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TREATMENT OF DAIRY WASTEWATER USING MICROBIAL FUEL CELLS: A SUSTAINABLE BIOELECTROCHEMICAL APPROACH

Jeldi Anitha[1], R. M. Kalyani1, CH. A. I. Raju[2], and Mani Deepa. I[3]

[1]Teaching Assistant, Department of Chemical Engineering, Andhra University, Visakhapatnam – 530 003, AP, India

[2]Professor, Department of Chemical Engineering, Andhra University, Visakhapatnam – 530 003, AP, India

[3]Assistant Professor, Department of Microbiology, Vignan Degree College, Palakaluru Road, Guntur, Andhra Pradesh, India

***Corresponding Author**

Prof. CH. A. I. Raju

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Abstract

The growing need for sustainable energy solutions and efficient wastewater treatment methods is bringing microbial fuel cells (MFCs) into the spotlight. One of the unique renewable energy options that effectively treats wastewater while simultaneously generating power is microbial fuel cells (MFCs). This research explores the potential of using MFCs to produce electricity from dairy wastewater, which is characterized by a high organic content. With its significant amounts of lactose, lipids, and proteins, dairy effluent serves as an excellent substrate for microbial activity. The MFC setup was constructed with two compartments utilizing graphite electrodes and a proton exchange membrane. The evaluation of performance was centered on voltage generation and power density. The microbial fuel cell (MFC), an essential category of bio-electrochemical systems, utilizes the activity of microorganisms.

Keywords: Microbial fuel cell; voltage, dairy wastewater, energy harvest, salt bridge, and green energy.

Introduction

Fossil fuels have been a reliable source of energy for many years. However, given the ongoing increase in the world's energy use, these fuels are not sustainablebecause burning fossil fuels releases carbon dioxide into the atmosphere, alternative fuels are desperately needed to combat global warming and the energy insecurity caused by the dramatic increase in fossil fuel consumption.Renewable energy is therefore thought to be a practical way to lessen the present energy problem. [1-6].Preventing water contamination and safeguarding freshwater sources continue to be major priorities in many countries, aside from handling the energy crisis [7]. One of the most significant environmental issues confronting humanity at the moment is surface water contamination, which is one of the most urgent environmental issues affecting human health [1]. The majority of wastewater from food processing is produced by the dairy industries in many countries, and as public awareness of the need for improved wastewater treatment standards has grown, process requirements have become increasingly stringent [2]. Activated sludge, trickling filters, aerobic lagoons, anaerobic lagoons, sequencing batch reactors (SBR), anaerobic sludge blankets (UASB), anaerobic filters, and constructed wetlands are examples of aerobic and anaerobic biological treatments that are frequently used to treat dairy wastewaters.Additionally, membrane technology or coagulation/flocculation are used to give chemical and physical treatment [3, 4]. However, these conventional techniques have a number of disadvantages, including substantial sludge formation, large energy requirements, and exorbitant costs [5]. Furthermore, the need for inexpensive, energy-efficient alternative treatment technologies has grown due to the high energy requirements of conventional treatment procedures. Because they have the ability to directly extract electricity from organic wastes and renewable biomass, microbial fuel cells (MFCs) have caught the interest of researchers among renewable energy options [6]. The wastewater used as the substrate in the MFC's anode chamber is a major factor affecting power output. Electrically active microbial communities, which lead to enhanced power generation, are aided by complicated substrates.The addition of novel microbes to MFCs is a crucial job for biochemical engineers because the activity of MFCs is contingent on the microbes. The selection of microorganisms is made in light of their superior catalytic activity and ability to produce electrons from organic waste. In MFC, the higher power yield can be obtained by optimizing the reactor geometry, the surface area in the cathode and anode, and the conductivity of the solution [8]. As a result, for MFC to develop a sustainable device for renewable energy via wastewater

treatment, technological advancements of the biochemical process are necessary. A microbial fuel cell typically has an anode and cathode chamber that are physically separated by a cation/proton exchange membrane.

In the anode chamber, microbes in wastewater function as biocatalysts, oxidizing organic materials and generating electrons and protons. Protons generated in this manner then pass via a proton exchange membrane into the cathode compartment. In contrast, electrons move toward the cathode via an external circuit that includes a resistor or a load. Water is produced in the cathode chamber by the reaction between protons and electrons. The objective of this research was to create an MFC to examine the best operating parameters for wastewater treatment and electricity generation, and then use the MFC's anode chambers to treat real dairy wastewater to assess its effectiveness in treating actual wastewater and producing bioelectricity.

2.0 Materials and methods:

The current research aimed to explore the effectiveness of biological methods for treating four distinct types of effluents. A Microbial Fuel Cell was employed for the continuous treatment of wastewater samples over 45 days, with samples collected at consistent intervals of 5 days.

2.1 Reagents and Chemicals:

$MgSO_4$, $CaCl_2$, $FeCl_3$, phosphate buffer solution, $Na_2S_2O_3$, $MnSO_4$, KI, Starch and conc.H_2SO_4, HCl (Concentrated), Barium chloride solution (10%), Silver nitrate solution (N/35.45), $K_2Cr_2O_7$ solution, sulphuric acid, Ferrous Ammonium Sulphate solution, Ferroin indicator, Silver nitrate solution($AgNo_3$) and potassium chromate indicator ($K_2Cr_2O_7$).

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$MgSO_4$ solution: Dissolve 22.5 grams of $MgSO_4$ in 1000 mL of distilled water in a standard volumetric flask. $CaCl_2$ solution: Dissolve 27.5 grams of $CaCl_2$ in 1000 mL of distilled water in a standard volumetric flask. $FeCl_3$ solution: Dissolve 0.25 grams of $FeCl_3$ in 1000 mL of distilled water in a standard volumetric flask. Phosphate Buffer Solution: Add 8.5 grams of KH_2PO_4, 21.75 grams of K_2HPO_4, 33.4 grams of Na_2HPO_4, and 1.7 grams of NH_4Cl in 1000 ml of distilled water in a standard volumetric flask. Dilution water: Take 1000ml of distilled water in a bottle. Add 1ml each of phosphate buffer (pH = 7.2), $MgSO_4$ solution, $CaCl_2$ solution and $FeCl_3$ solution $MnSO_4$ Dissolve 50g of $MnSO_4$ in 1000 mL of distilled water in a standard volumetric flask. Alkaline potassium iodide azide

Dissolve 40g of NaOH, 20g of KI in 100 ml of distilled water in a standard volumetric flask and add 0.5 g of reagent-grade sodium azide to the cooled solution. N/40 $Na_2S_2O_3$: Dissolve 6.20g of $Na_2S_2O_3$ in 1000 ml of distilled water in a standard volumetric flask. Standardize with N/40 $K_2Cr_2O_7$. Starch solution: Add 2 grams of starch powder in 100 ml of distilled water and dissolve it by heating. Standard 0.25N sodium dichromate ($K_2Cr_2O_7$) solution: Dissolve 12.259 g of pure $K_2Cr_2O_7$ in distilled water and dilute to 1 liter. Add about 120 g of sulphuric acid. Sulphuric acid- silver sulphate reagent. Add 5.5 g of $AgSO_4$ to 1 kg of Conc.H_2SO_4. Keep the same overnight. Standard 0.1 N Ferrous Ammonium Sulphate solution (Fe): Dissolve 30gms of pure salt in distilled water. Add 20ml of conc. H_2SO_4 and dilute to 1 liter. Ferroin indicator: Dissolve 1.485 g of 1-10 Phenanthraline monohydrate with 0.695 g pure $FeSO_4.7H_2O$ in distilled water. Dilute to 100ml. The indicator is commercially available. Conc. H_2SO_4. $AgNO_3$ solution: Dissolve 4.775g of $AgNO_3$ in 1 liter of water,and the solution is standardized with NaCl solution. $K_2Cr_2O_7$ Indicator: Dissolve 5 g of $K_2Cr_2O_7$ in 100 mL of distilled water. Hydrochloric or sulfuric acid, 1:1: Mix equal volumes of acid and reagent water.

2.3Microbial Fuel Cell using a salt bridge:

Airtight plastic bottles with 1.5-liter volumes were utilized to create the dual-chamber MFC (anode and cathode chambers). Every bottle featured a side hole with a 1 cm radius that was linked to a Polyvinyl chloride (PVC) pipe positioned at a height of 9 cm from the bottom of the bottle (approximately at the midpoint). By warming 100 g of agar with 100 g of sodium chloride (NaCl) in a 1000 ml water bath, the liquid agar was permitted to cool and then transferred into a Polyvinyl chloride pipe, which was sealed at one end with a plastic cap and tape. The agar was permitted to solidify without interruption. The tubing made of Polyvinyl chloride, combined with the salt-agar mixture, was epoxy-secured between the two bottles and served as a salt bridge, facilitating proton transfer during the operation of the Microbial Fuel Cell. Copper electrodes measuring 7 cm in length, 5cm in width, and 0.3mm in thickness were utilized.

The separation between the two chambers was kept at distances of 5, 10, 15, 20, and 25 cm in the Microbial Fuel cell arrangement. The circuit was connected to the electrodes using copper wires. A digital multimeter measured the values of an external resistance (R) of 100, 200, 330, 470, 500, and 1000Ω. The gathered sample was analyzed using standard industry methods to monitor the biodegradation process within the Microbial Fuel Cell. Various parameters are utilized to assess the characteristics of wastewater.In this study, pH, total suspended solids, total dissolved solids, biological oxygen demand, chemical oxygen demand, dissolved oxygen, chlorides, sulfates, and other parameters were assessed to determine the efficiency of the Microbial Fuel Cell. A wastewater sample is collected and analyzed every 5 days to assess its different parameters. Voltage and current are measured with a multimeter throughout the operation.

Figure 01: MFC system during operation

3.0 RESULTS AND DISCUSSION:

A microbial fuel cell (MFC) represents a new form of renewable energy by generating electricity from materials typically regarded as waste, like industrial byproducts or wastewater. A microbial fuel cell functions as a biological reactor that converts the chemical energy found in organic compounds into electrical energy via the actions of microorganisms under aerobic conditions. In a microbial fuel cell, the anode and cathode are linked through an external circuit and divided by a proton exchange membrane. Anodic materials need to be electrically conductive, biocompatible, and chemically stable when in contact with the substrate. Noncorrosive stainless steel can be used to make metal anodes. Graphite plates or rods serve as the fundamental materials for anode electrodes due to their low cost, ease of handling, and distinct surface area. Graphite felt terminals are utilized to offer significantly greater surface areas. The influence of the salt extension concentration and the salt podium: The gathering of salt in the proton exchange membrane is especially crucial for moving the hydrogen particles. The initial segment of the study examined KCl and NaCl to determine their potential as strong salts in proton exchange membranes. The study clearly showed that there were rather small variations in current yield among these salts. Due to the isolated particles in the salt podium facilitating proton exchange through the salt podium, molar convergence is necessary. The salt expansion made with 10M NaCl yielded perfect results. It delivered a staggering current of 859 mA.

3.1 Effect of Dextrose dosage on Voltage, V

The purpose of this parameter is to investigate the influence of different dextrose dosages (1–10 g/L) on potential. For five days, the voltage generated in the MFC compartment was monitored. The voltage increased as the concentration of dextrose climbed from 1 to 6 g/L, and there was no change or rise in the voltage beyond 6 g/L dosage [9]. The voltage increased significantly from 245 to 671 mV, and additional increases in dextrose concentration had little effect on the voltage production. As a result, the ideal concentration of dextrose for future MFC investigations was determined to be 6 g/l.

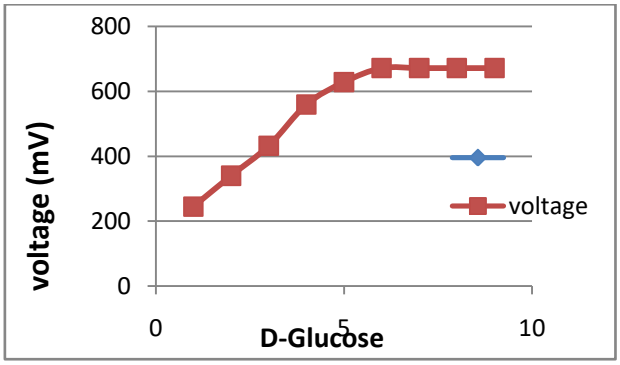

Figure 02: Variation of D-Glucose dosage

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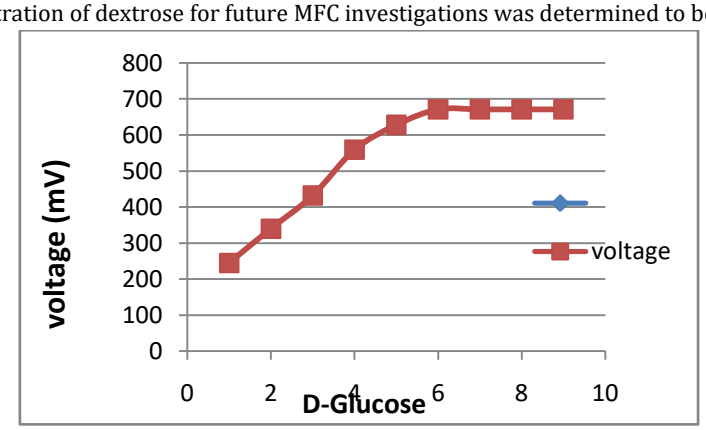

Figure 04: Variation of D-Glucose dosage

3.2 Effect of Ammonium Dihydrogen Orthophosphate on Voltage

The purpose of this parameter is to investigate the influence of different Ammonium hypophosphate dosages (5-10 g/L) on potential. For five days, the voltage generated in the Microbial Fuel Cell compartment was monitored. The voltage increased as

the concentration of ammonium phosphate increased from 0.5 to 7 g/L, and there was no change or increase in the voltage beyond 7 g/L dosage. The voltage increased significantly from 72 to 258 mV, while increasing the ammonium phosphate content did not boost the voltage production [10]. As a result, the ideal concentration of Ammonium phosphate for future MFC investigations was determined to be 7 g/l.

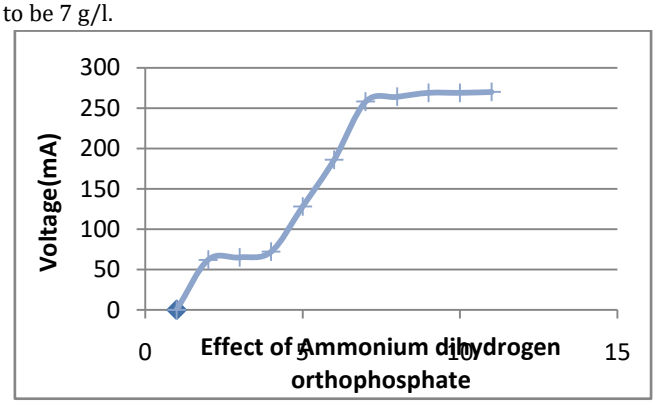

Figure 05: Variation of Ammonium dihydrogen ortho phosphate dosage

3.3 Effect of Agar AgarConcentration on Voltage

The goal of this parameter is to look at the effect of different Agar Agar concentration dosages (20–160 g/L) on potential. The voltage produced in the Microbial Fuel Cell compartment was measured during five days. When the concentration of Agar Agar was increased from 20 to 100 g/L, the voltage increased, but after 100 g/L dosage, there was little change or rise in the voltage. While raising the Agar Agar concentration did not raise the voltage output, the voltage increased dramatically from 330 to 680 mV. As a result, 100 g/L of Agar Agar concentration was judged to be the optimal concentration for further Microbial Fuel Cell experiments [11].

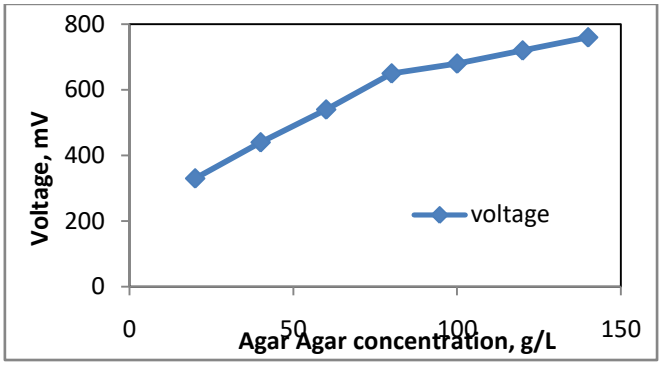

Figure 06: Variation of Agar Agar concentration with voltage

3.4 Effect of Salt Bridge Distance on Voltage

This parameter aims to see how different Salt Bridge distances (5–10cm) influence the potential. The voltage generated in the Microbial Fuel Cell compartment was measured over five days. As the concentration of the Salt Bridge distance increased from 5 to 10 cm, the voltage increased, but there was no change or decrease in the voltage beyond 10 cm dosage. The voltage increased significantly from 93 to 142 mV, while raising the Salt Bridge distance had a decreasing effect on the voltage output [12]. As a result, 10 cm of Salt Bridge distance was chosen to be the optimal concentration for further Microbial Fuel Cell study.

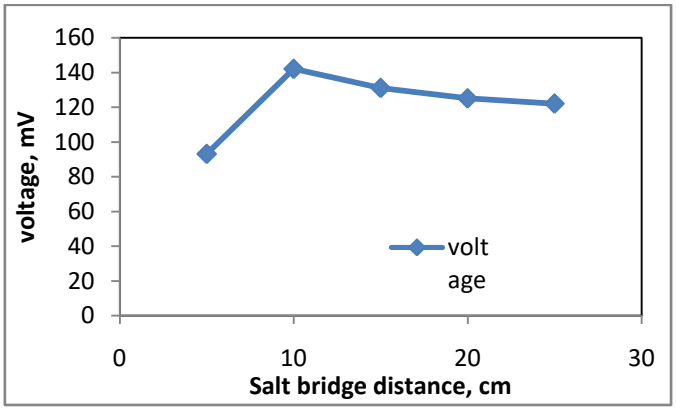

Figure 07: Variation of salt bridge distance with voltage

3.5 Effect of NaCl Concentration with Voltage

The objective of this parameter is to look at how varied NaCl concentration (20–160 g/L) affects the potential. The voltage generated in the Microbial Fuel Cell compartment was measured over five days. When the concentration of NaCl was increased from 20 to 100 g/L, the voltage increased, but there was no change or rise after a 10 mg/L dosage. The voltage increased significantly from 65 to 290 mV, while increasing the NaCl concentration had little effect on the voltage. As a result, the optimal NaCl concentration for future Microbial Fuel Cell studies has been established to be 100 g/L [14].

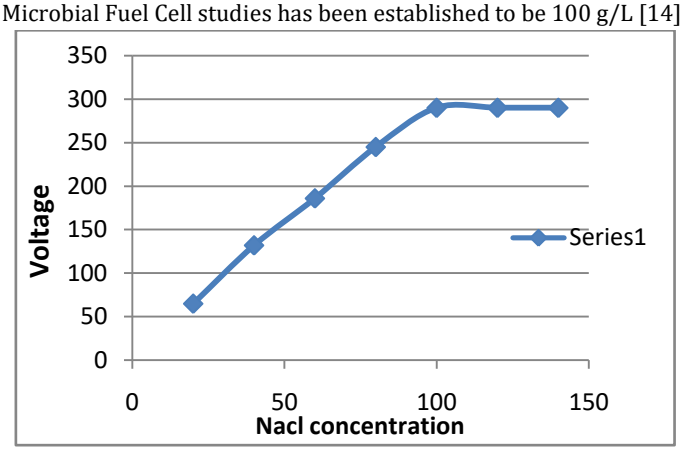

Figure 08: Variation of NaCl concentration with Voltage

3.6 Effect of Power Density:

The effect of Microbial Fuel Cell on Power density of the Dairy wastewater is illustrated in the Figure 24.17 The Power density increased from 1.29 mW/m² to 684.8 mW/m² **[15]** .

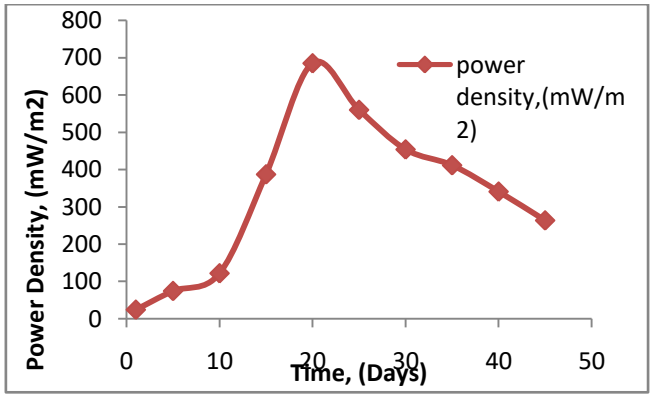

Figure 09:. Variation of Power density with time

3.7 Polarisation Curve:

A variable resistor box with a resistance range of 100 to 1000 Ω was used to conduct polarisation experiments. Voltage was measured in each sample when the cell reached the pseudo-steady state under the proper resistor value (typically after 1 min). For each external resistance load, the current density was estimated. The polarisation and power curves, respectively, demonstrate voltage and power output vs current density measured in the polarisation test. Figure 4.18 depicts the evolution of voltage and power density over time. The R^2 is 0.978 is near to 1,so the values coincide **[16]**.

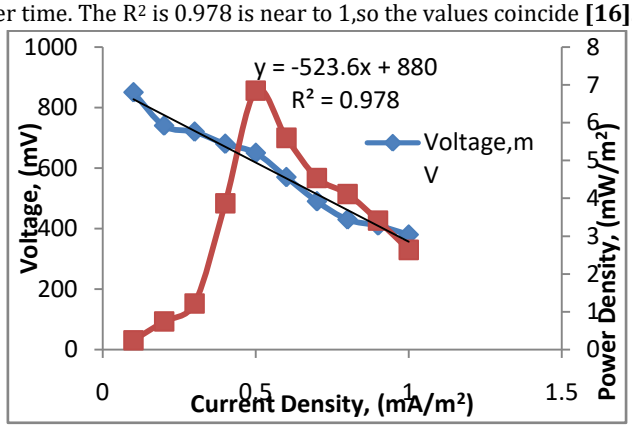

Figure 10: .Variation of Current and Power densities during Microbial Fuel Cell monitoring

3.8Effect of Resistor

Power yield was additionally assessed as an element of the outside obstruction event. The force yield fluctuated and wasnoticed for MFCsworking under 10, 47, 220, and 500 Ω separately. Indeed, even at higher current densities, the force yield was low, which showed that most of the substrate was not used for current. the increase of voltage values gradually slowed down when external resistance was further increased to 1000 Ω. Similar work is done by others [17].

10 Ohm Load Resistance

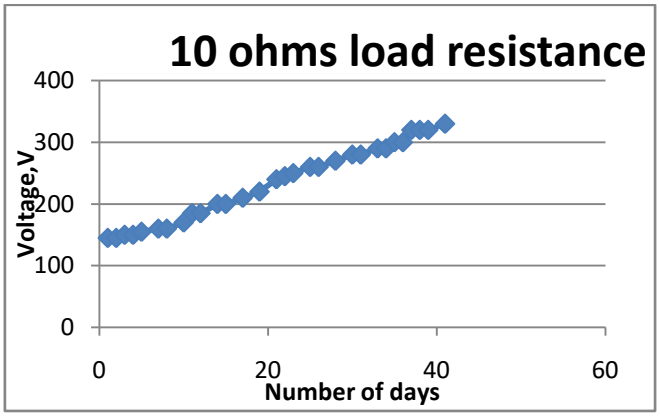

Figure 11(a): Plot for Number of Days vs Voltage

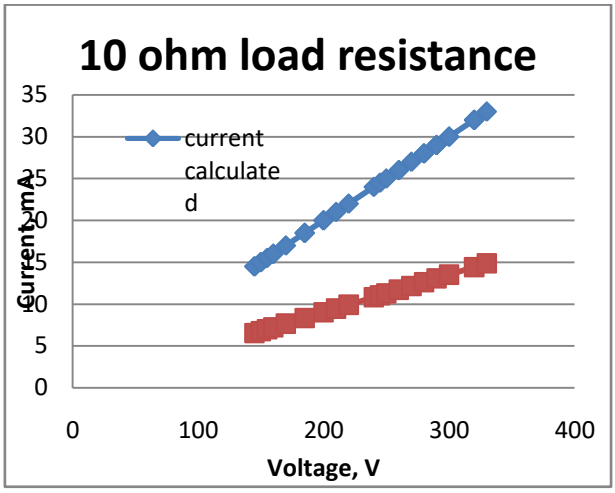

Figure 12 (b): Plot for Voltage vs Current

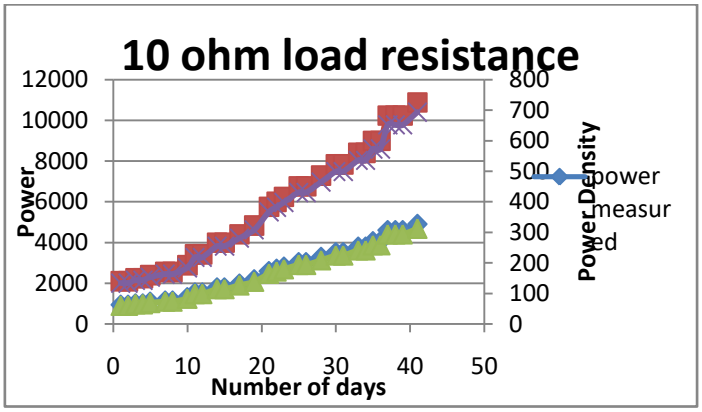

Figure 13 9(c): Polt for Number of Days vs Power and Power Density

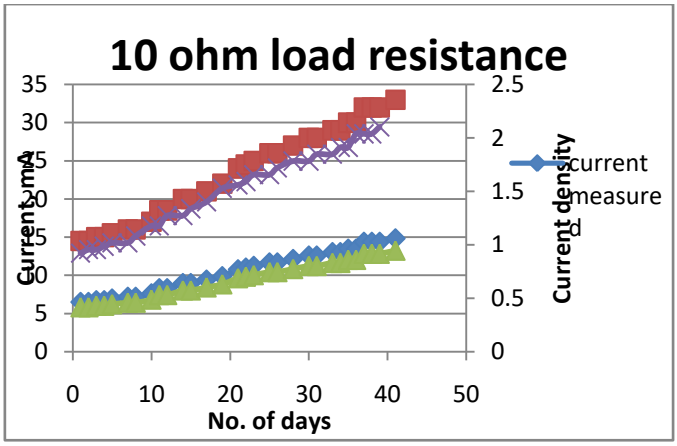

Figure 14 (d): Plot for Number of Days vs Current and Current Density

47 Ohm Load Resistance

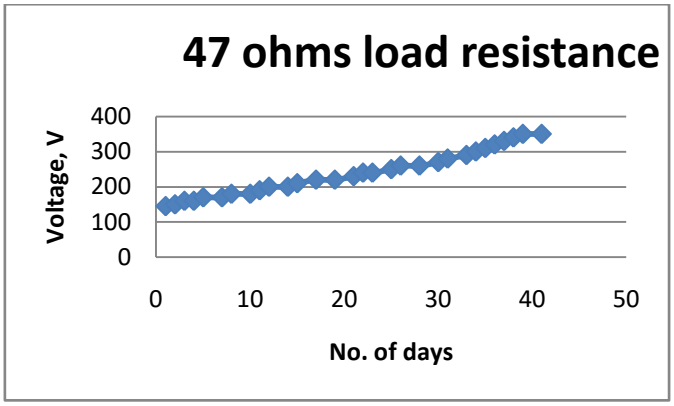

Figure 15 9(e): Plot for Number of Days vs Voltage

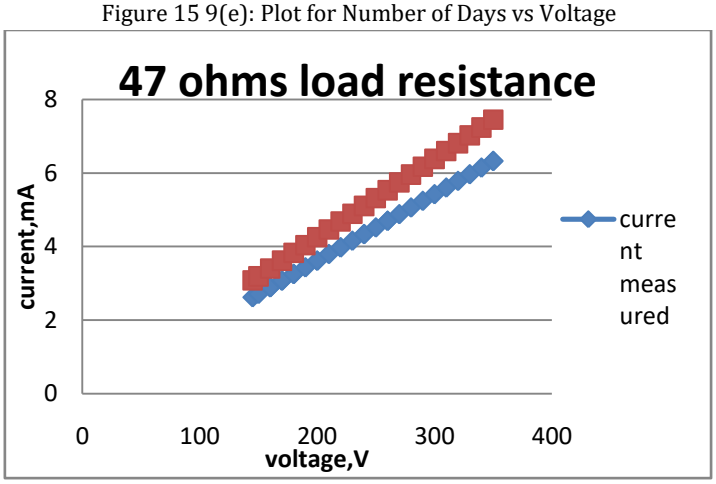

Figure 16 9(f): Plot for Voltage vs Current

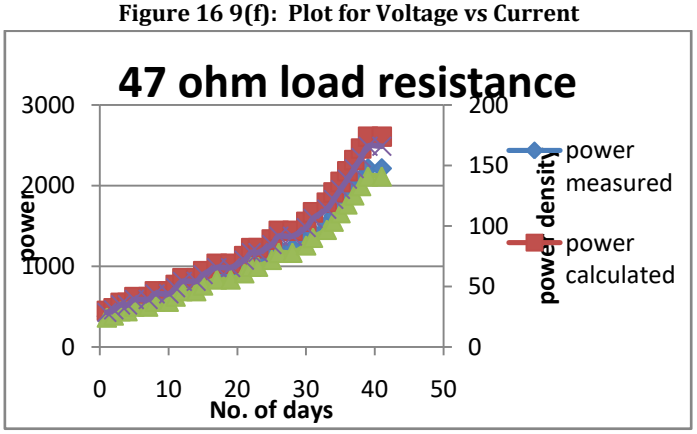

Figure 17(g): Polt for Number of Days vs Power and Power Density

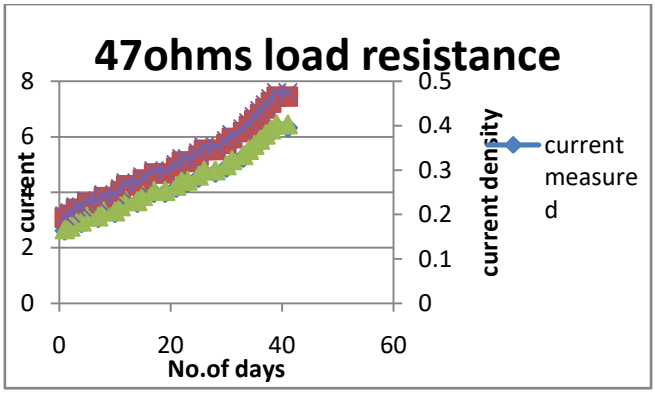

Figure 18(h): Plot for Number of Days vs Current and Current Density

220 Ohm Load Resistance

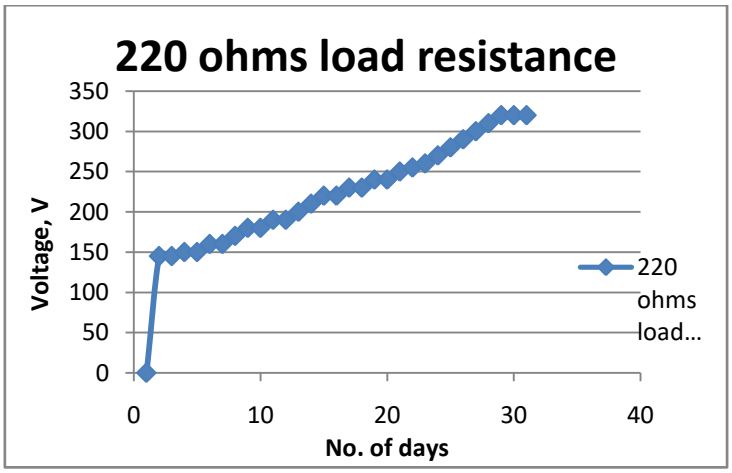

Figure 20(i): Plot for Number of Days vs Voltage

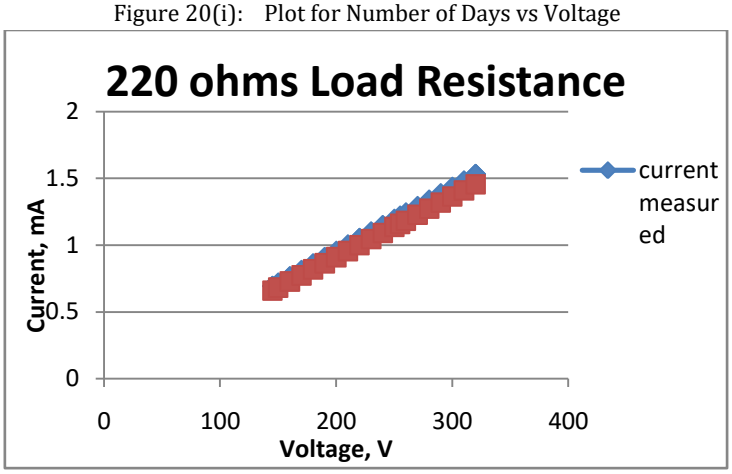

Figure 21(j): Plot for Voltage vs Current

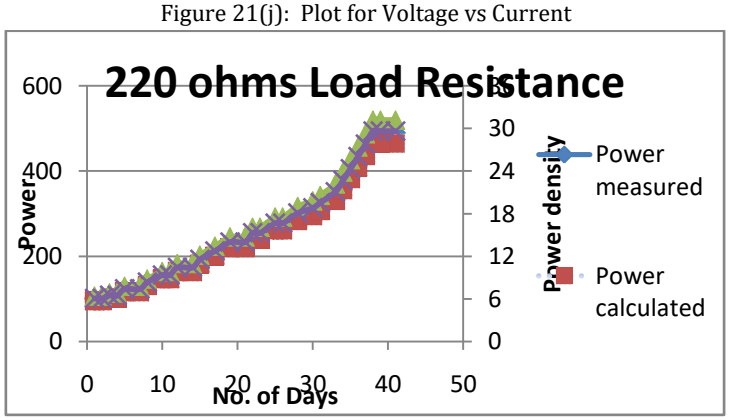

Figure 22(k): Polt for Number of Days vs Power and Power Density

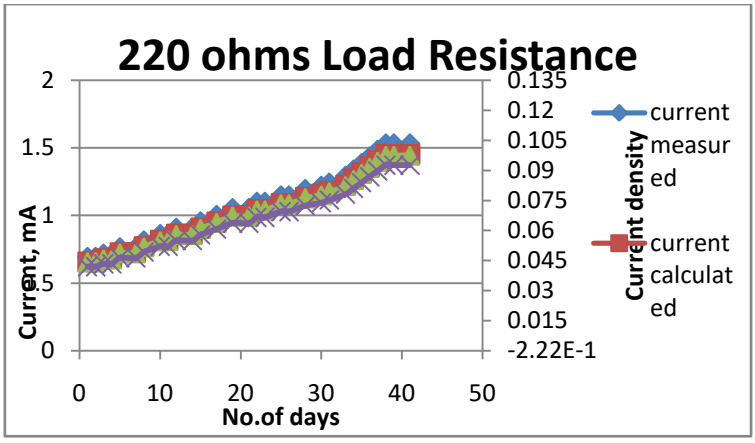

Figure 23(l): Plot for Number of Days vs Current and Current Density

500 Ohm Load Resistance

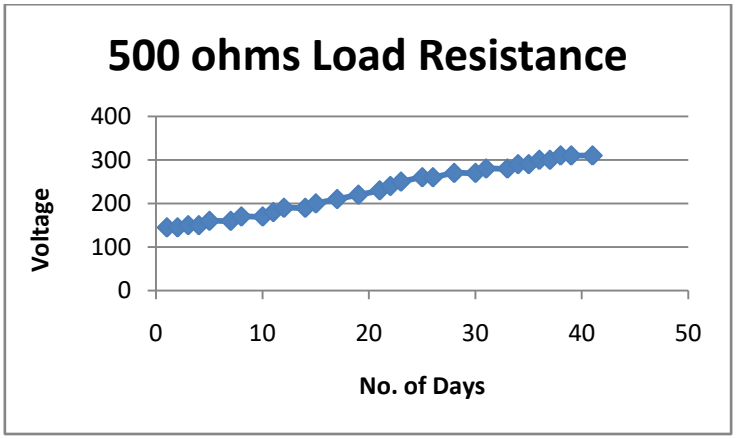

Figure 24(m): Plot for Number of Days vs Voltage

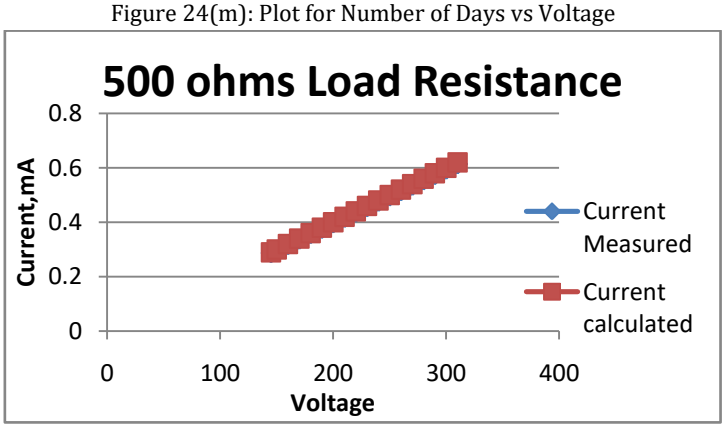

Figure 25(n): Plot for Voltage vs Current

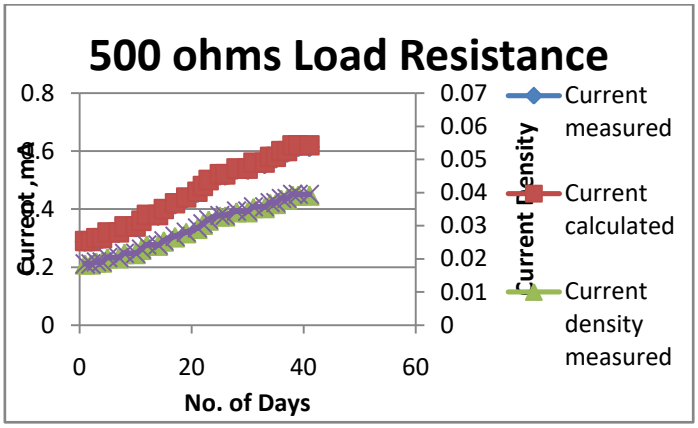

Figure 26(o): Plot for Number of Days vs Current and Current Density

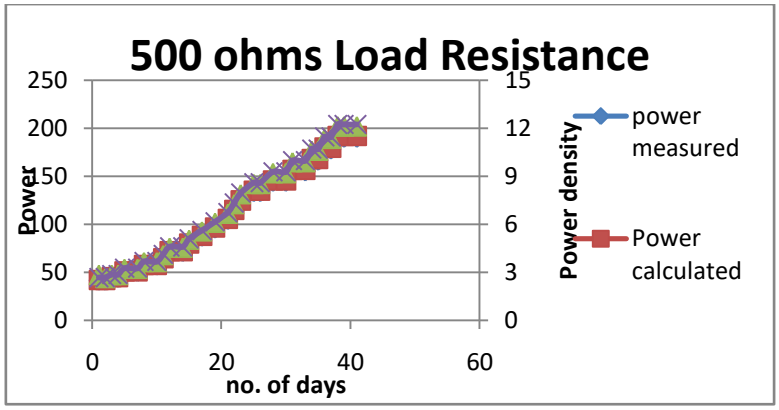

Figure 27(p): Polt for Number of Days vs Power and Power Density

The current produced grew over time as the resistance was raised from 10 to 500, with the greatest current being produced by the lowest resistance. The current slowly increased and stabilized after an initial dip as the resistance was raised from 220 to 500. The current took less time to stabilize after changing the resistance, but it took longer for the current to stabilize after making bigger resistance adjustments. As the resistance decreased from higher to lower, there was a significant rise in current.

4.0 Conclusions

The purpose of the study was to investigate the biological methods employed in wastewater treatment. This physical examination was chosen for Microbial Fuel Cells to improve the quality of wastewater. This MFC technology improves alternative energy sources, which is its major contribution. From a chemical engineering standpoint, it also provides an added benefit for environmental restoration by being useful for wastewater treatment and energy generation.

According to the experimental study, dairy wastewater is a viable substrate for microbial fuel cells, allowing for the simultaneous production of electricity and reduction of organic load. The MFC demonstrated consistent voltage and power output, demonstrating the system's viability for waste-to-energy conversion. According to the research, dairy effluent-powered MFCs are a promising decentralized approach for treating wastewater and producing renewable energy. Future research should concentrate on scaling up for real-world uses, improving electrode materials, and maximizing reactor designs.

5.0 Funding

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6.0 Acknowledgement

Nil

7.0 Informed Consent

Not Applicable

8.0 Ethical Statement

Not Applicable

9.0 References

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