Design and Development of an MFC-Based Renewable Energy System Using Vegetables Waste Feedstock

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ABSTRACT: The rapid increase in global energy consumption and the environmental impacts caused by fossil fuels have motivated the search for sustainable energy alternatives. Among various renewable options, bioenergy obtained from organic residues is gaining importance due to its eco-friendly nature. This project turns that waste into useful electricity and dry compost, using only simple tools and natural bacteria. The waste to electricity concept focuses on transforming the chemical energy stored in organic matter into usable electrical power. Vegetable waste is mechanically processed to form slurry containing conductive organic compounds. This mixture serves as an active medium for electrochemical or microbially driven reactions When electrodes like zinc and copper are immersed in the substrate, redox reactions produce a measurable voltage. The generated electrical output can be stored in rechargeable cells and used for low-power applications. The project offers dual advantages by combining waste management with renewable energy production. Vegetable and fruit residues contain carbohydrates, acids, and moisture that enhance ionic conductivity, making them suitable for electricity generation. The leftover solid waste after juice extraction is dried using heat and pressure. The dry pulp can then be composted safely to become a nutrient-rich soil. In addition to generating electricity, this project provides insight into bio-electrochemical systems, waste valorization, and sustainable technology development. It encourages the reduction of landfill waste while fostering community-level renewable energy initiatives. By integrating waste management with clean energy generation, the project contributes to environmental conservation and supports broader sustainability goals. Thus, it serves as both a functional prototype and a step toward achieving eco-friendly, resource-efficient solutions.

KEYWORDS: FUEL CELL, BIOENERGY, MOISTURE.

I.INTRODUCTION: The rising global energy demand and environmental pollution from conventional fossil fuels have compelled researchers and engineers to explore cleaner, sustainable, and renewable energy sources. Among the several renewable options such as solar, wind, and hydro, bio-energy derived from organic waste materials is emerging as an innovative and eco-friendly alternative. Organic waste, especially fruit and vegetable waste, is abundant, renewable, and biodegradable. Instead of being disposed of in landfills, where it emits methane and contributes to greenhouse gases, such waste can be effectively utilized to generate electricity. The concept of “Waste to Electricity” is based on converting biochemical energy stored in organic waste into electrical energy through electrochemical or microbial processes. The waste is first crushed to obtain a semi-liquid mixture. The liquid portion, rich in electrolytes and organic compounds, acts as the medium for electrochemical reactions. When metal electrodes such as zinc and copper are inserted into the mixture, a potential difference is created due to redox reactions, generating electrical energy.

This energy can be stored in a rechargeable battery and used to power low-voltage devices such as LEDs or sensors. This system demonstrates a dual benefit efficient waste management and renewable energy generation. Vegetable and fruit waste are rich in carbohydrates, acids, and moisture, which contribute to high ionic conductivity, making them suitable for electricity generation. The system’s design is simple, low-cost, and environmentally friendly, making it suitable for small-scale rural applications and educational demonstrations. Furthermore, the project provides an opportunity to understand fundamental concepts of bio-electrochemical systems, waste valorization, and sustainable technology. It supports the vision of reducing landfill waste and promoting green energy initiatives at the community level. Thus, this project not only serves as a prototype for renewable energy systems but also as a contribution toward achieving sustainable development goals.

II.PROPOSED SYSTEM: The block diagram of the project provides a simplified representation of the overall process involved in generating renewable bioenergy from waste vegetable feedstock through Microbial Fuel Cell (MFC) integration.

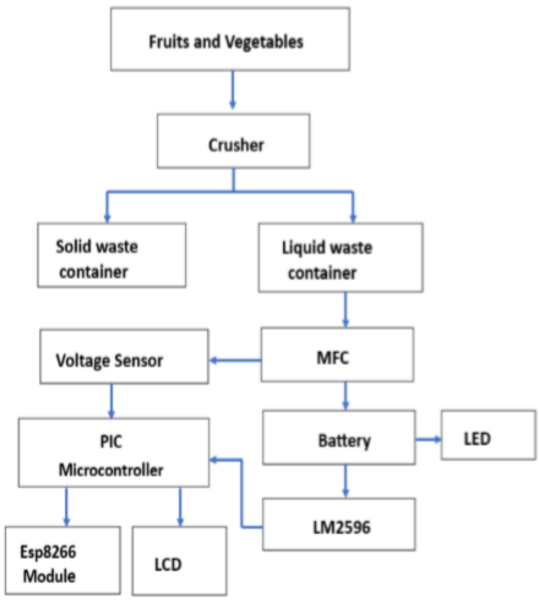

Fig 1 Block Diagram of MFC-Based Renewable Bioenergy System

• **Vegetable Waste Feedstock** Vegetable peels, spoiled vegetables, and leftover food are collected as the primary organic feedstock for the system. These wastes are then crushed and mixed with water to form slurry, which serves as the substrate or food source for the microorganisms in the microbial fuel cell (MFC). This slurry provides the essential nutrients that allow the microbes to thrive and initiate the bio-electrochemical reactions necessary for electricity generation.

• **Juice Mixer / Grinder** The juice mixer or grinder is used to crush and blend the vegetable waste into a fine slurry. This increases the surface area of the organic matter, making it easier for microbes in the MFC to decompose and release electrons efficiently.

• **Hand Force** Hand force is applied to operate the grinder manually in case of no electrical power supply. It ensures the process remains functional in rural or off-grid areas, promoting a low-cost and sustainable waste-processing method.

• **Liquid Waste Container** The liquid waste container stores the semi-liquid slurry produced after grinding. This container supplies the prepared substrate to the MFC, where microbial metabolism occurs to produce electrical energy.

• **Fog Dispenser** The fog dispenser is used to maintain proper humidity and moisture levels within the system. Microorganisms in the MFC require a moist environment to survive and function effectively. The fog dispenser sprays fine mist or moisture, preventing the system from drying out. By ensuring optimal environmental conditions, it supports microbial growth, enhances metabolic activity, and helps maintain stable and continuous electricity production.

• **Solid Waste Container** The solid waste container collects the leftover insoluble material separated from the liquid waste. These solid residues can later be used for composting or other eco-friendly waste disposal methods.

• Microbial Fuel Cell (MFC)

The Microbial Fuel Cell is the core component of the entire system. Inside the MFC, microorganisms break down organic matter present in the slurry through a biological oxidation process. During this process, electrons and protons are released. The electrons travel through an external circuit from the anode to the cathode, generating an electric current. Meanwhile, protons move through a membrane to complete the reaction. This process not only generates electricity but also reduces organic waste, making the system both energy-producing and environmentally beneficial.

• **Electrical Circuit** The electrical circuit connects the MFC to other components like the battery and output devices. It plays a key role in controlling and managing the generated electricity. The circuit may include components such as resistors, diodes, and voltage regulators to stabilize the voltage and prevent fluctuations. It ensures safe transmission of power, protects the system from overload, and improves overall efficiency by minimizing energy losses.

• Battery The battery is used to store the electrical energy produced by the MFC. Since microbial activity may vary over time, the electricity generation may not always be constant. The battery helps overcome this issue by storing excess energy when production is high and supplying power when production is low. This ensures a continuous and reliable energy output, making the system more practical for real-world applications.

• USB Module The USB module serves as the output interface of the system. It allows the stored electrical energy in the battery to be used for powering small electronic devices. With the help of this module, the system can charge mobile phones, operate LED lights, or run small sensors. This demonstrates the practical usability of the generated bioelectricity and highlights the potential of converting organic waste into useful energy for everyday applications.

Schematicdiagram

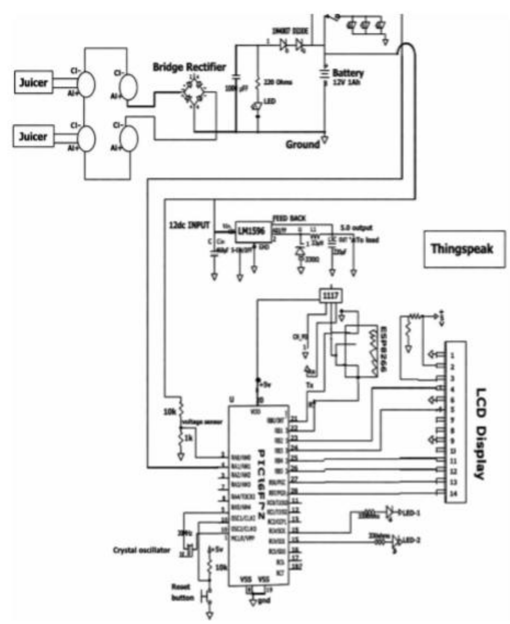

Fig 2 Proposed Schematic Diagram

This circuit diagram represents a complete system designed to generate electricity from waste vegetable feedstock using a Microbial Fuel Cell (MFC) and monitor the output using embedded and IoT technologies. The process begins with the MFC units shown on the left side of the diagram. In these chambers, microorganisms break down organic matter present in vegetable waste and release electrons as part of their metabolic activity. These electrons flow from the anode to the cathode, producing a small electrical output. Since the voltage generated is very low and not perfectly stable, it cannot be used directly for practical applications. To make the generated power usable, the output from the MFC is passed through a bridge rectifier, which ensures that the electrical signal is converted into a proper DC form with correct polarity. After rectification, a large capacitor (1000 μF) is used to filter and smooth the voltage by removing fluctuations or ripples. An LED along with a resistor is connected in this stage to indicate that power is being generated. Additionally, diodes are used to prevent reverse current flow, protecting both the MFC and the storage components.

The stabilized DC output is then used to charge a 12V battery, which acts as an energy storage unit. Since the voltage required for electronic components is lower and must be stable, a voltage regulator (LM2596 buck converter) is used to step down the battery voltage to a constant 5V. This regulated voltage ensures reliable operation of the microcontroller and other connected modules. At the core of the system is the PIC16F72 microcontroller, which acts as the brain of the project. It continuously monitors the voltage generated by the MFC through a voltage sensing circuit made using a resistor divider. This sensor reduces the voltage to a safe level that the microcontroller can read. The PIC processes this data and performs multiple tasks such as displaying the voltage on an LCD and sending it to a wireless communication module. For user interaction, a 16×2 LCD display is connected to the microcontroller. It provides real-time information such as the generated voltage and system status. Supporting components like a crystal oscillator ensure proper timing for the microcontroller, while a reset button allows the system to be restarted when needed. Indicator LEDs are also included to show different states of operation, such as power availability or system activity. To enable remote monitoring, an ESP8266 WiFi module is interfaced with the microcontroller. This module transmits the collected data to an IoT platform called

ThingSpeak. Through this platform, users can view the voltage output and performance of the system in the form of graphs and data logs from anywhere. This adds a smart monitoring feature to the project, making it more efficient and user-friendly. Overall, the circuit demonstrates how renewable energy can be generated from organic waste and effectively utilized. It not only converts bio-waste into electrical energy but also integrates storage, regulation, real-time monitoring, and cloud connectivity, making it a complete and practical solution for sustainable energy generation.

III.RESULTS: The hardware module of the Renewable Bioenergy Generation from Waste Vegetable Feedstock via Microbial Fuel Cell Integration serves as the core of the entire energy conversion process. It incorporates a combination of sensors, processing units, and electrochemical components to enable the efficient breakdown of organic waste, generation of bioelectricity, and continuous monitoring of system performance. This integrated setup automates feedstock handling, microbial activity regulation, electrical output measurement, and overall system functionality to ensure optimized and sustainable bioenergy production.

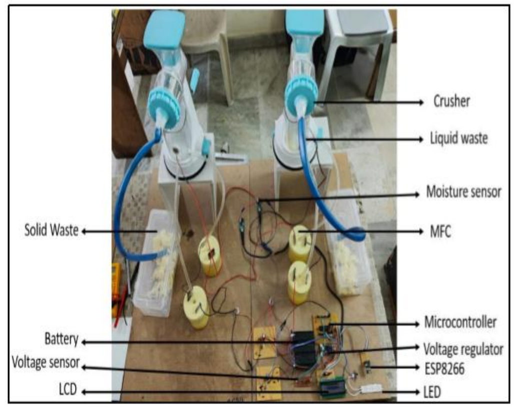

Fig 3 Hardware Module

Case-1: Testing MFC output using fresh vegetable feedstock The setup shown represents the practical testing of a Microbial Fuel Cell (MFC) using fresh vegetable feedstock to generate electricity. Vegetable waste is placed inside the chamber, where microorganisms break down the organic matter and release electrons during their metabolic process. These electrons flow from the anode to the cathode through an external circuit, producing a small electrical output. The chamber is covered to maintain suitable conditions for microbial activity, which is essential for efficient energy generation. The generated voltage is collected through connecting wires and passed to a small interfacing circuit, which helps in stabilizing and routing the signal..

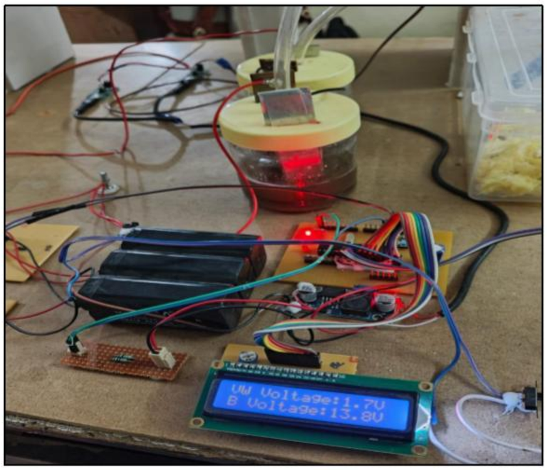

Fig 4 Output Using Fresh Vegetable Feedstock

The measured voltage is displayed in real time on a 16×2 LCD screen, allowing continuous monitoring of the system's performance. The output depends on factors like the type of vegetable waste, moisture content, and microbial activity, and it typically increases as the system stabilizes. Overall, this setup demonstrates the successful generation and monitoring of bio-electricity from organic waste, validating the effectiveness of the project. Overall, this setup demonstrates the real-time generation and measurement of bioelectricity from vegetable waste. It confirms that renewable energy can be produced from biodegradable materials and successfully monitored using embedded systems, forming a key part of your project validation.

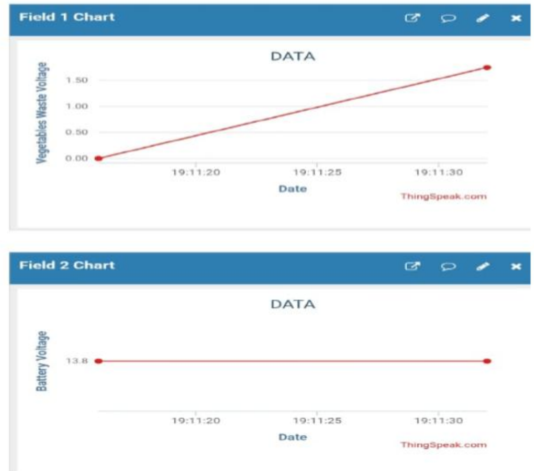

Fig 5 Performance Evaluation of MFC Using Fresh Waste

The ThingSpeak cloud interface is used to monitor and visualize the output of the Microbial Fuel Cell (MFC) in real time. The graph shows voltage on the y-axis and time on the x-axis, where each data point represents a voltage reading captured by the microcontroller and transmitted through the ESP8266 WiFi module to the cloud platform. This visualization helps in analyzing how the voltage varies over time due to microbial activity, feedstock type, and environmental conditions. It enables users to observe trends, detect fluctuations, and monitor the system remotely, making the project more efficient and easy to evaluate.

Case-2: Testing MFC output using Rotten vegetable feedstock In this case, the microbial fuel cell was operated using rotten vegetable waste that had naturally decomposed for 3–4 days, showing dark coloration and a strong odor. This setup represents the experimental case where rotted (decomposed) vegetable feedstock is used in the Microbial Fuel Cell (MFC). In this condition, the vegetable waste has already undergone partial decomposition, resulting in higher microbial activity. This enhances the breakdown process and releases more electrons, leading to better and more stable voltage generation compared to fresh feedstock. The electrodes placed inside the jars collect this bio-electric energy and transfer it to the external circuit.

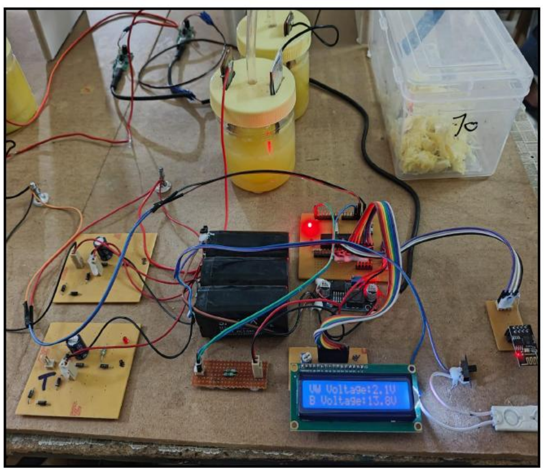

Fig 6 Output Using Rotten Vegetable Feedstock

The generated output is processed, stored in the battery, and monitored using the microcontroller system. The LCD display in the figure shows an MFC voltage of approximately 2.1 V and a battery voltage of around 13.8 V, indicating efficient energy generation and storage. Compared to the fresh vegetable case, this setup produces higher and more consistent voltage, clearly demonstrating that rotted feedstock improves the performance of the MFC system. This observation highlights the importance of feedstock condition in bio-energy generation. As decomposition increases, microbial activity becomes more active and efficient, resulting in enhanced electrical output. Hence, using rotted vegetable waste can significantly improve the overall efficiency and reliability of the MFC-based renewable energy system.

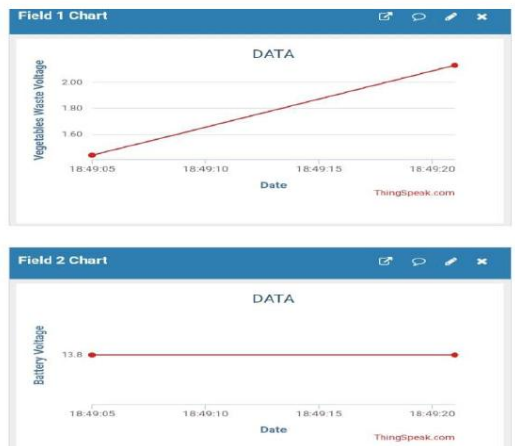

Fig 7 Performance Evaluation of MFC Using Rotten Waste

The figure shows a ThingSpeak graph representing the real-time voltage output of the Microbial Fuel Cell (MFC) using vegetable feedstock. The x-axis indicates time (with timestamps), and the y-axis represents the generated voltage. The graph begins at approximately 1.5–1.6 V around 18:49:05, showing that the system is actively producing electrical energy. An increasing trend is observed in the graph, where the voltage rises gradually over time. This indicates that microbial activity inside the MFC is becoming more effective, leading to enhanced breakdown of organic matter and increased electron release. As a result, the electrical output improves steadily. Overall, the graph highlights the dynamic behavior of the MFC system, where voltage output changes with time based on factors like microbial activity and feedstock condition. It also demonstrates the effectiveness of real-time monitoring using ThingSpeak, which helps in analyzing performance and optimizing the system for better energy generation.

Case-3: Comparative Evaluation of Fresh vs Rotten Vegetable MFC Performance This case compares the performance of the MFC in Case-1 and Case-2 to evaluate the influence of substrate freshness on bioelectricity production. Rotten vegetables provided stronger and quicker voltage development due to the availability of pre-degraded organic matter, while fresh vegetables delivered steadier and more controlled voltage profiles over time. Although the rotten feedstock achieved higher initial output, it also exhibited instability, more corrosive behavior toward the aluminum anode, and more abrupt pH changes. In contrast, the fresh feedstock supported healthier and more sustained microbial activity. The comparison shows that rotten vegetables give higher peak power, but fresh vegetables provide more consistent and predictable performance, making them more suitable when long-term stability is required. The comparison graph showing current generation in MFCs using fresh (green) and rotten (red) vegetable feedstocks.

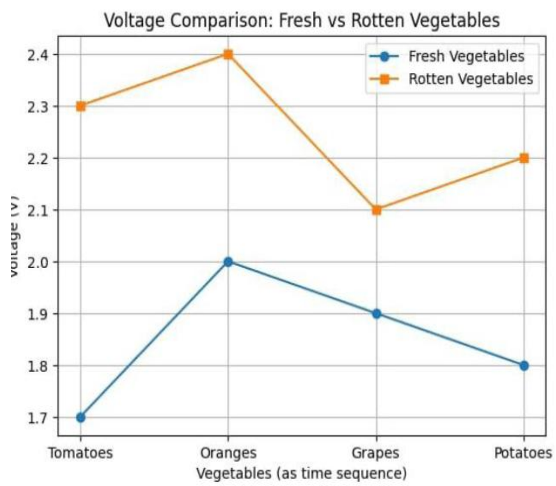

Fig 8 Fresh vs Rotten Vegetable MFC Performance

IV.CONCLUSION: This project successfully demonstrates the potential of converting biodegradable kitchen waste such as fruit and vegetable peels into useful electrical energy through electrochemical principles. The experimental setup effectively showcases how organic waste, which is typically discarded as garbage, can serve as a valuable renewable resource for energy generation. By utilizing natural decomposition and microbial activity, the system produces measurable electrical output, validating the concept of bio-electrochemical energy conversion. Establishes a strong foundation for future development and research in the field of bio-electrochemical energy system. The developed system is low-cost, simple to construct, and environmentally friendly, making it suitable and small-scale applications. Using easily available materials, the setup requires minimal maintenance and operates efficiently with biodegradable waste as the primary input. In conclusion, the project presents a promising model for decentralized energy generation and environmental conservation. With further optimization in terms of electrode design, microbial activity, and system configuration, the power output can be significantly increased. Large-scale implementation of this technology could contribute to reducing landfill waste, lowering carbon emissions, and promoting cleaner, renewable energy sources.

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