus time (Day).

Table 1 *The data collection of voltage (mV) of DPFC within 4 days*

Chamber Section	Voltage (mV)			
	Day 1	**Day 2**	**Day 3**	**Day 4**
A	18	24	28	33
B	406	438	460	500
C	533	570	590	602

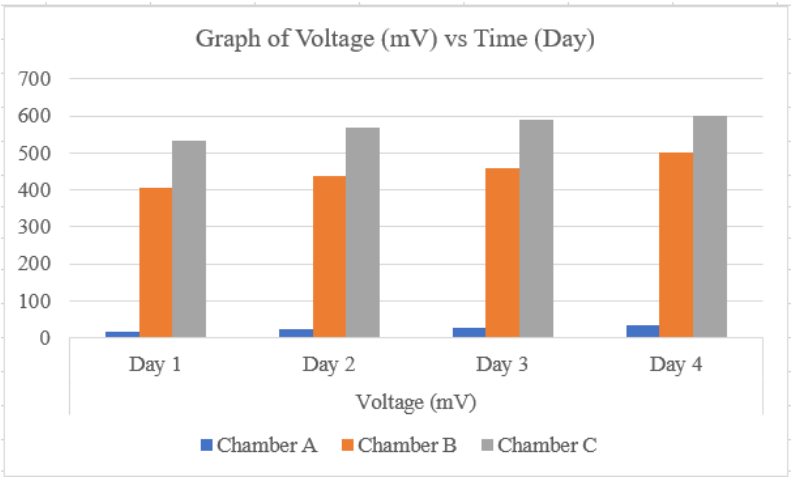


Fig. 9 *The graph of voltage (mV) versus time (Day)*

Based on the data collection of Table 1 reveals distinct voltage outputs for three different chambers over four days. Chamber A exhibited a gradual increase in voltage, starting from 18 mV on Day 1 and reaching 33 mV on Day 4, reflecting slow microbial activity due to its packed electrode configuration. Chamber B demonstrated moderate voltage output, increasing from 406 mV on Day 1 to 500 mV on Day 4, which can be attributed to its planar electrode configuration using graphite felt sheets and aluminum plates that enhance electron transfer. Chamber C showed the highest performance, with voltage rising from 533 mV on Day 1 to 602 mV on Day 4, owing to the use of carbon cloth mesh and aluminum mesh in its planar electrode configuration, which likely improved the surface area for microbial activity and facilitated better electron transfer. Therefore, Chamber C being the most efficient, followed by Chamber B, and Chamber A producing the lowest output.

Table 2 *The data collection of current density (mA/m^2) of DPFC within 4 days*

Chamber Section	Current Density (mA/m^2)			
	Day 1	**Day 2**	**Day 3**	**Day 4**
A	0.14	0.186	0.217	0.256
B	3.172	3.422	3.594	3.906
C	2.613	2.794	2.892	2.95

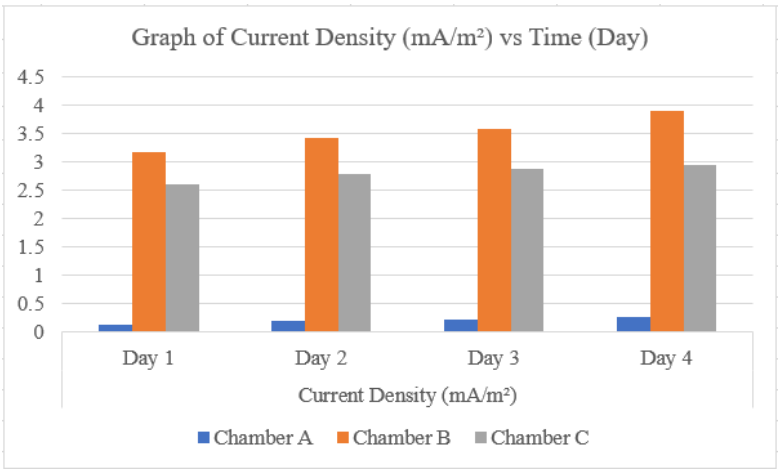


Fig. 10 *The graph of current density (mA/m^2) versus time (Day)*

Progress in Engineering Application and Technology Vol. 6 No. 2 (2025) p. 171-183

In data collection on Table 2 shows the current density (mA/m^2) of the DPFC, which highlights the performance of the three chambers over four days. Chamber A exhibited the lowest current density, starting at 0.14 mA/m^2 on Day 1 and steadily increasing to 0.256 mA/m^2 on Day 4, which corresponds to its low voltage output and limited microbial activity. Chamber B demonstrated the highest current density among the chambers, starting at 3.172 mA/m^2 on Day 1 and rising to 3.906 mA/m^2 by Day 4. This superior performance is attributed to its planar electrode configuration with graphite felt sheets and aluminum plates, which facilitated efficient electron transfer. Chamber C also showed notable performance, with current density increasing from 2.613 mA/m^2 on Day 1 to 2.95 mA/m^2 on Day 4. Although Chamber C had the highest voltage output while its current density was slightly lower than Chamber B due to differences in electrode materials and microbial activity. As the results, the current density of Chamber B is leading the most efficient, followed by Chamber C and Chamber A.

Table 3 *The data collection of power density (µW/m^2) of DPFC within 4 days*

Chamber Section	Current Density (µW/m^2)			
	Day 1	**Day 2**	**Day 3**	**Day 4**
A	2.52	4.64	6.076	8.448
B	1288	1500	1653	1953
C	1393	1593	1706	1777

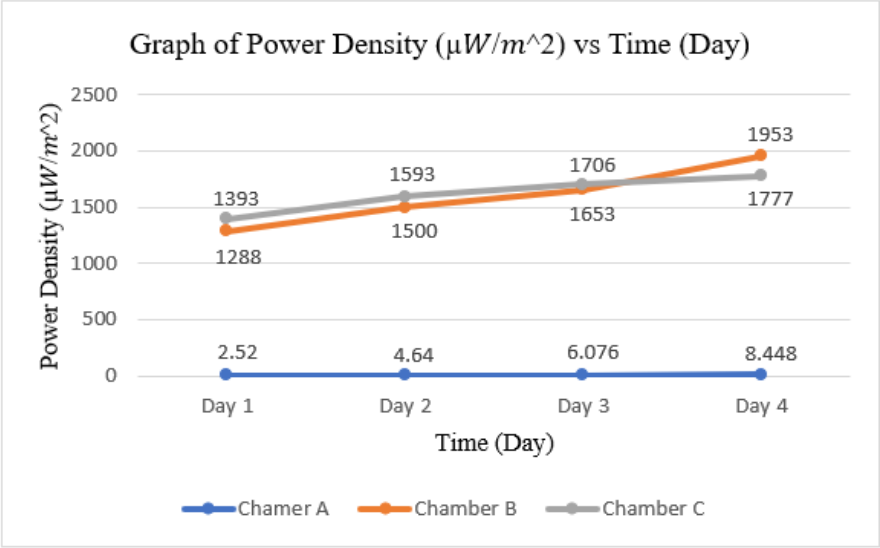


Fig. 11 *The graph of power density (µW/m^2) versus time (Day)*

Table 3 shows the data collection of power density (µW/m^2) for the DPFC which demonstrates the efficiency of energy generation across the three chambers over four days. Chamber A consistently displayed the lowest power density, beginning at 2.52 µW/m^2 on Day 1 and gradually increasing to 8.448 µW/m^2 by Day 4. This limited performance is due to the simpler electrode configuration and less effective electron transfer. Chamber B achieved moderate power densities, starting at 1288 µW/m^2 on Day 1 and climbing steadily to 1953 µW/m^2 by Day 4. This performance highlights the influence of its electrode configuration, which effectively enhanced microbial activity and electron transport. Chamber C exhibited the highest power density throughout the observation period, with values starting at 1393 µW/m^2 on Day 1 and rising to 1777 µW/m^2 on Day 4. This superior performance can be attributed to the efficient interaction of its electrode materials with the microbes, optimizing energy output. Therefore, the data emphasize that power density of Chamber C outperforming the other chambers, followed by Chamber B and Chamber A.

Overall, based on the analysis of voltage, current density, and power density over four days, Chamber C consistently demonstrated the best overall performance in optimizing electricity output of the DPFC. While Chamber B recorded the highest current density and Chamber C achieved the highest voltage and power density,

indicating more efficient energy generation due to its planar electrode configuration using carbon cloth mesh and aluminum mesh, which likely enhanced microbial activity and electron transfer. The results indicated that Chamber C, which used a planar configuration with carbon cloth and aluminum mesh, produced the highest voltage and current output, thereby confirming that electrode material and configuration significantly impact electricity generation. It is discussed that the aims goal of the objective 1 and objective 2 on this project was effectively met. This directly supports the objective's intention to understand how electrode choices influence performance of DPFC in order to identify the optimal combination for enhanced power generation efficiency.

3.3 Outcome Results of Series-Parallel of DPFC

The Chamber C have been selected to be improvise and optimize the output electricity of DPFC in order to achieve the objectives of the project. Based on that configuration, a series-parallel of DPFC have been constructed as the new construction implementation of DPFC. The outcome results of that configuration will be focus on data analysis of voltage and current output, boosting voltage output on DC-DC booster of DPFC, and the charging and discharging process of rechargeable battery that supply to electrical DC load such as DC light bulbs. Table 4 shows the data collection of voltage and current output of series-parallel DPFC.

Table 4 *The data collection of voltage and current output of series-parallel DPFC*

Connections	Voltage Output (V)	Current Output (mA)
Series-Parallel	8.0	50

Table 4 highlights the electrical performance of the Dirt Powered Fuel Cell (DPFC) when connected in a series-parallel configuration, showing a significant improvement in output values. Specifically, the setup achieved a voltage output of 8.0 volts and a current output of 50 milliamperes (mA), demonstrating the effectiveness of combining both series and parallel connections to optimize power generation. The series connection contributes to increasing the overall voltage, while the parallel arrangement enhances the current output, resulting in a balanced and more efficient energy supply. This configuration proves to be a practical approach to maximizing the electricity output of the DPFC system, indicating its potential for scalable and reliable applications in sustainable energy generation.

Table 5 *The data collection of boosting voltage on DPFC*

Components	**Voltage Input of Booster (V)**	**Voltage Output of Booster (V)**	**Duration Boosting Period**
Series-Parallel of DPFC	8.0	2.25	30 minutes

Based on the data shown in Table 5, the boosting process appears ineffective during that period because the output voltage of 2.25 V is significantly lower than the input voltage from the DPFC of 8.0 V, which is the opposite of the intended function of a DC-DC booster. Supposedly, the working boost converter should increase, not decrease, the voltage. This discrepancy suggests a few possible issues such as the booster module may be incorrectly configured like wrong output setting, damaged, or incompatible with the very low current supplied by the DPFC. Additionally, the input current capability of the DPFC might be insufficient to drive the boost converter effectively, especially if the converter requires a certain minimum load or startup voltage under real current draw. Due to the low current series-parallel DPFC in this project which is 50mA may cause the lower voltage output of booster in order to boost up the voltage. Therefore, as the results this boosting is not successfully achieve the exact expectation of the project which need to boost up voltage output to charge the battery at battery storage in DPFC.

Table 6 *The data collection of charging and discharging process with load and without load on DPFC*

State of Charge	Condition of Electrical Load	Duration Time of Process	Normal Condition of The Battery	Voltage Output of The Battery
Discharging	With load (2 DC light bulbs)	30 minutes	14.8V	10.5V
Charging	Without load	30 minutes	10.5V	10.5V

Table 6 shows the data collection of charging and discharging process with load and without load on DPFC. As the results, the charging process appears ineffective because the battery voltage remained at 10.5V, with no noticeable increase after 30 minutes. This indicates that the battery was not effectively charged. The main reason lies in the mismatch between the output of the DPFC and the charging requirements of the battery. Firstly, the battery's nominal voltage is 14.8V, its need at least 14.4–15V input for rechargeable battery (Li-ion) to initiate a proper charging. In this project, a series-parallel of DPFC only provides 8V, which is insufficient to overcome the internal resistance of the battery and initiate charging. Even if the voltage were adequate, the current output of 50mA is very low, which leads to extremely slow or negligible charging, especially for higher-capacity batteries. Furthermore, the booster is not functioning correctly, since the lower current of a series-parallel of DPFC that cannot be stepped up to the required charging voltage. As a result, the battery receives neither sufficient voltage pressure to charge nor enough current to accumulate significant energy. This explains why the voltage of the battery stayed nearly constant at 10.5V, showing no effective charging occurred.

Overall, the objective 3, which aims to develop a functional DPFC system capable of powering a load such as a DC light bulb using a series-parallel connection method was not achieved. Since, the boosting process which essential for further validating the output is failed to perform as expected. Although the DPFC system produced 8V in series-parallel configuration and the DC-DC booster only produced 2.25V, far below the required level to demonstrate enhanced system efficiency. Although the series-parallel configuration improved the raw output of the DPFC to 8V and 50mA, but the system failed to charge the battery due to insufficient voltage and current, and consequently could not deliver consistent power to the DC light bulb. The battery voltage remained unchanged during charging, and only discharged when powering the bulb, indicating that the DPFC system in its current state, could not function independently to support a load.

3.5 Limitations and Recommendations Outcome Results of Series-Parallel of DPFC

Based on the data presented in Tables 4, 5, and 6, the overall performance of the Dirt Powered Fuel Cell (DPFC) system demonstrates both potential and limitations in its current design, particularly regarding its ability to support practical energy storage applications. Table 4 shows that the series-parallel configuration of DPFC successfully generated a stable voltage of 8.0 V and a current of 50 mA, indicating that combining series and parallel connections effectively balances voltage and current output. However, Table 5 reveals a critical issue with the DC-DC booster, which failed to perform its intended function of increasing the voltage instead, it outputted only 2.25 V which far lower than the DPFC input of 8.0 V. This unexpected result suggests limitations related to the booster module's configuration, compatibility, or operational threshold, possibly caused by the DPFC's low current output, which may fall below the minimum requirement for the booster to function properly. Table 6 further emphasizes the system's shortcomings, showing that the charging process was ineffective, as the battery voltage remained at 10.5 V after 30 minutes, well below the required 14.4–15 V for lithium-ion batteries. The combination of insufficient voltage from the DPFC and the non-functional booster prevented the system from meeting the charging threshold, and the low current of 50mA, further hindered the ability to deliver meaningful energy to the battery.

These findings highlight several key limitations which the current DPFC output is too low to meet the operational requirements of common energy storage systems as well as the DC-DC booster module either lacks proper configuration or is incompatible with low-power sources and also the system lacks a proper integration strategy between power generation, voltage regulation, and energy storage. For the recommendations in this project, improve the DPFC's current output by optimizing electrode materials, configurations, and substrate

composition to support higher microbial activity and electron transfer. Selecting a DC-DC booster designed specifically for ultra-low power inputs, or incorporating a supercapacitor buffer to stabilize and amplify the voltage input before entering the booster, could improve conversion efficiency. Matching the storage component battery to the capabilities of the DPFC such as using lower-voltage, lower-capacity batteries or energy storage devices like supercapacitors that would ensure better compatibility. Implementing real-time voltage regulation and load management could prevent system inefficiencies and improve energy capture and storage. These recommendations are essential to enhance the reliability, efficiency, and practical application of DPFC systems for renewable energy solutions.

4. Conclusion

In conclusion, the project successfully demonstrated the construction and evaluation of a dirt-powered fuel cell system, meeting the primary objectives of analyzing electrode configurations and material impacts. The planar electrode configuration, particularly in Chamber C, provided the highest electricity output, validating the choice of carbon-based anode and metal-based cathode materials. The series-parallel configuration improved voltage and current output, confirming its benefit for power optimization. However, the system failed to boost voltage adequately and charge a battery, revealing critical limitations in the power electronics integration. These findings serve as a valuable reference for enhancing MFC systems in future research toward practical and sustainable energy applications. Therefore, in the future work should focus on improving the power management system of the DPFC, especially by selecting more suitable DC-DC boosters that can operate efficiently at low input currents typical of microbial fuel cells. Additionally, incorporating supercapacitors for energy buffering or selecting a lower-voltage, smaller-capacity battery may provide a better match for the DPFC's output. Advanced microbial cultivation techniques or soil amendments can also be explored to improve consistency and power density. Finally, integrating real-time monitoring systems could support long-term analysis and scaling of DPFCs for broader sustainable energy applications.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, University Tun Hussein Onn Malaysia for its support.

References

[1] J. Dziegielowski, M. Mascia, B. Metcalfe, M. Di Lorenzo, Voltage evolution and electrochemical behaviour of soil microbial fuel cells operated in different quality soils, Sustain. Energy Technol. Assess. 56 (2023) 103071. https://doi.org/10.1016/j.seta.2023.103071.

[2] T. Naaz, A. Kumar, A. Vempaty, N. Singhal, S. Pandit, P. Gautam, S.P. Jung, Recent advances in biological approaches towards anode biofilm engineering for improvement of extracellular electron transfer in microbial fuel cells, Environ. Eng. Res. 28 (2023) 220666-0. https://doi.org/10.4491/eer.2022.666.

[3] G. Palanisamy, S. Thangarasu, R.K. Dharman, C.S. Patil, T.P.P.S. Negi, M.D. Kurkuri, R.K. Pai, T.H. Oh, The growth of biopolymers and natural earthen sources as membrane/separator materials for microbial fuel cells: A comprehensive review, J. Energy Chem. 80 (2023) 402–431. https://doi.org/10.1016/j.jechem.2023.01.018.

[4] P.D. Kolubah, H.O. Mohamed, M. Ayach, A. Rao Hari, H.N. Alshareef, P. Saikaly, K.J. Chae, P. Castaño, W2N-MXene composite anode catalyst for efficient microbial fuel cells using domestic wastewater, Chem. Eng. J. 461 (2023) 141821. https://doi.org/10.1016/j.cej.2023.141821.

[5] S.P. Jung, S. Son, B. Koo, Reproducible polarization test methods and fair evaluation of polarization data by using interconversion factors in a single chamber cubic microbial fuel cell with a brush anode, J. Clean. Prod. 390 (2023) 136157. https://doi.org/10.1016/j.jclepro.2023.136157.

[6] S.S. Satpathy, P.C. Ojha, R. Ojha, J. Dash, D. Pradhan, Recent modifications of anode materials and performance evaluation of microbial fuel cells: A brief review, J. Energy Eng. (2021). https://doi.org/10.1061/JLEED9/EYENG-5732.

[7] Alka Kaushik, S.K. Jadhav (2022) Efficiency of food waste as fuel source in Microbial Fuel Cell: A review. NewBioWorld A Journal of Alumni Association of Biotechnology, 4(2):31-35. https://doi.org/10.52228/NBW-JAAB.2022-4-2-6.

[8] Yaqoob AA, Ibrahim MNM, Rafatullah M, Chua YS, Ahmad A, Umar K. Recent Advances in Anodes for Microbial Fuel Cells: An Overview. Materials (Basel). 2020 May 1;13(9):2078. doi: 10.3390/ma13092078. PMID: 32369902; PMCID: PMC7254385.

[9] Choudhury, P., Prasad Uday, U. S., Bandyopadhyay, T. K., Ray, R. N., & Bhunia, B. (2017). Performance improvement of microbial fuel cell (MFC) using suitable electrode and Bioengineered organisms: A review. Bioengineered, 8(5), 471–487. https://doi.org/10.1080/21655979.2016.1267883.

[10] El. Mekawy, A.; Hegab, H.M.; Losic, D.; Saint, C.P.; Pant, D. Applications of graphene in microbial fuel cells: The gap between promise and reality. Renew. Sustain. Energy Rev. 2017, 72, 1389–1403. https://doi.org/10.1016/j.rser.2016.10.044.

[11] Cai, T.; Meng, L.; Chen, G.; Xi, Y.; Jiang, N.; Song, J.; Zheng, S.; Liu, Y.; Zhen, G.; Huang, M. Application of advancedanodesinmicrobialfuelcellsforpowergeneration: Areview. Chemosphere2020,248,125985–125999. https://doi.org/10.1016/j.chemosphere.2020.125985.

[12] Chen,S.; Patil, S.A.; Brown, R.K.; Schröder, U. Strategies for optimizing the power output of microbial fuel cells: Transitioning from fundamental studies to practical implementation. Appl. Energy 2019, 233, 15–28. https://doi.org/10.1016/j.apenergy.2018.10.015.

[13] Wei, J.; Liang, P.; Huang, X. Recent progress in electrodes for microbial fuel cells. Bioresour. Technol. 2011, 102, 9335–9344. https://doi.org/10.1016/j.biortech.2011.07.019.

[14] J. Prasad and R. K. Tripathi, "Maximum electricity generation from low cost sediment microbial fuel cell using copper and zinc electrodes," 2017 International Conference on Information, Communication, Instrumentation and Control (ICICIC), Indore, India, 2017, pp. 1-4, doi: https://doi.org/10.1109/ICOMICON.2017.8279078.

[15] Q. Wotawa-Bergen, D. B. Chadwick, K. E. Richter, L. M. Tender, C. E. Reimers and Y. Gong, Operational testing of sediment microbial fuel cells in San Diego Bay, OCEANS 2010 MTS/IEEE SEATTLE, Seattle, WA, 2010, pp. 1-6.

[16] X.Xu,O. Zhao , M. Wu , J Ding, W. Zhang, Biodegradation of organic matter and anodic microbial communities analysis in sediment microbial fuel cells with/without Fe(III) oxide addition, Bioresource Technology 225 (2017) 402–408.

[17] E. Abazarian, R. Gheshlaghi, M. A. Mahdavi, The effect of number and configuration of sediment microbial fuel cells on their performance in an open channel architecture, Journal of Power Sources 325 (2016) 739 744.

[18] H.Zhang, D.Zhu, T.S.Song, P.Ouyang, J.Xie, Effects of the presence of sheet iron in fresh water sediment on the performance of a sediment microbial fuel cell, international journal of hydrogen energy 40 (2015) 16566 -1657.

[19] D.Majumder,J.P.Maity,C.Y.Chen,C.C.Chen,T.C.Yang,Y.F.Chang,D.W. Hsu,H.R.Chen, Electricity generation with a sediment microbial fuel cell equipped with an air-cathode system using photo bacterium, International journal of hydrogen energy 39 (2014)21215-21222.

[20] M. Lo, "Design and Implementation of Novel Plant-Based Hybrid Microbial Fuel Cell (MFC) Systems with Dry and Wet Configurations," 2023 IEEE International Conference on Energy Technologies for Future Grids (ETFG), Wollongong, Australia, 2023, pp. 1-7, doi: https://doi.org/10.1109/ETFG55873.2023.10407768.