Renewable Energy Through Soil Segmented Bio-Batteries

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***Abstract*—The increasing global demand for energy and the environmental challenges posed by fossil fuels necessitate the exploration of alternative, renewable energy sources. Soil-based bio-batteries offer a sustainable solution by converting organic matter into electricity. This study introduces segmented bio-batteries, which integrate multiple microbial cells in series or parallel, improving power density and scalability. Manure from cattle, birds, and sheep is used as an organic substrate to enhance microbial activity, optimizing energy output. Experimental results demonstrate the effectiveness of segmented bio-batteries in generating electricity, recycling agricultural waste, and reducing carbon footprints, making them viable for rural electrification and environmental sustainability.**

Keywords—Microbial fuel cells (MFCs), Segmented bio-batteries, Renewable energy, Power density enhancement, Agricultural applications, Soil-based energy systems, Sustainable energy, Waste-to-energy conversion, Eco-friendly power generation, Rural electrification.

I. INTRODUCTION

Microbial fuel cells (MFCs) using soil can turn biomass into energy, but scaling up and improving power output is a challenge [6]. We propose using segmented bio-batteries, which combine multiple small cells to generate more power, making the system more efficient and reliable [3], [7]. These bio-batteries offer an alternative energy source for areas without access to traditional grids and can help make urban and environmental systems more eco-friendly [9]. Our paper also discusses how this system works and presents test results proving its effectiveness [8]. With the growing need for clean, renewable energy, soil-based MFCs using animal manure offer a promising solution [1]. This research involves extracting energy from soil-based MFCs and storing it in electronic components for later use [7]. Additionally, it explores how to create a segmented battery to enhance energy storage and efficiency [4].

The importance of this research lies in its potential to provide a reliable and sustainable energy source from organic waste, which is often abundant in rural and agricultural areas [9]. By integrating microbial fuel cells with segmented bio-batteries, we can create a system that not only produces energy but also stores it for future use, offering a practical solution for off-grid power needs [3], [8]. This innovation is particularly beneficial in remote regions, where conventional power infrastructure is costly and difficult to establish [8]. Additionally, the system promotes the recycling of organic waste, reducing environmental impact and contributing to cleaner, greener energy production [9].

The development of segmented bio-batteries also brings significant advantages in terms of energy efficiency and scalability [4], [5]. By connecting multiple small cells in series or parallel, the system can be scaled up to meet larger energy demands without compromising power density [3]. This approach also ensures that the energy storage system remains flexible and adaptable to various applications, from powering small devices to larger systems [7]. With the potential to enhance energy independence and reduce reliance on fossil fuels, this research aligns with global efforts to shift towards more sustainable and eco-friendly energy solutions, ultimately contributing to a greener future [6].

This research also opens up new possibilities for integrating renewable energy systems into everyday applications [13]. By harnessing energy from microbial fuel cells and improving it with segmented bio-batteries, we can create a more sustainable way of powering not only off-grid communities but also urban infrastructures that prioritize eco-friendly and cost-effective energy solutions [9], [14]. The ability to extract and store energy from organic waste not only addresses the growing need for renewable power but also helps mitigate the environmental impact of waste disposal [6]. This technology, with its focus on low-cost, renewable energy generation and storage, could play a key role in the global transition towards cleaner, more resilient energy systems, particularly in areas that face energy access challenges [9].

II. LITERATUR REVIEW

The idea of using soil-based microbial fuel cells (MFCs) to generate electricity has been widely researched, showing the potential of biomass as a renewable energy source. Hassan [1] demonstrated that different types of manure, such as cattle, bird, and sheep manure, impact MFC performance, with cattle manure producing the highest voltage. This aligns with our project's goal of utilizing organic waste like animal manure to enhance energy production in soil-based MFCs. Similarly, Jiang et al. [2] highlighted that soil composition, particularly organic carbon content and pH, plays a crucial role in optimizing MFC energy output, reinforcing the importance of proper soil management in our research.

Wu et al. [3] introduced a low-power DC/DC booster circuit capable of increasing the voltage from MFCs from 100–300 mV to over 3V, making it practical for low-power applications. This aligns with our efforts to store the generated energy into electronic components for later use. To improve energy storage and scalability, our project focuses on segmented bio-batteries, which combine multiple small cells. Silveira et al. [4] discussed a high-efficiency DC–DC boost converter with high voltage gain, offering insights into designing energy storage systems for segmented bio-batteries. Additionally, Lee and Do [5] proposed a quadratic boost converter that minimizes voltage stress while maximizing efficiency, further guiding our approach to creating a reliable energy storage solution.

Pandey and Dubey [6] reviewed the potential of MFCs in bioenergy, wastewater treatment, and biosensors, identifying challenges like low power density and high internal resistance. Their findings emphasize the need for innovative designs, such as segmented bio-batteries, to enhance MFC efficiency. Rahimnejad et al. [10] compared batch and continuous flow operations in MFCs, demonstrating that continuous flow systems provide better power density and stability. This supports our project's focus on improving scalability and reliability through segmented designs.

Several other studies contribute valuable insights to our project. For example, Prasad and Tripathi [7] showed how a DC-DC converter paired with a supercapacitor could significantly enhance energy storage duration in plant microbial fuel cells, an idea relevant to scaling up our system. Suradi and Mohamad [8] emphasized the role of soil moisture in optimizing MFC output, which supports the design considerations for our segmented batteries. Zulkipli et al. [9] found that barren soils could generate higher voltages, showcasing the adaptability of soil-based MFCs in different environments.

Tardast et al. [11] and Najafpour et al. [12] explored cost-effective approaches to enhance MFC performance using waste materials and oxidizing agents. These findings align with our aim to create an affordable system for energy generation in rural areas. Zhou et al. [13] and Zhou et al. [14] highlighted recent advances in MFC technology, including bio-electrochemical improvements and reactor designs that enhance scalability and energy production efficiency. Izadi and Rahimnejad [15] demonstrated the dual functionality of MFCs for electricity generation and environmental benefits, such as sulfide removal, adding to the sustainable aspect of our project.

III. METHODOLOGY

(1) Approach

Two electrodes are placed in the system, each with a different electrode potential to create a voltage difference. These electrodes are connected to an external circuit to allow the flow of electrons. A substrate layer, made of biowaste mixed with fertilizer, is prepared to serve as the energy source. A compost layer is created as the base, with a soil layer spread on top to provide an environment suitable for microbial activity. The entire setup is divided into multiple segments or cells.

Each cell produce its own voltage , so when we aggregate these all segments we get a significant voltage generated. The continuous breakdown of biowaste by microbes ensures a steady supply of electrons, resulting in consistent electricity generation. The segmented design allows the bio-battery to scale up its power output for specific applications. Regularly adding fresh biowaste and keeping the system moist ensures optimal conditions for microbial activity. Monitoring voltage output and keeping the system moist ensures optimal conditions for microbial activity. Monitoring voltage output and maintaining the electrodes help sustain the efficiency of the bio-battery.

(2) Procedure

a) Place two electrodes in the bio-battery, ensuring they have different electrode potential.

b) Microorganisms in the substrate break down the organic material. During the breakdown process, chemical reactions occur, releasing electrons. The anode collects these electrons. The collected electrons are conducted through the electrode material and directed toward an external circuit.

c) Divide the bio-battery setup into multiple segments or cells. Connect the cells in series as it increases the voltages of individual cells.

d) Design a system using electronic components like capacitors and diodes for efficient transmission of power and preventing reverse currents or losses.

e) The energy stored in the battery is released in a controlled manner to provide a stable and constant voltage output.

f) This ensures the bio-battery can power devices with specific voltage requirements.

(3) Project Execution and Design

a. Assess the availability of biowaste and soil as substrate materials. Analyse the energy requirements of the target application (e.g., LED).

b. Cost estimation for components such as electrodes, substrate materials, and electronic circuitry. Including expenses for prototyping, testing and potential scaling.

c. Choose materials of good conductivity and durability like Metals.

d. Ensure the system is modular for potential scaling in rural and remote areas. Integrate an electrical system to store and regulate energy output.

e. A segment is designed in which there is organic waste and moisture, the microbes are allowed to develop which then circulate through the whole cell.

f. Design multiple cells with independent substrates and electrodes to maximize voltage generation.

g. Connect capacitors to a rechargeable battery to store energy for continuous supply.

h. Designing a suitable internal cell configuration for optimal voltage and current generation.

(4) Implementation

A) Put the mineral rich soil in the one of the container, divide the container into multiple segments.

B) Place the copper plates which acts as positive terminal of battery and zinc plate which acts as negative terminal of battery at all the segments.

C) Connect the copper plates and zinc plates in series with each other to get constant voltage. Check the voltage that is receiving from the copper plate and zinc plates in the multimeter. Install capacitors to store energy temporarily.

D) Use diodes or transistors for voltage regulation and stabilization.

E) Connect the LED to the circuit to check whether the current is flowing through the circuit.

(5) Tools Used

a. Copper and Zinc plates – Both of these metals have different electrode potentials allowing them to act as electrodes for our setup.

b. Capacitors- Capacitors in this experiment are used to temporarily store the electrical energy generated by the bio-battery. They help smooth out any fluctuations in voltage, ensuring a steady and stable energy supply to the devices or systems connected to the battery. By charging and discharging as needed, capacitors play a key role in regulating the power output.

c. Diodes - Diodes are used to control the direction of the current flow in the circuit. They allow the current to move in only one direction, preventing energy stored in the capacitor or battery from flowing back into the bio-battery system

d. Segmented Container- A segmented container as shown in Fig 1 is used in this experiment to divide the bio-battery into multiple independent cells. Each segment acts as a separate unit that generates its own voltage. By segmenting the setup, it becomes possible to connect the cells in series to increase the overall voltage or in parallel to enhance the current output. This modular design improves the efficiency and scalability of the system, allowing adjustments based on the energy requirements.

Fig 1 : Segmented Container

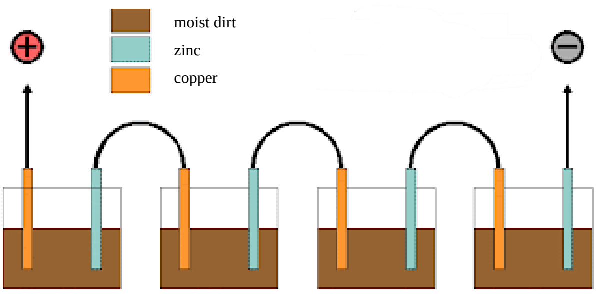

Fig 2 : Setup Diagram

IV. RESULTS AND DISCUSSION

Results:

The bio-battery successfully generated electricity by utilizing biowaste and microbial activity. The segmented cells produced measurable voltages, and connecting them in series resulted in a temporary boost in the overall output, although the LED glowed for a very short time.

The energy storage system, which used capacitors, provided stable voltage during the charging process, but the voltage quickly dropped once the capacitors were connected. Maintaining substrate moisture and microbial activity was essential to ensure consistent energy production over time.
While the bio-battery demonstrated the potential for soil-based microbial fuel cells (MFCs) to generate renewable energy, the voltage output from each segmented cell was in line with expected results, confirming that segmentation helped achieve the desired energy levels.

However, the LED glow time was brief, indicating the need for further optimization in energy storage and stability. In conclusion, the capacitors effectively stored energy, but their discharge rate and the overall energy efficiency need improvement for more reliable performance in real-world applications.

Discussion:

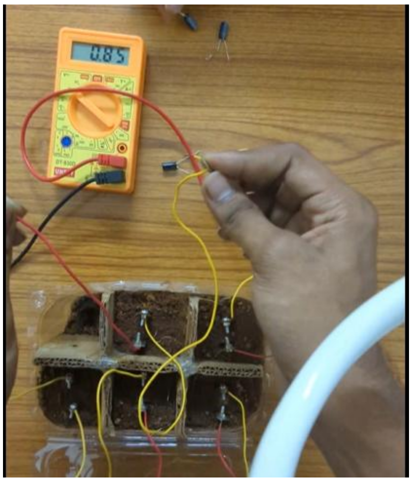

Fig 3: Voltage reading from each cell

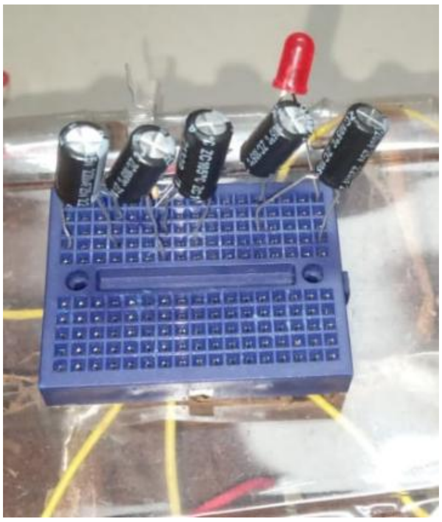

Fig 4: Capacitor Arrangement

In this setup, we manually charged and discharged the capacitors to make an LED glow. The arrangement of the capacitors used is shown in Fig. 4, with the output from the cells being 0.80 volts, as shown in Fig. 3. To automate the process, we can use a transistor as a switch to control the charging and discharging of the capacitors. A 555 timer IC can be used to create a switching application for this process.

Each capacitor can be assigned to each segment, with a transistor acting as a switch between each capacitor in the series connection. When charging, the series connection will be an open circuit, allowing the capacitor to charge. During discharging, the series connection will be a closed circuit, while the connection between the bio-cell and capacitor will be an open circuit to prevent the stored energy from flowing back into the soil. This switching mechanism will be controlled by the 555 timer IC.

Initially, a 5V external power supply is required to power the 555 timer IC. Over time, once the system stabilizes and more energy is extracted from the soil, the power generated by the microbial fuel cells can be used to continuously power the circuit, eliminating the need for an external power supply. This modification will make the system fully automated, improving its efficiency and functionality for long-term use.

CONCLUSION

In this study, we explored using microbial fuel cells (MFCs) combined with segmented bio-batteries to generate and store energy from soil. Our results showed that the segmented cells could produce power, and we used capacitors to store the energy. By manually charging and discharging the capacitors, we were able to power a small LED, demonstrating that the system can store and use energy.

Although the current setup required manual charging, we suggested future improvements that could make the process automatic. Using transistors and a 555 timer IC, the system could work on its own, without needing manual input. This upgrade would help the system run more efficiently, using power generated from the soil.

This research shows the potential of soil-based MFCs and segmented bio-batteries as a green energy solution. With more development, this approach could provide a reliable energy source for remote areas, helping with both energy generation and waste management.

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