



Combined Treatment and Power Generation from fertilizer waste water Using Microbial Fuel Cell

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ABSTRACT

The increasing environmental problem of fertilizer wastewater associated by high loads of pollutants, necessitates the microbial fuel cell innovative treatment technologies that not only mitigate pollution but also generate power. This research investigates the dual-purpose application of Microbial Fuel Cells (MFCs) for the combined treatment and power generation from fertilizer wastewater, offering a sustainable solution that integrates wastewater remediation with renewable energy production. The study explores the design, optimization, and performance evaluation of single- and dual-chamber microbial fuel cell systems using urea fertilizer wastewater as substrates. Key parameters including chemical oxygen demand (COD) removal efficiency, dissolve Oxygen, % ammonia and % Urea reduction, Current and power density were monitored under varying operational conditions (e.g., electrode materials, pH, temperature, retention time). Advanced electrochemical and microbiological techniques were employed to characterize the anodic biofilms and understand the dynamics of the electroactive microbial communities driving the simultaneous biodegradation and electron transfer processes. Result demonstrate that microbial fuel cell can achieve treatment of fertilizer wastewater (COD > 80%, ammonia > 70%) while generating stable output outputs up to 0.66MA and voltage of 0.91V, depending on reactor configuration and substrate concentration. The experimental result shows that Ammonia fertilizer plant effluent is one of the best substrates for energy generation in mfc. The integration of bio electrochemical systems with fertilizer industry effluents not only enhances wastewater treatment efficiency but also contributes to decentralized. This thesis provides a comprehensive analysis of the feasibility, challenges, and scalability of MFC technology for agro-industrial applications, contributing to the global pursuit of circular economy models and sustainable wastewater-energy nexus solutions.

Keywords:

Combined Treatment, From fertilizer, Microbial Fuel Cell

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INTRODUCTION

The need for alternative energy sources to fulfil the environmental friendliness goals in energy production and substitute the depleting fossil fuel reserves has seen active research and a variety of potential alternatives. Microbial Fuel Cells (MFCs) have emerged as a

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promising technology that can address both the energy and wastewater treatment challenges faced by the fertilizer industry. MFCs are bio-electrochemical devices that utilize microorganisms to catalyse the oxidation of organic compounds present in wastewater, generating electrical energy as a by-product. The unique synergy between wastewater treatment and energy generation within MFCs makes them an attractive option for sustainable industrial applications.

The microbial communities within MFCs, known as electrogenic bacteria, have the inherent capability to metabolize organic pollutants, breaking them down into simpler compounds and releasing electrons in the process. These electrons can be harnessed as electrical current, offering the potential for on-site power generation. Simultaneously, the microbial metabolism reduces the organic load in the wastewater, effectively treating it.

Since the global demand for sustainable and environmentally friendly energy sources has intensified in recent decades, driven by concerns about climate change, depleting fossil fuel reserves, and the desire to reduce greenhouse gas emissions. Concurrently, industries are under increasing pressure to adopt environmentally responsible practices, particularly in the treatment of wastewater, to mitigate their environmental impact. Among these industries, fertilizer production stands out as a significant consumer of energy and generator of pollution, particularly in the form of wastewater rich in organic contaminants.

Fertilizer plants play a vital role in modern agriculture by supplying essential nutrients to crops, thereby enhancing agricultural productivity. However, the production of fertilizers involves chemical processes that consume substantial energy and generate wastewater containing various pollutants, including high levels of organic matter, nitrogen compounds, and phosphates. The discharge of untreated or inadequately treated wastewater from fertilizer plants poses a severe threat to aquatic ecosystems and human health, primarily due to eutrophication and the release of harmful chemicals into water bodies.

Conventional wastewater treatment methods employed by fertilizer plants often require significant energy inputs and are associated with operational costs. These methods may not efficiently remove all organic contaminants and, in some cases, produce secondary waste streams that require further treatment or disposal. Thus, there is a pressing need to explore sustainable and cost-effective approaches to treat fertilizer plant wastewater while simultaneously harnessing the energy potential inherent in the organic matter within this wastewater.

Microbial fuel cells (MFCs) have emerged in recent years as a promising yet challenging technology. For decades, microbes that produce electricity were a biological curiosity. The idea of using microbial cells in an attempt to produce electricity was first conceived at the turn of the nineteenth century. M. C. Potter was the first to perform work on the subject in 1911 (Potter, 1911). Potter, a professor of botany at the University of Durham, managed to generate electricity from *E. coli*, however the work was not to receive any major coverage. In 1931 however Barnet Cohen drew more attention to the area when he created a number of microbial half fuel cells that, when connected in series, were capable of producing over 35 volts, though only with a current of 2 milliamps (Cohen, 1931).

Logan et al. (2006) reported that bacteria are most preferred microbes that can be used on MFCs to generate electricity while accomplishing biodegradation of organic matters or wastes. The first studies into the application of direct transformation of chemical into electrical energy by the exploitation of microbial processes arose during the 1970s. Mainly

because of the abundance of fossil oil and gas, it received only temporary attention. It was not until the 1990s, when interest in sustainable and renewable energy sources expanded, that the idea was revived and the research intensified.

However, the real interest in MFCs has tremendously grown in recent years, both in terms of number of researchers as well as the applications for these systems. Also, the reported electric current output from the MFCs has also increased tremendously over the recent years. Over the past years, MFCs as a new source of bio-energy have been extensively reviewed. These include information on the various terminology and measurements used in these systems (Logan et al., 2006), state of the art information on MFCs and recent improvements in MFC technologies (Du et al., 2007), comparison of MFCs with conventional anaerobic digestion (Pham et al., 2006), practical implementation of BESs (Rozendal et al., 2008), bio-anode performance in BES (Pham et al., 2009b), cathodic limitations in MFCs (Rismani-Yazdizadeh et al., 2008). The mechanism of external electron transfer from two main bacteria in BES studies, *Geobacter sulfurreducens* and *Shewanella oneidensis* was described in great detail by DeBabov (2008). 'Microbial fuel cells' (Logan, 2008) is another source of comprehensive information on MFCs. Logan (2009) presented the power densities for MFCs, normalized to electrode- projected surface areas reported over the years 1998–2008.

The two major challenges facing the world today are the growing demand for energy and ecologically and environmentally sound methods of waste disposal. These challenges were occasioned by rapid population growth and cumulative industrialization processes. Some current research, especially into microbial fuel cells has discovered that the organic wastes in our environment are not useless, but are rather valuable energy sources. The novel technological approach to facilitate direct conversion of waste water into usable energy is the microbial fuel cell.

Microbial fuel cell (MFC) is simply a device which converts biodegradable materials in waste waters, organic residues, sediments, and living plants directly into electricity. The recent global energy crisis has re-invigorated interests in Microbial Fuel Cells, MFCs, among academic researchers as a way to generate electric power from biomass without a net carbon emission into the ecosystem. This is basically why advanced research has been in top gear on how to generate sufficient and sustainable amount in order to meet the ever-increasing energy demand of our contemporary society.

Over the years, electrical energy has been generated by hydro, wind, nuclear, thermal and electromagnetic induction powered by fossil fuels in generators. The operations of these energy sources tend to introduce unfriendly materials into the environment which oftentimes arouse the attention and curiosity of environmental experts of how to curb this menace. Greenhouse gases such as oxides of carbon and nitrogen emanating from such devices attack the ozone layer thereby exposing the biomass to hazardous ultraviolet radiation which by implication may ultimately lead to the much-dreaded global warming. Microbial fuel cell (MFC), being a bi-functional device, has a great potential to offer solution to this global concern by generating direct electricity during biodegradation of organic matter. This feat in biotechnology not only produces 'green energy' for the world energy augmentation but also simultaneously treats the organic waste water hence saving the environment from perpetual degradation (Liu et al, 2004). MFC technology therefore holds a bright environmental future considering this possibility of producing power in an

environmentally safe and sustainable manner from renewable feed stock and hence reduces dependence on fossil fuels.

Microbial fuel cells (MFCs) convert organic waste including low-strength wastewaters and lignocellulosic biomass (plant biomass that is composed of cellulose, hemicellulose, and lignin) into electricity. Microbial production of electricity may become an important form of bio-energy in future because MFCs offer the possibility of extracting electric current from a wide range of soluble or dissolved complex organic wastes and renewable biomass. A large number of substrates have been explored as feed. The major substrates that have been tried include various kinds of artificial and real wastewaters and lignocellulosic bio-mass, hence a review of the various substrates that have been explored in MFCs so far, their resulting performance, limitations as well as future potential substrates. Some of the most common substrates and their influence on MFC performance are discussed below in detail.

(i) Acetate

Acetate is a simple substrate and it is extensively used as carbon source to induce electro-active bacteria (Bond et al., 2002). In order to benchmark new MFC components, reactor designs or operational conditions, acetate is commonly used as a substrate because of its inertness towards alternative microbial conversions (fermentations and methanogenesis) at room temperature (Aelterman, 2009). Further, acetate is the end product of several metabolic pathways for higher order carbon sources (including the Entner–Doudoroff pathway for glucose metabolism) (Biffinger et al., 2008).

When acetate was compared with a protein-rich wastewater as substrate in MFC, the MFC based on acetate-induced consortia achieved more than 2-fold maximum electric power, and one half of optimal external load resistance compared to the MFC based on consortia induced by a protein-rich wastewater (Liu et al., 2009). However, the protein-rich wastewater being a complex substrate provides the possibility of enriching more diverse microbial community than acetate. Having a more diverse microbial community helps to use various substrates or to convert complex organics to simpler compounds such as acetate which is used as electron donor for current production.

(ii) Glucose

Glucose is another commonly used substrate in MFCs. Kim et al.

(2000) reported that the performance of a MFC containing *Proteus vulgaris* depended on the carbon source in the initial medium of the microorganism and glucose initiated cells in MFC run for a short time period compared with galactose. Rabaey et al. (2003) re-ported that a maximum power density of 216 W/m³ was obtained from a glucose fed-batch MFC using 100 mM ferric cyanide as cathode oxidant.

In another study, the energy conversion efficiency (ECE) of acetate and glucose as substrates in MFC was compared (Lee et al., 2008). The ECE was 42% with acetate, but was only 3% with glucose which led to a low current and power density as well.

In a recent study by Chae et al. (2009), glucose-fed MFC generated the lowest CE as a result of electron loss by competing bacteria, but its relatively diverse bacterial structure enabled much wider substrate utilization and the greatest PD. The low CE was due to the fact that glucose is a fermentable substrate implying its consumption by diverse competing metabolisms such as fermentation and methanogenesis that cannot produce electricity. To explain the much wider substrate specificity of the glucose-enriched MFC than the others, Chae et al. (2009) proposed the presence of a more complex mixed consortium of diverse

electricigens or their syntrophic bacteria as a result of the production of diverse fermentation byproducts during glucose degradation.

(iii) Lignocellulosic biomass

The abundance and renewability of lignocellulosic materials from agricultural residues renders them a promising feedstock for cost-effective energy production (Huang et al., 2008). However, lignocellulosic biomass cannot be directly utilized by microorganisms in MFCs for electricity generation. It has to be converted to monosaccharides or other low-molecular-weight compounds (Ren et al., 2007). Electricity generation in MFCs from corn stover waste biomass using samples prepared through either neutral or acid steam-exploded hydrolysis processes that convert the hemicellulose to soluble sugars was explored by Zuo et al. (2006).

Maximum PDs using an air-cathode containing a diffusion layer and increased solution conductivity (20 mS/cm) were 371 mW/m² and 367 mW/m² for the neutral and acid hydrolysates (1000 mg COD/L, 250 X). Very recently, the use of raw corn stover as a substrate for electricity generation in a single-chambered MFC was demonstrated (Wang et al., 2009b) though the power output was much less than that with glucose as substrate.

(iv) Synthetic wastewater

Synthetic or chemical wastewater with well-defined composition is also used by several researchers as it is easy to control in terms of loading strength, pH and conductivity. Venkata Mohan et al. (2008a,b) have used synthetic wastewater at different loading rates in similar MFC configurations to achieve variable performances. Several media used for bacterial growth contains significant amount of redox mediators, such as cysteine, and high strength wastewater contains reduced sulfur species, which can work as abiotic electron donor and increase power production for a short while (Aldrovandi et al., 2009) thus not representing the true performance of the system. This can be avoided by using a minimal salt medium with a single electron donor such as glucose or acetate.

To check the influence of wastewater composition on the performance of MFC, Rodrigo et al. (2009) fed MFCs with two different synthetic wastewaters with the same organic pollutants (glucose and peptone) and same organic loading (315 mg/dm³) but with a different ratio of readily/slowly biodegradable substrate. The MFC fed with slowly biodegradable waste was more efficient in terms of electricity production probably due to the production of intermediates favoring electricity formation.

(v) Brewery wastewater

Wastewater from breweries has been a favorite among researchers as a substrate in MFCs, primarily because of its low strength. Besides, it is suitable for electricity generation in MFCs due to the food-derived nature of the organic matter and the lack of high concentrations of inhibitory substances (for example, ammonia in animal wastewaters) (Feng et al., 2008). Although the concentration of brewery wastewater varies, it is typically in the range of 3000–5000 mg of COD/L which is approximately 10 times more concentrated than domestic wastewater (Vijayaraghavan et al., 2006). It could also be an ideal substrate for MFCs due to its nature of high carbohydrate content and low ammonium nitrogen concentration.

Beer brewery wastewater treatment using aircathode MFC was investigated by Feng et al. (2008) and a maximum PD of 528 mW/m² was achieved when 50 mM phosphate buffer was added to the wastewater. In this case the maximum power produced by brewery

wastewater was lower than that achieved using domestic wastewater, when both wastewaters were compared at similar strengths. This might be due to difference in conductivities of two wastewaters.

Recently, Wen et al. (2009) using a model based on polarization curve for the MFC, reported that the most important factors which influenced the performance of the MFC with brewery wastewater were reaction kinetic loss and mass transport loss (both were 0.248 V when current density was 1.79 A/m²). These can be avoided by increasing the concentration of brewery wastewater and by increasing the reaction temperature and using a rough electrode to provide for more reaction sites.

(vi) Starch processing wastewater

Starch processing wastewater (SPW) contains a relatively high content of carbohydrates (2300–3500 mg/L), sugars (0.65–1.18%), protein (0.12–0.15%) and starch (1500–2600 mg/L), representing an important energy-rich resource, which can be potentially converted to a wide variety of useful products (Jin et al., 1998). SPW was used as a fuel to enrich a microbial consortium generating electricity and current generation (0.044 mA/cm²) was coupled to a fall in COD from over 1700 mg/L to 50 mg/L in 6 weeks (Kim et al., 2004). Lu et al. (2009) operated a MFC with SPW containing 4900 mg/L of COD over four cycles and obtained a maximum voltage output and power density of 490.8 mV and 239.4 mW/m² in the third cycle. However, the CE was only 7%. They attributed this low CE to oxygen diffusion to the anode compartment resulting in oxidization of other electron acceptors, biomass production and fermentation.

MFC consists of anode and cathode chambers separated by a proton exchange membrane (PEM). The anode chamber holds the substrate (fuel) while the cathode chamber contains a solution of an oxidizing agent. Being a system that operates on biological principles: every anaerobic degradation of organic matter occurring in the anode chamber is an oxidation process which leads to proton and electron recovery (power production), the electron thus produced are transferred to the anode in any of the following ways: using mediators produced by the bacteria; exogenous mediators (ones external to the cell) such as methylene blue, thionine, neutral red, etc.; or by direct transfer of electrons from electrochemically active bacteria cells (cytochromes) to the electrode. The latter case is often the basis for comparison between MFCs and the enzymatic fuel cells (EFCs), as the latter uses redox enzymes that do not take part in direct electron transfer but requires electron mediators (Scott and Murano, 2007). Mediator application became necessary due to the non-conducting nature of most of the microbial cell surfaces which by implication hampers the electron transfer efficiency. Mediators are, however, toxic and expensive and could adversely affect the growth and activity of the bacteria in the cell. This tendency often limits the commercial application potential of the MFC (Ghangrekar and Shinde, 2008). The electrons thus produced are transferred to the cathode via external circuit while the protons are transferred internally through the PEM. The cathode chamber being fully aerated contains an oxidizing agent which supplies the oxygen the eventually combines with the proton and electrons to form water.

Recently, a number of bacteria have been isolated based on their ability to transfer electrons to the anode (Du et al, 2007) in mediatorless MFCs, such bacteria may include: *shewanellaputrefaciens*, *GeobacterSulphureduciens*, *Geobactermetallireduciens* and

Rhodospirillum rubrum. The presence of these bacteria limits the use of mediators, thus increasing the commercial application potential of the MFC.

As a biological system, the pH is an important factor that determines which microorganisms are able to survive and operate in a particular environment, such as the anode chamber of the MFC. Most microorganisms prefer pH values that approximate that of distilled water (neutral, 7.0). This makes it imperative to stabilize a neutral pH in MFCs during operation.

In addition to the microorganisms that can transfer electrons to the anode, the presence of other organisms appear to benefit MFC performance. MFCs operated using mixed cultures gave substantially greater power densities than those with pure cultures (Rabaey et al, 2004). Mixed cultures are more suitable for water treatment, as single organism metabolize quite limited organic compounds (Kim et al, 2007) and this limits the power density.

Although the power outputs of MFCs are generally low and variable. Several research objectives have been geared at improving the MFC power output by employing various strategies. There are a number of reasons why less than perfect coulombic efficiency or low power might be observed in MFC: these include: the efficiencies of the anode and cathode as a measure of their electrode potentials, the presence of the competing electron acceptors and the microbial composition of the electrophilic community at the anode (Scott and Murano, 2007). In the same vein, the power performance of MFC can be attributed directly to the type of substrate used. For example, the use of ammonia fertilizer wastewater improves cell power density owing to the high concentration of organic matter compared to some other substrates such as domestic waste water or manure (Scott and Murano, 2007). Although the effluent has very high Chemical Oxygen Demand, COD₅, it is non-toxic because of high concentration of organic matter in it which consists mainly of protein.

In this research, efforts have been made to generate and improve the microbial fuel cell power performance by considering the use of agar-agar as a proton exchange membrane (PEM), the brine as the catholyte and the substrate (fuel) used was the effluent from ammonia fertilizer plant

Microbial fuel cells (MFCs) are amongst the potential alternative solutions to the energy dilemma. MFCs take advantage of the oxidation of organic compounds to produce electricity. Their advantages include combining bio-treatment of wastewater and electricity production, their environmental friendliness and ability to be used in remote areas.

However, the wide scale application and realistic scaling up of MFC to significantly substitute current fossil fuel energy generation techniques remain elusive. This is because of the requirement of large area of operation for meaningful power production, low power output due to internal resistances, poor reproducibility of the setups and expensive artificial/defined media for the anode chamber (Logan and Regan, 2006 a, b; Liu and Li, 2007).

Furthermore, the biology of microbial consortia involved is yet to be fully understood (Bullen et al., 2006). Despite the highlighted shortcomings, considerable progress has been made in electrode modifications to increase power output. Such efforts entail incorporation of nano particles and catalysts on the electrodes (Scott et al., 2007; Sharma et al., 2008; Nambiar et al., 2009; Tsai et al., 2009) and the used of cheap materials as electrode. While these efforts have yielded notable increases in power, the power remains insufficient to fill in the required credibility gap (Ieropoulos et al., 2005; Pant et al., 2010).

Hence, searching for cheaper substrates and high performing microorganisms can augment the current electrode modification effort. Think about use of waste and alternative microbial sources is ongoing (Asad et al., 2007; Pant et al., 2010) but the searching is not exhaustive. The prospect of simultaneous wastewater bio-treatment and electricity generation is attractive.

The relevance of Microbial Fuel Cells extends to various domains, ranging from environmental protection and sustainable energy production to scientific research and education. Their ability to simultaneously address environmental and energy challenges makes them a promising technology with broad applications and potential positive impacts on society and the environment.

As a matter of fact, harvesting electricity from organic waste through microbial fuel cell provides tremendous comparative advantages over the use of batteries. MFC makes use of organic waste which is carbon neutral and its oxidation only releases a little amount of carbon black into the atmosphere. According to Lovely (2003), MFC operation in energy production is an outstanding feat that is significantly different from the use of methanol-driven fuel cells. Abiotic fuel cells, such as hydrogen fuel cell, require high temperatures and expensive catalysts which are toxic, to promote oxidation of the electron donors. Contrary to this, MFC employs naturally occurring microorganisms to catalyze the oxidation of fuels (substrates) at room temperature and could also be potentially designed to function at any temperature at which the microorganism can still survive.

Microbial fuel cell can also be considered as a more suitable and promising alternative for harnessing of electrical energy from various organic substrates using different cell configurations and mechanisms of electron transfer. The renewed interest in this biological fuel cell is that they operate under mild reaction conditions, namely ambient temperature and pressure, and use inexpensive catalysts, i.e. microorganisms or enzymes which do not necessarily introduce greenhouse gases into the atmosphere. Apart from electricity generation, MFCs also find useful application as wastewater treatment facilities to break down organic matters and thereby helping to solve environmental issues.

Nevertheless, apart from MFC, another type of biological fuel cell is the enzymatic fuel cell. A problem with most redox enzymes is that they do not take part in direct electron transfer with conducting supports. Hence electron mediators are used for the electrical connection of the biocatalyst and the electrode. Several methods have thus been used to functionalize the electrode surface with layers consisting of redox enzymes, electrocatalysts and biocatalysts that promote electrochemical transformation at the electrode interface. An alternative to redox enzymes is the use of microorganisms in biological fuel cells which eliminates the isolation of individual enzymes, thereby providing cheaper substrates for biological fuel cells. The field of biological fuel cells including MFCs has been the subject of several reviews.

However, the technologies available in these recent times have not been able to provide sufficient power density that could power higher voltage electrical appliances. Hence considerable research work and enormous challenges are yet to be overcome to multi-disciplinary approach, especially by the combined effort of microbiology, electrochemistry and chemical engineering to develop MFCs as an alternative, economical and reliable technology that would satisfy the energy need of the contemporary society.

MFC serves a more suitable and sustainable alternative to electrical energy production over the use of the commonly applied electrochemical cells and batteries considering its numerous relative advantages. The operation of MFC involves the use of biochemical action of microorganisms on waste organic matter which is the effluent from the ammonia fertilizer plant, referred to as the substrate, to generate electricity. This is basically the idea behind the design and construction of microbial fuel cells (MFCs).

Statement of the problem

The discharge of untreated wastewater from fertilizer plant into the environment has adversely affected the ecosystem. Aquatic lives have become endangered; some are migrating, dying while others have gone into extinction. Global power supply for decades have come primarily from fossil fuel which is fast depleting and short supply now poses a problem to human development. It is expected that with improvements in technology and knowledge about these unique systems (MFC), the amount of electric current (and electric power) which can be extracted from these systems will increase tremendously providing a sustainable way of directly converting lignocellulosic biomass or wastewaters to useful energy, though the current and power yields are relatively low at present. Although research works have proven that it is possible to generate electricity from microorganism in wastewater, it has also been observed that the power generated from MFC has been very small and cannot be used efficiently for human activities.

If properly managed, waste management can furthermore be a significant source of environmental control and, in some ways, economic improvement. The environment will be safer, and most waste materials can be recycled with the correct technology, while others can be turned into commercially viable products. Today, however, the streets are littered with trash, and industrial effluents are released straight into the environment with little regard for the negative consequences. The potential of these wastes to better the global ecosystem is less important to this generation of engineers. If adequate research is not conducted to find a long-term remedy, this problem will likely worsen. Can industrial effluents be acted upon to meet national safe discharge or recyclable standards, and if so, how? Can available solid wastes, such as fruit waste that litter the environment, be put to greater use? Is it possible to save money by transforming the mounds of sludge formed during wastewater treatment into human-consumable items, so helping the economy? This dissertation will investigate the effective treatment of meat processing industrial wastewater and palm oil mill industrial effluent through coagulation using natural coagulants (papaya seeds and groundnut shells) and viable product formulation using post coagulation sludge to answer the questions raised above.

Aim and Objectives of the study

This research aims to achieve a sustainable solution that addresses both energy and environmental challenges by utilizing microbial fuel cell for power generation using fertilizer waste water and treatment of the fertilizer waste effluent

Human activities are dependent on energy. The present-day energy demands and the availability of fossil fuels for energy production around the globe are precarious, thus driving the quest for the alternatives to fossil fuels. A renewable source of power production such as Microbial Fuel Cell provides an alternative for the power production.

This research seeks to examine the following:

1. To generate bio-electricity from microorganisms inherent in ammonia fertilizer plant liquid effluent using microbial fuel cell in order to provide a renewable source of energy as an alternative to fossil fuel.
2. To investigate the efficiency of MFC in treatment of the effluent, if it could substitute the high cost treatment method employed by the company.
3. To analyze the strength and biodegradability of ammonia fertilizer plant liquid effluent as substrate to sustain a steady microbial oxidative action after a long time of MFC operation.
4. To examine how the electrical potential generated by MFC could be increased or controlled.
 5. To examine or identify the possible factors that could affect the operation of MFC with a view to meting out solutions to them.
 6. To design a low cost mediatorless MFC employing low cost materials which has the possibility of being implemented in the waste water treatment plant in the economic perspective.

The Significance of the study:

This project focuses on using fertilizer plant waste water as the substrate in the MFC and the possibility of extracting electric current from this soluble or dissolved complex organic wastes and renewable biomass. Hence, this project compares the bio-electricity generated from microorganism in the fertilizer plant waste water with the power generated from other substrates used by other researchers. Microbial Fuel Cells (MFCs) are significant areas of research and application with relevance in various fields due to their unique capabilities and potential benefits.

Here are some of the key areas where MFCs have relevance:

1. **Wastewater Treatment:**

MFCs are used to treat various types of wastewater, including domestic, industrial, and agricultural effluents. They offer a sustainable and energy-efficient approach to removing organic pollutants from water while simultaneously producing electricity. This is particularly relevant in regions with limited access to clean water and a need for eco-friendly wastewater treatment solutions.
2. **Renewable Energy Generation:**

MFCs have the potential to produce renewable energy from organic waste materials. They can be employed to harness energy from sources like municipal sewage, agricultural residues, and food industry by-products. This is relevant in the context of reducing greenhouse gas emissions and transitioning to clean energy sources.
3. **Remote and Off-Grid Applications:**

MFCs can provide power in remote or off-grid locations where access to a reliable electrical grid is limited. This is relevant for powering sensors, environmental monitoring systems, and small-scale devices in areas such as remote agriculture, wildlife conservation, and military operations.
4. **Environmental Monitoring:**

MFCs can be used as biosensors to monitor the health of ecosystems. They can detect changes in microbial activity, which can be indicative of environmental stressors like

- pollution or climate change. This is relevant for assessing and protecting natural resources.
5. **Bioremediation:**
MFCs can enhance bioremediation processes by promoting the growth of specific bacteria that can degrade pollutants more effectively in contaminated environments. This is relevant for cleaning up sites contaminated with oil, heavy metals, or organic pollutants.
 6. **Space Exploration:**
MFCs have been considered for use in space exploration missions. They can potentially generate electricity from organic waste materials, such as food waste, within closed-loop life support systems, reducing the need to transport energy sources from Earth
 7. **Education and Research:**
MFCs serve as valuable educational tools and research platforms. They allow students and scientists to study microbial metabolism, electrochemistry, and sustainable energy concepts. This is relevant for advancing scientific knowledge and training the next generation of researchers and engineers.
 8. **Sustainable Agriculture:**
MFCs can be integrated into agricultural systems to treat agricultural runoff, improve soil health, and promote sustainable farming practices. They can help reduce the environmental impact of agriculture by mitigating nutrient pollution and improving water quality.
 9. **Waste Valorisation:**
MFCs can convert organic waste materials into valuable products, such as electricity or biofuels. This can be relevant for reducing the volume of waste going to landfills and generating additional revenue streams from waste materials.
 10. **Carbon Capture and Utilization:**
MFCs have the potential to capture carbon dioxide (CO₂) emissions and convert them into useful products through microbial processes. This is relevant in the context of mitigating climate change and developing carbon utilization technologies.
 11. **Biotechnology and Pharmaceuticals:**
Microbial Electrochemistry: MFCs have applications in biotechnology and pharmaceuticals, including microbial biosensors and the study of electroactive microorganisms for bio electrochemical processes.
 12. **Sustainable Development Goals (SDGs):**
SDG Alignment: MFCs contribute to several United Nations Sustainable Development Goals, including Goal 7 (Affordable and Clean Energy), Goal 6 (Clean Water and Sanitation), and Goal 9 (Industry, Innovation, and Infrastructure).

METHODOLOGY

This chapter outlines the materials and methods used to design, fabricate, and operate the microbial fuel cell (MFC) for combined treatment and power generation from fertilizer wastewater. The materials selected for the construction of the MFC are described, along with their specifications and sources. The methodology section provides a detailed account

of the experimental setup, procedures, and techniques employed to achieve the objectives of this study.

Materials

The materials used in this study include:

1. Structural Components: Plastic bottles, PVC pipes, and flanges for constructing the MFC chambers.
2. Electrodes and Conductive Materials: Charcoal and flexible wire for the anode and cathode.
3. Chemicals and Reagents: Agar agar, salt, and distilled water for preparing the electrolyte and other solutions.
4. Adhesives and Sealants: Epoxy for sealing and bonding components.

Wastewater Sample: Ammonia fertilizer plant effluent collected from Notore Chemicals Industry Limited, Onne, Rivers State

Microbial fuel cells consist of various materials which include:

S/NO	Materials	Quantity	Make	Specification
1	Plastic bottle	10	Dana plast, Nigeria	5.0L
2	Plastic pipe (PVC)	5	Tigre, Nigeria	1 inch
3	Plastic Flanges	10	Tigre, Nigeria	32 × 1"
4	Agar agar	20g	Hack, UK	Powering
5	Salt	300g	Dangote Salt, Nigeria	-----
6	Flexible Wire	3 yrds	Sunshine wire, Nigeria	-----
7	Charcoal	450g	Prepared Locally	610°c
8	Epoxy	4		
9	PVC Trunking	10		
10	Cement	250g	Dangote cement, Nigeria	
11	Distilled Water	25L	Condensed water from Air-conditioner	
12	Ammonia fertilizer plant effluent	25L	Notore Chemicals Industry Limited, onne, Rivers State.	

The table lists the equipment used in an experiment or study, along with their quantities and specifications.

1. S/N: Serial number, a unique identifier for each equipment.
2. Equipment: The name of the equipment used, such as Autoclave, Multi-meter, pH Meter, etc.
3. Quantity: The number of units of each equipment used.
4. Make/Specification: The manufacturer or specific model of the equipment, where applicable.

The table includes a range of equipment, including:

1. Laboratory equipment (e.g., Autoclave, Conical Flask, pH Meter)
2. Measurement instruments (e.g., Multi-meter, Thermometer, Weighing Balance)
3. General-purpose tools (e.g., Razor, Masking Tape)

The table provides a concise overview of the equipment used in the study, which can be useful for:

1. Understanding the methodology
2. Identifying potential sources of error or variation

S/NO	Equipment	Quantity	Make	Specification
1	Autoclave	1		
2	Multi-meter	1	ALDA, DT-830D	
3	Masking Tape	1		
4	Razor	1		
5	Measuring Cylinder	1		
6	Conical Flask	1		
7	pH Meter	1	Hanna Instrument, M12151	
8	Thermometer	1		
9	Weighing Balance	1		

Materials Collection

- a. Gather all necessary materials, including PVC pipes, flanges, epoxy, ethanol, and masking tape.
- b. Ensure the materials are of high quality and suitable for the experiment.

Salt Bridge Assembly

- a. Cut 1-inch diameter PVC pipes into 5 pieces, each 0.08m long.
- b. Fix PVC sockets (flanges) to both ends of each pipe using epoxy, resulting in a new length of 0.103m.
- c. Sterilize each pipe with ethanol to eliminate microorganisms.
- d. Seal the open ends with masking tape to maintain sterility.

Best Practices

- a. Clearly define your research objectives and methodology.
- b. Ensure proper documentation and presentation of findings.
- c. Use established standards for quality and integrity in research.
- d. Consider potential limitations and biases in your study .

Additional Considerations

- a. Research Ethics: Ensure your research complies with ethical standards, particularly when working with microorganisms.
- b. Data Analysis: Plan your data analysis approach to extract meaningful insights from your experiment.
- c. Result Interpretation: Interpret your results in the context of existing literature and research

Procedure for Proton Exchange Membrane (PEM) Preparation

The following steps outline the procedure for preparing the PEM:

1. Agar Solution Preparation:
 - a. Dissolve 40g of agar in 1L of distilled water.
 - b. Add 7.5g of salt to the agar solution.
2. Sterilization:

- a. Autoclave the agar mixture at 121°C for 15 minutes to ensure sterility.
3. PEM Fabrication:
 - a. Seal one end of the PVC pipe.
 - b. Pour the warm agar/salt mixture into the PVC pipe before it thickens.
 - c. Allow the agar/salt mixture to cool and solidify for approximately 30 minutes.
4. Assembly:
 - a. Cut open the sides of the plastic bottles to create holes for the PEM.
 - b. Fix the PEM into the holes on the bottles.
 - c. Epoxy end caps or flanges to the sides of the PVC pipe.
 - d. Allow the epoxy to harden completely.

By following this procedure, a functional PEM can be prepared for use in microbial fuel cells. The PEM plays a crucial role in facilitating ion exchange between the anode and cathode chambers, enabling the generation of electricity

Preparing the Charcoal

The charcoal used in this study was prepared from Mahogany wood, which was purchased from the market. The wood was converted into charcoal through a controlled burning process in a laboratory furnace at a temperature of approximately 610°C.

This process involved the following steps:

1. Pyrolysis: The Mahogany wood was heated in the absence of oxygen, resulting in the decomposition of the wood into charcoal.
2. Temperature Control: The furnace temperature was maintained at around 610°C to achieve the desired level of carbonization.
3. Charcoal Formation: The resulting charcoal was collected and used as the electrode material in the microbial fuel cell.

The use of charcoal as an electrode material can offer several benefits, including:

- a. High Surface Area: Charcoal has a high surface area, which can enhance the electrochemical reactions occurring at the electrode.
- b. Conductivity: Charcoal can exhibit some level of electrical conductivity, making it suitable for use as an electrode material

Preparing the electrodes



Figure 1: Formation and preparation of the electrode.

- a. Grind charcoal to have a fine powder
- b. Mix the charcoal fine powder with cement at the ratio of 2:1

- c. Add a small quantity of water of about 130ml
- d. Cut the PVC trunking to the desired length (24.2cm)
- e. Lubricate with oil (vegetable oil) the inside of the PVC trunking to allow easy removal of the electrode when it solidifies
- f. Pour the charcoal into the mould (PVC trunking), insert a flexible wire into it and allow it for about 48 hours to get strong



Figure 2: Lubricate electrode with multimeter

- a. Test the electrode with multimeter – there should be a small amount of resistance between a point on the electrode and the end of the wire opposite the electrode
At anode, pass the electrode through a hole in the bottle lid and seal with epoxy.
Cathode chamber does not necessarily need a lid.
- 1) Assemble MFC



Figure 3: connect salt bridge with two plastic bottles and the use epoxy

Two plastic bottles with lids for anode and cathode respectively were drilled from the side with about 1inch diameter of the hole. Ion exchange membrane was fixed with one end connected to the anode chamber and the other connected to the cathode chamber. Epoxy was used to seal and firmly fixed the IEM to the chambers. After about 3 hours, water was used to check for leakages. Holes of about 0.015m were made on the lids for electrodes.

Running the MFC

- b. Add the Ammonia fertilizer plant effluent to the anode chamber
- c. Add conductive solution to the cathode chamber (salt water – 300g of salt is dissolved in 25litres of water)
- d. Insert electrode into the anode and cathode chambers.
- e. Connect external load (light emitting diode), and start measuring voltage.

After all preparations were done, the Ammonia fertilizer plant effluent was poured into the 5.0L anode chamber. The anode was covered and sealed to prevent oxygen from entering. The anode chamber must be anaerobic.

The cathode chamber (the oxidant) was filled with the catholyte (brine) and was not sealed but partially covered to allow enough oxygen which helps in oxidation.

Collection of anolytes

The ammonia fertilizer plant liquid effluent which is the anolyte (substrate), was collected from Notore chemicals industry limited, Onne, Port-Harcourt, Rivers State.

Preparation of the catholyte

The cathode chamber is the oxidant chamber which uses brine as the proton's acceptor. The catholyte was prepared by dissolving 300.00g of the salt in 25liters of distilled water and stirred very well to completely dissolve. The prepared catholyte was poured into each of the cathode chambers of the three set-ups.

CELL SETUP

The anode chamber containing Ammonia fertilizer plant effluent was connected through flexible wires with light emitting diode (LED) to the cathode chamber containing brine. The two chambers were linked with a salt bridge inter-connection. The microbial fuel cell voltage for each set-up was monitored daily using a digital multi-meter. Reading of voltage and current was done within few minutes of stabilization.

Important Hints for Operating your MFC

1. Oxygen must be kept out of the anode chamber
2. For long term operation, electrodes should be constructed in a way that limits corrosion of copper wire due to contact with liquid
3. Power can be significantly increased by using a catalyst (typically platinum) on the cathode. Note: Platinum is expensive

Calculation of Charcoal Electrode Surface Area

The surface area of the charcoal electrode was calculated as follows:

- a. Width: 1.5 cm = 0.015 m
- b. Length: 24.2 cm = 0.242 m

The surface area (A) of the electrode was calculated using the formula:

$$\begin{aligned} A &= \text{Length} \times \text{Width} \\ &= 0.242 \text{ m} \times 0.015 \text{ m} \\ &= 3.63 \times 10^{(-3)} \text{ m}^2 \end{aligned}$$

Therefore, the surface area of the charcoal electrode is $3.63 \times 10^{(-3)} \text{ m}^2$.

This calculation provides the surface area of the electrode, which is an important parameter in electrochemical reactions. The surface area can influence the rate of reaction, current density, and overall performance of the microbial fuel cell.

RESULT AND DISCUSSION

Experimental Conditions

The experiments were conducted at laboratory room temperature, typically around 25°C, during daytime tests. The cells were subjected to overnight cooling when the laboratory heating was switched off. Due to equipment constraints and the simultaneous testing of multiple cells, it was impractical to maintain a constant temperature. However, this approach allowed for testing under conditions that mimic potential practical applications of microbial fuel cells (MFCs) using waste, which would likely involve variable temperatures.

Experimental Setup

The fuel cell was configured as a battery to establish power output without concerns about fuel delivery. This setup enabled the evaluation of the MFC's performance under various conditions.

Key Findings

The results of this study demonstrate that industrial wastewaters, particularly Ammonia Fertilizer Plant Effluent, can be a potential substrate for bioelectricity generation. The MFC technology offers a promising approach for efficient and cost-effective wastewater treatment, which could offset the expensive technologies currently employed by many industries. Furthermore, the use of cheaper and locally sourced materials can replace expensive components in MFCs

Power Output Results

The power output results from five different MFC setups with a salt bridge are presented below:

Cell	Power Density (mW/m ²)	Current Density (mA/m ²)
1	120.3306	146.0055
2	113.0579	148.7603
3	134.5455	181.8182
4	108.9807	126.7218
5	124.1047	146.0055

The results indicate that Cell 3 produced the highest power density of 134.5455 mW/m² and current density of 181.8182 mA/m². These findings suggest that Ammonia Fertilizer Plant liquid effluent is a suitable substrate for MFCs

The results of this study have significant implications for the development of sustainable and cost-effective wastewater treatment technologies. The use of MFCs can provide a novel approach for generating bioelectricity while treating wastewater, offering a promising solution for industries seeking to reduce their environmental footprint



Figure 3:1. Photograph showing voltage taken on the 14th day from cell

Figure 3.1: Voltage Measurement on the 14th Day

This figure shows a photograph of the voltage measurement taken from one of the microbial fuel cells (MFCs) on the 14th day of operation.

- a. Voltage Reading: The photograph captures the voltage reading on the multimeter, which indicates the electrical potential difference generated by the MFC.
- b. Cell Performance: The voltage measurement provides insight into the performance of the MFC, with higher voltages typically indicating better performance.
- c. Experimental Data: This figure represents a snapshot of the experimental data collected during the study, which can be used to analyze the trends and patterns in the MFC's performance over time.



Figure 3:2. Photograph of five cells set-up during operation

Figure 3.2: Experimental Setup of Five Microbial Fuel Cells

This figure shows a photograph of the experimental setup of five microbial fuel cells (MFCs) during operation.

- MFC Configuration: The photograph depicts the five MFCs set up in the laboratory, each consisting of anode and cathode chambers connected by a salt bridge.
- Experimental Conditions: The image provides a visual representation of the experimental conditions under which the MFCs were operated, including the laboratory setting and equipment used.
- Comparative Analysis: The simultaneous operation of five MFCs allows for comparative analysis of their performance, enabling the identification of trends and patterns in the data

Table 4.1 Result Data Table Experimental Setup of Five Microbial Fuel Cells

Reactor Configuration			Substrate	Ammonia fertilizer Plant Effluent		
Chamber	Single	Dual	Catholyte	Salt Water(Brine)		
		√/	Electrode Type	Cathode	Anode	
Parameters	Start	End		Charcoal	Charcoal	
pH	8.29	6.72	Open Circuit			
Temperature	26°C		Close circuit	√/		
Conductivity	330μs	3360μs	Startup Date	13/04/2025		
% Urea	287.5ppm	0.55ppm	Electrode Size	3.62×10 ⁻³ m ²		
% NH ₃	1381ppm	222ppm				
BOD	715mg/L					
	266mg/L					

COD	949mg/L 61.6mg/L						
Date	CELL 1 (One)			CELL 2 (Two)			
	Days	Voltage (V)	Current (mA)		Days	Voltage (V)	Current (mA)
13/04/2025	1	0.36	0.04		1	0.41	0.22
14/04/2025	2	0.44	0.08		2	0.45	0.18
15/04/2025	3	0.54	0.12		3	0.48	0.19
16/04/2025	4	0.56	0.10		4	0.46	0.23
17/04/2025	5	0.43	0.15		5	0.49	0.20
18/04/2025	6	0.52	0.16		6	0.51	0.24
19/04/2025	7	0.41	0.14		7	0.53	0.25
20/04/2025	8	0.53	0.16		8	0.55	0.26
21/04/2025	9	0.55	0.18		9	0.54	0.35
22/04/2025	10	0.38	0.21		10	0.60	0.32
23/04/2025	11	0.59	0.20		11	0.61	0.36
24/04/2025	12	0.70	0.22		12	0.59	0.36
25/04/2025	13	0.88	0.36		13	0.55	0.38
26/04/2025	14	0.89	0.4		14	0.68	0.39
27/04/2025	15	0.91	0.48		15	0.77	0.40
28/04/2025	16	0.81	0.45		16	0.81	0.37
29/04/2025	17	0.61	0.53		17	0.89	0.41
30/04/2025	18	0.44	0.39		18	0.82	0.43
01/05/2025	19	0.55	0.20		19	0.80	0.42
02/05/2025	20	0.78	0.18		20	0.83	0.46
03/05/2025	21	0.71	0.19		21	0.76	0.54
04/05/2025	22	0.62	0.32		22	0.69	0.51
05/05/2025	23	0.55	0.4		23	0.61	0.53
06/05/2025	24	0.61	0.3		24	0.55	0.59
07/05/2025	25	0.57	0.22		25	0.48	0.56
08/05/2025	26	0.52	0.24		26	0.50	0.51
09/05/2025	27	0.47	0.24		27	0.45	0.52
10/05/2025	28	0.38	0.23		28	0.41	0.44
11/05/2025	29	0.31	0.19		29	0.37	0.35
12/05/2025	30	0.25	0.19		30	0.32	0.30

This table presents the results of an experiment conducted on two microbial fuel cells (MFCs), labeled as Cell 1 and Cell 2. Here's a breakdown of the table:

Reactor Configuration and Operating Conditions

- a. Substrate: The MFCs were fed with Ammonia Fertilizer Plant Effluent.
- b. Chamber: The reactor configuration is a single chamber for both cells.
- c. Catholyte: Salt Water (Brine) was used as the catholyte.
- d. Electrode Type: Both the anode and cathode were made of charcoal.

- e. Electrode Size: The electrode surface area was $3.62 \times 10^{-3} \text{ m}^2$.

Initial and Final Parameters

- pH: The pH decreased from 8.29 to 6.72 over the course of the experiment.
- Temperature: The temperature was around 26°C.
- Conductivity: The conductivity increased from 330 μS to 3360 μS .
- Urea and Ammonia Removal: The MFCs showed a significant reduction in urea and ammonia concentrations.

Performance Data

- Voltage and Current: The table presents the voltage and current output of both Cell 1 and Cell 2 over a period of 30 days.
- Trends: The data shows fluctuations in voltage and current output over time, with some days showing higher performance than others.

Key Observations

- Variability: The performance of both cells varied over time, with some days showing higher voltage and current output than others.
- Comparison: Cell 2 generally showed higher voltage and current output than Cell 1, especially towards the end of the experiment

Table 2: Results Cell 3, Cell 4, Cell 5

Days	CELL 3 (Three)		CELL 4 (Four)			CELL 5 (Five)		
	Voltage (V)	Current (mA)	Days	Voltage (V)	Current (mA)	Days	Voltage (V)	Current (mA)
1	0.37	0.32	1	0.35	0.14	1	0.37	0.30
2	0.37	0.33	2	0.39	0.15	2	0.38	0.30
3	0.38	0.30	3	0.43	0.10	3	0.35	0.27
4	0.43	0.31	4	0.40	0.13	4	0.35	0.32
5	0.40	0.33	5	0.39	0.13	5	0.40	0.36
6	0.43	0.42	6	0.39	0.17	6	0.45	0.41
7	0.48	0.42	7	0.41	0.20	7	0.43	0.40
8	0.53	0.46	8	0.43	0.19	8	0.46	0.40
9	0.56	0.49	9	0.44	0.20	9	0.48	0.38
10	0.60	0.54	10	0.43	0.22	10	0.54	0.45
11	0.61	0.58	11	0.45	0.25	11	0.56	0.42
12	0.66	0.62	12	0.42	0.26	12	0.55	0.44
13	0.74	0.66	13	0.50	0.35	13	0.52	0.50
14	0.80	0.50	14	0.55	0.37	14	0.58	0.52
15	0.83	0.46	15	0.59	0.37	15	0.62	0.51
16	0.82	0.44	16	0.64	0.40	16	0.66	0.51
17	0.85	0.40	17	0.71	0.39	17	0.71	0.54
18	0.81	0.37	18	0.80	0.41	18	0.77	0.58
19	0.79	0.41	19	0.86	0.46	19	0.85	0.53
20	0.75	0.41	20	0.81	0.35	20	0.83	0.50
21	0.70	0.43	21	0.75	0.35	21	0.79	0.38
22	0.66	0.40	22	0.67	0.32	22	0.81	0.39
23	0.61	0.38	23	0.61	0.25	23	0.74	0.42

24	0.55	0.31		24	0.54	0.28		24	0.69	0.41
25	0.58	0.35		25	0.49	0.29		25	0.67	0.43
26	0.51	0.37		26	0.44	0.27		26	0.61	0.44
27	0.47	0.34		27	0.48	0.25		27	0.58	0.39
28	0.41	0.32		28	0.46	0.22		28	0.53	0.37
29	0.37	0.30		29	0.41	0.23		29	0.49	0.33
30	0.33	0.30		30	0.40	0.21		30	0.44	0.32

This table presents the performance data of three additional microbial fuel cells (MFCs), labeled as Cell 3, Cell 4, and Cell 5. Here's a breakdown of the data:

Performance Trends

- a. Voltage and Current: The voltage and current output of each cell varied over the 30-day period, with some cells showing more stable performance than others.
- b. Peak Performance: Cell 3 showed the highest peak voltage (0.85 V) and current (0.66 mA), while Cell 4 had a more stable but lower performance.

Comparative Analysis

- a. Cell 3: Showed the highest voltage and current output among the three cells, with a peak power output on day 17.
- b. Cell 4: Had a more stable performance, but with lower voltage and current output compared to Cell 3 and Cell 5.
- c. Cell 5: Showed a consistent increase in voltage and current output over the first 20 days, followed by a gradual decline.

Key Observations

- a. Variability: The performance of each cell varied over time, with some days showing higher voltage and current output than others.
- b. Differences: The three cells showed distinct performance trends, suggesting differences in their operating conditions, electrode properties, or microbial communities.

This data can be used to:

- a. Compare the performance of different MFC configurations or operating conditions.
- b. Identify trends and patterns in MFC performance over time.
- c. Optimize MFC design and operating conditions for improved performance and stability.

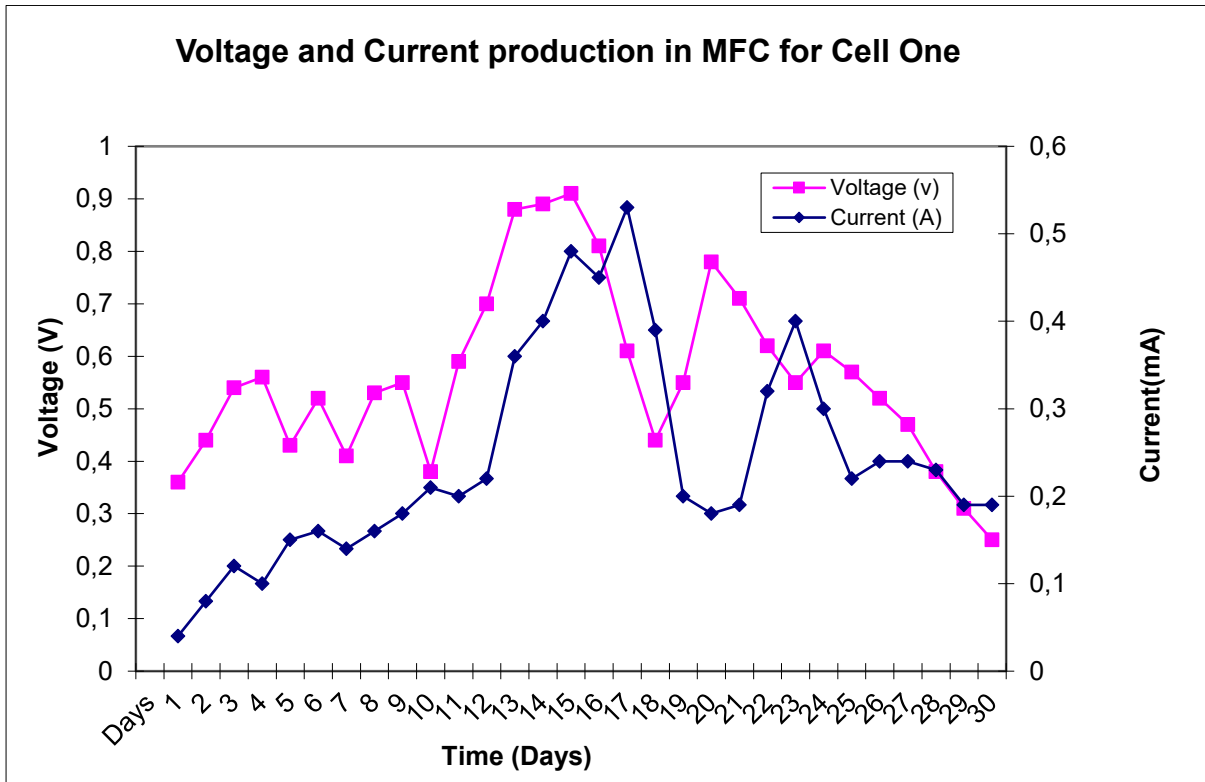


Fig. 3.3 graph of Voltage and Current production in MFC for Cell One

This figure shows the graph of voltage and current production in a microbial fuel cell (MFC) for Cell One over a period of time.

- Voltage and Current Trends:** The graph displays the trends of voltage and current output over time, allowing for the visualization of the MFC's performance.
- Correlation:** The graph show a correlation between voltage and current output, indicating the relationship between the electrical potential difference and the flow of electrons.
- Performance Evaluation:** The graph provides a visual representation of the MFC's performance, enabling the evaluation of its efficiency, stability, and potential for optimization

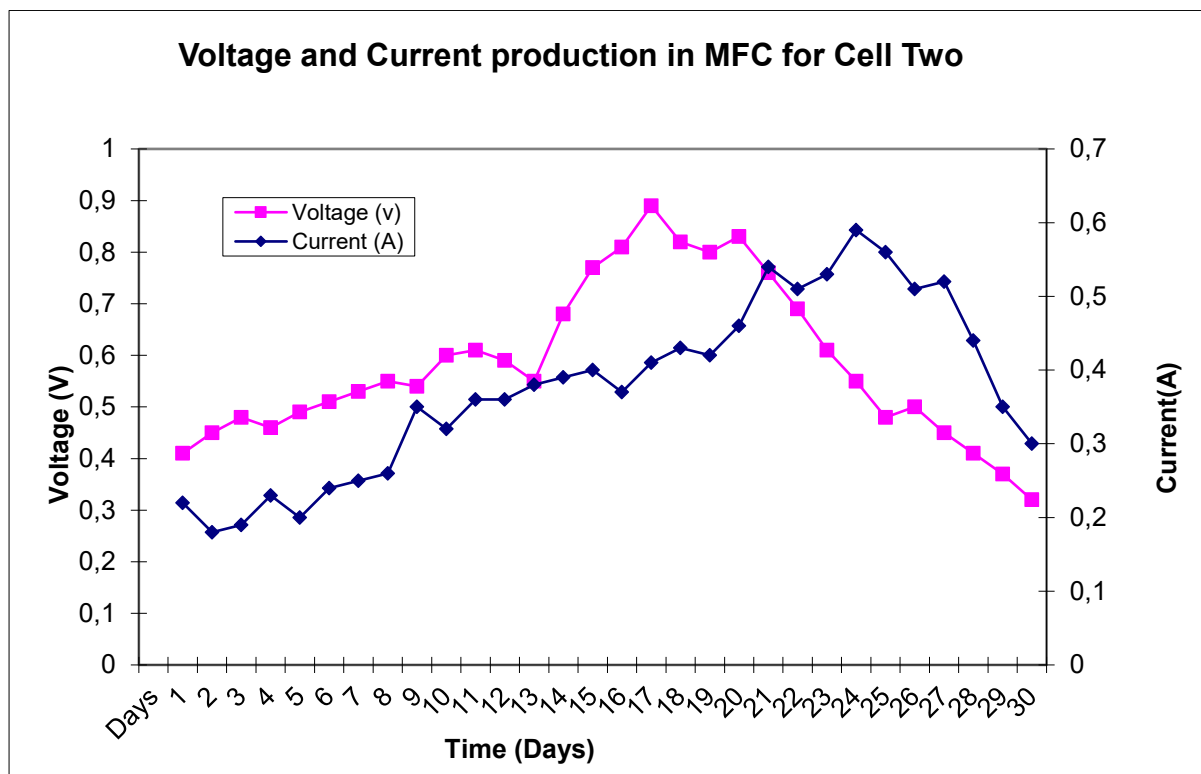


Fig. 3.4. graph of Voltage and Current production in MFC for Cell Two

This figure shows the graph of voltage and current production in a microbial fuel cell (MFC) for Cell Two over a period of 30 days.

Voltage Trend

- a. Range: The voltage output ranges from 0.1V to 0.9V, indicating a significant variation in electrical potential difference over the 30-day period.
- b. Trend: The voltage output likely increases and decreases over time, with some fluctuations, showing the dynamic nature of the MFC's performance.

Current Trend

- a. Range: The current output ranges from 0.1mA to 0.7mA, indicating a notable variation in electron flow over the 30-day period.
- b. Trend: The current output may follow a similar trend to the voltage output, with some fluctuations, showing the relationship between voltage and current in the MFC.

Key Observations

- a. Performance Variability: The graph shows variability in both voltage and current output over the 30-day period, which may be due to factors such as changes in microbial activity, substrate consumption, or electrode properties.
- b. Peak Performance: The graph may reveal peak voltage and current output values, indicating the maximum performance of the MFC

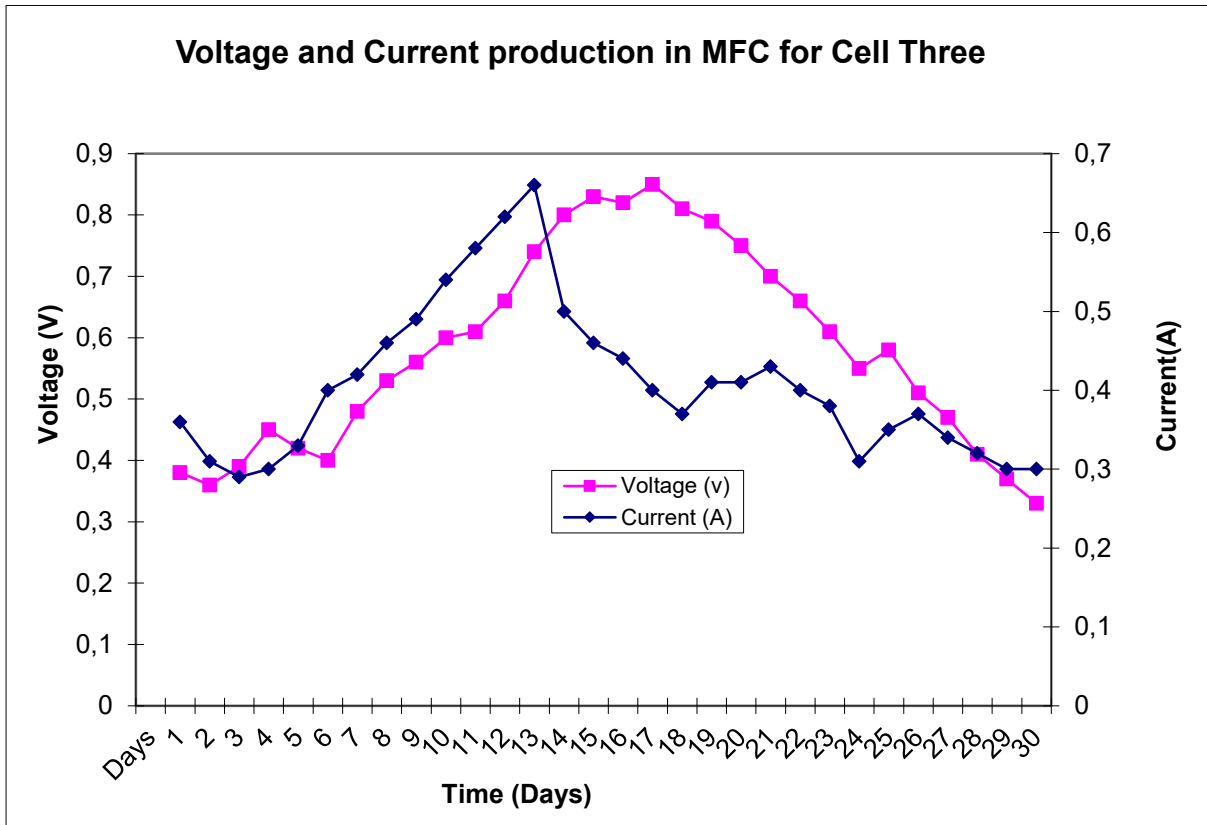


Fig. 3.5 graph of Voltage and Current production in MFC for Cell Three

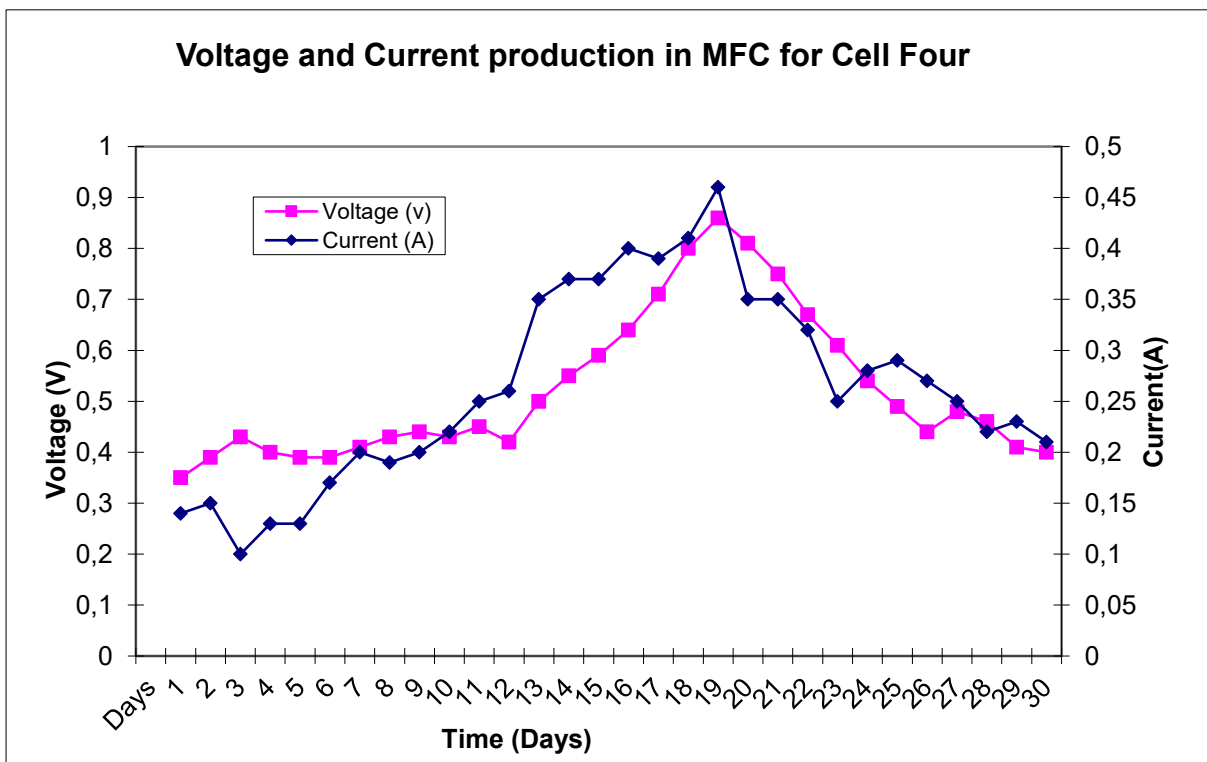


Fig. 3.4 graph of Voltage and Current production in MFC for Cell Four

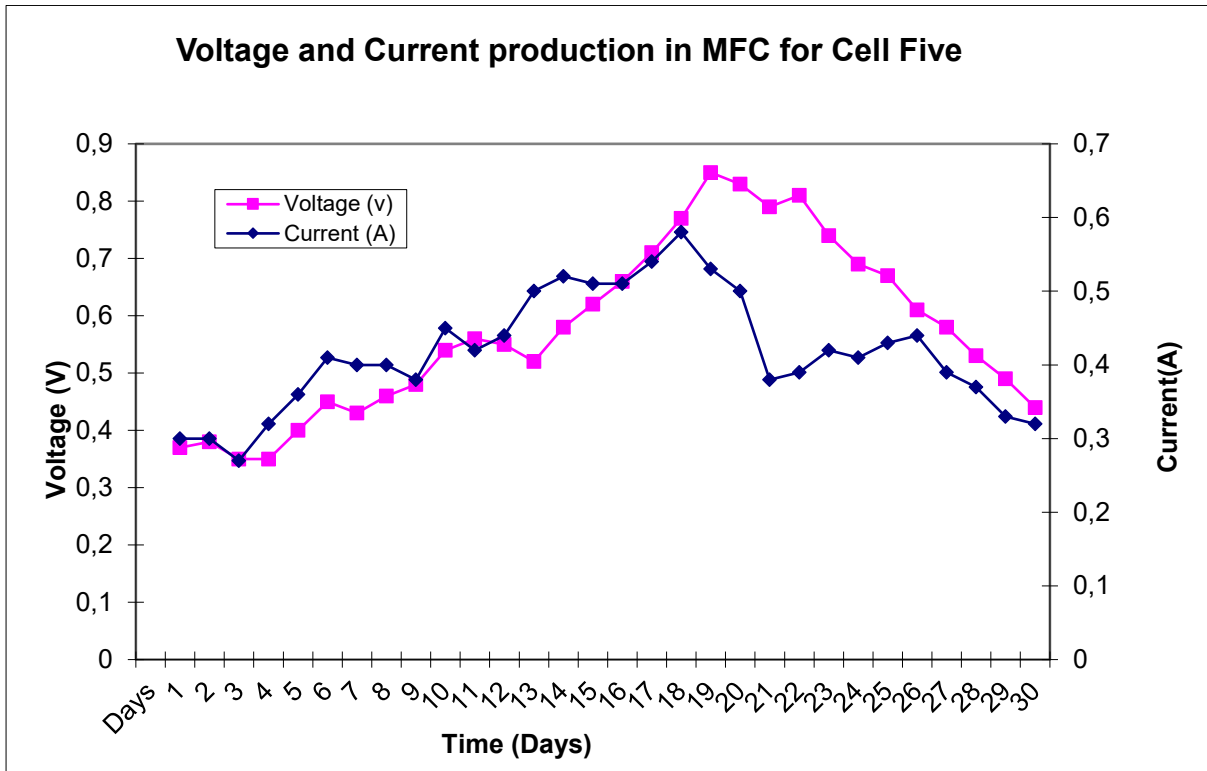


Fig. 3.5 graph of Voltage and Current production in MFC for Cell Five

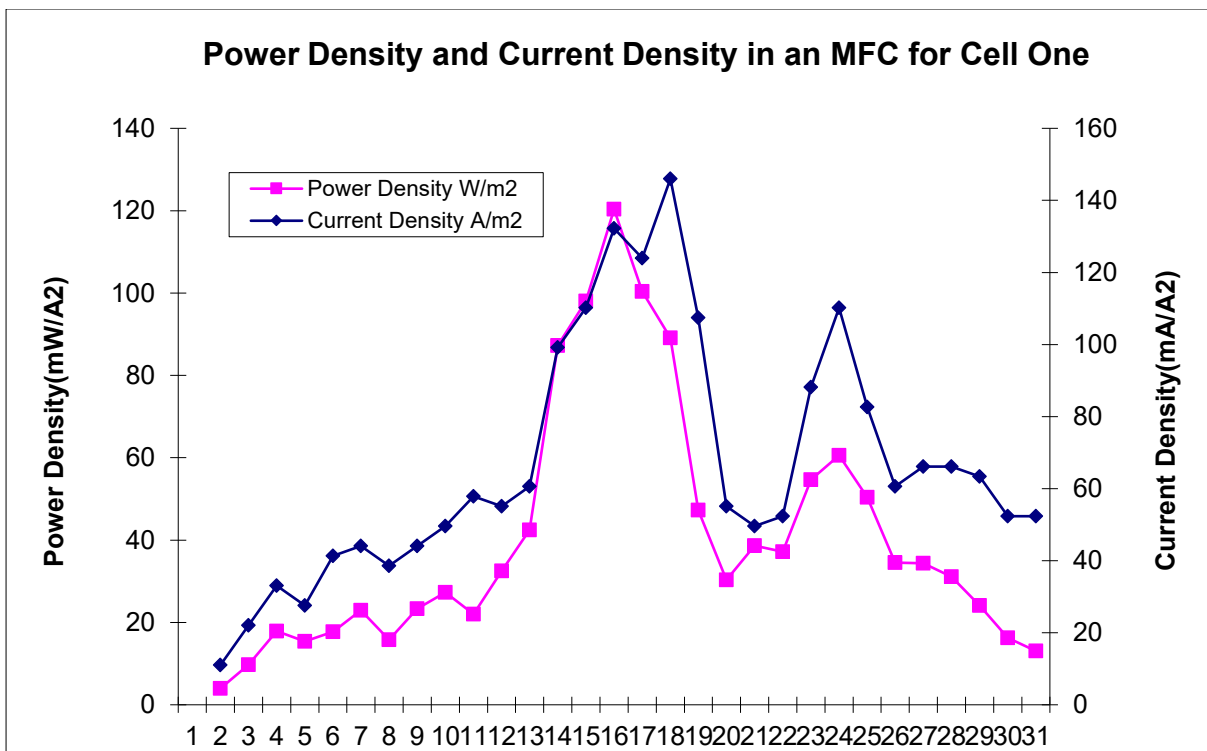


Fig.3.6 graph of Power and Current Density in an MFC for Cell One

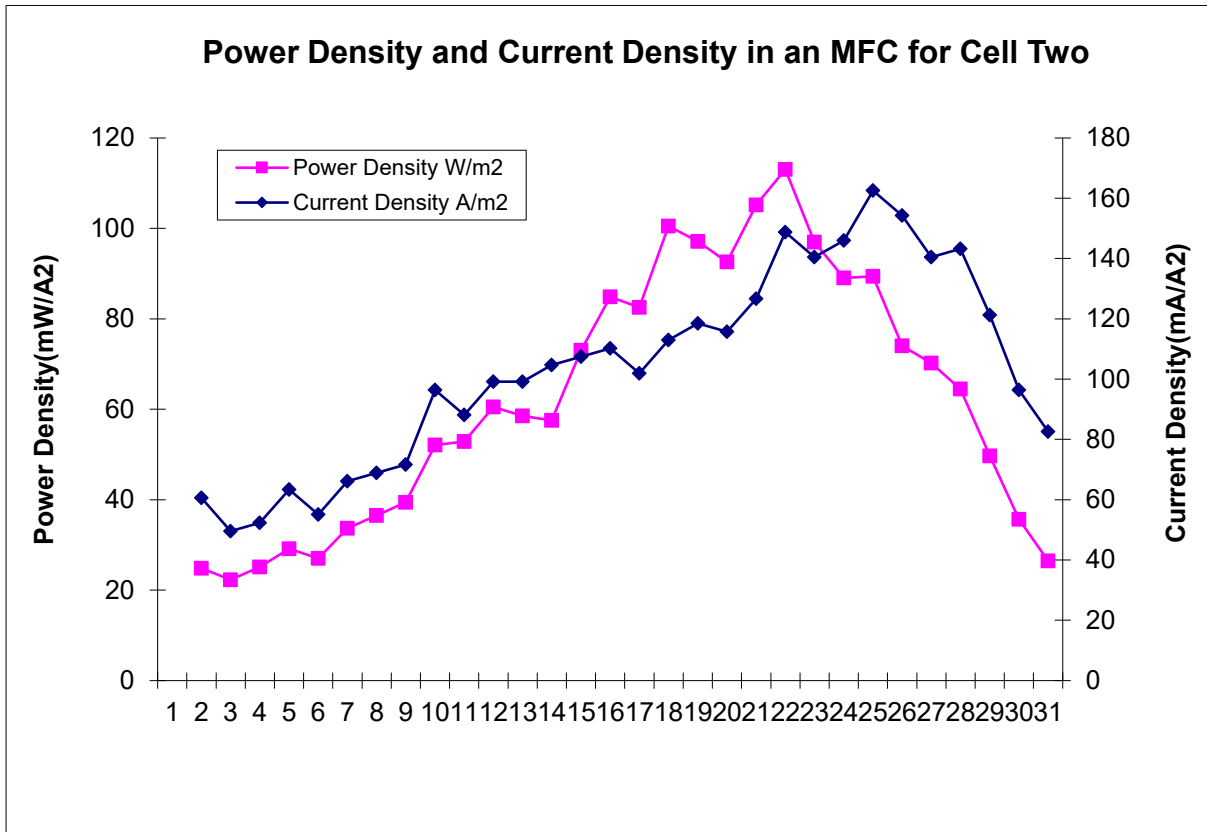


Fig.3.7 graph of Power and Current Density in an MFC for Cell Two

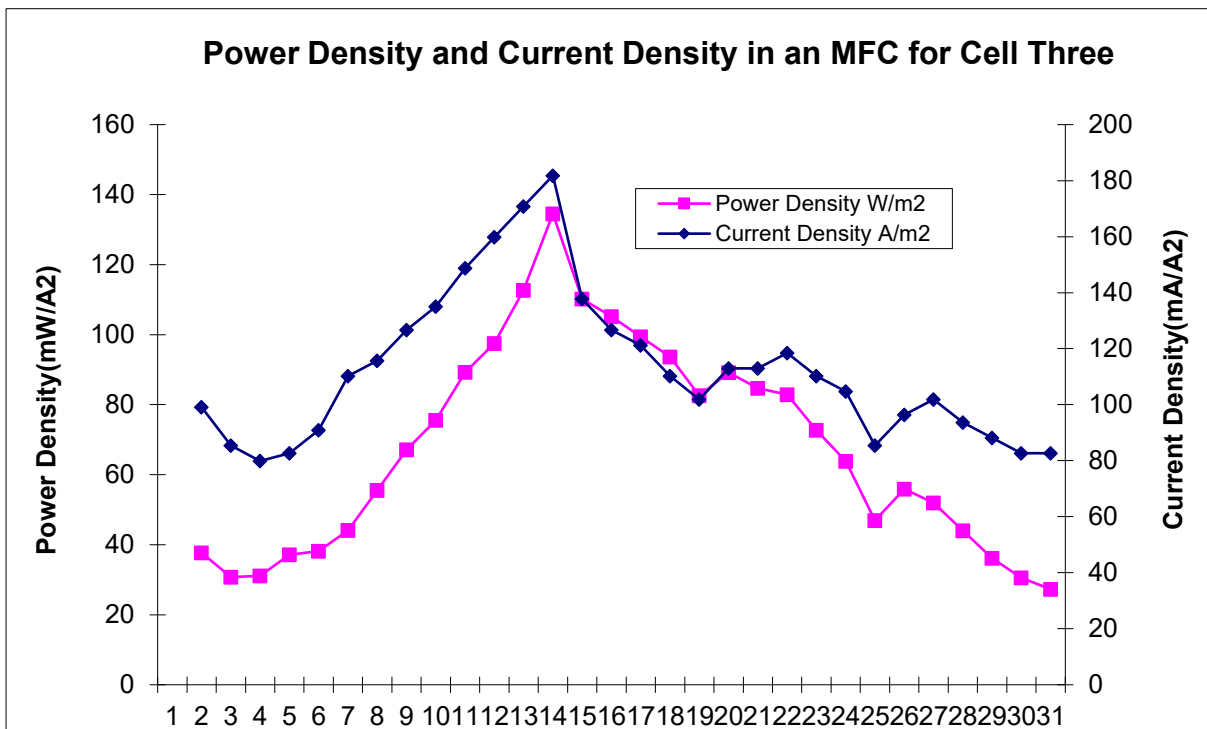


Fig.3.8 graph of Power and Current Density in an MFC for Cell Three

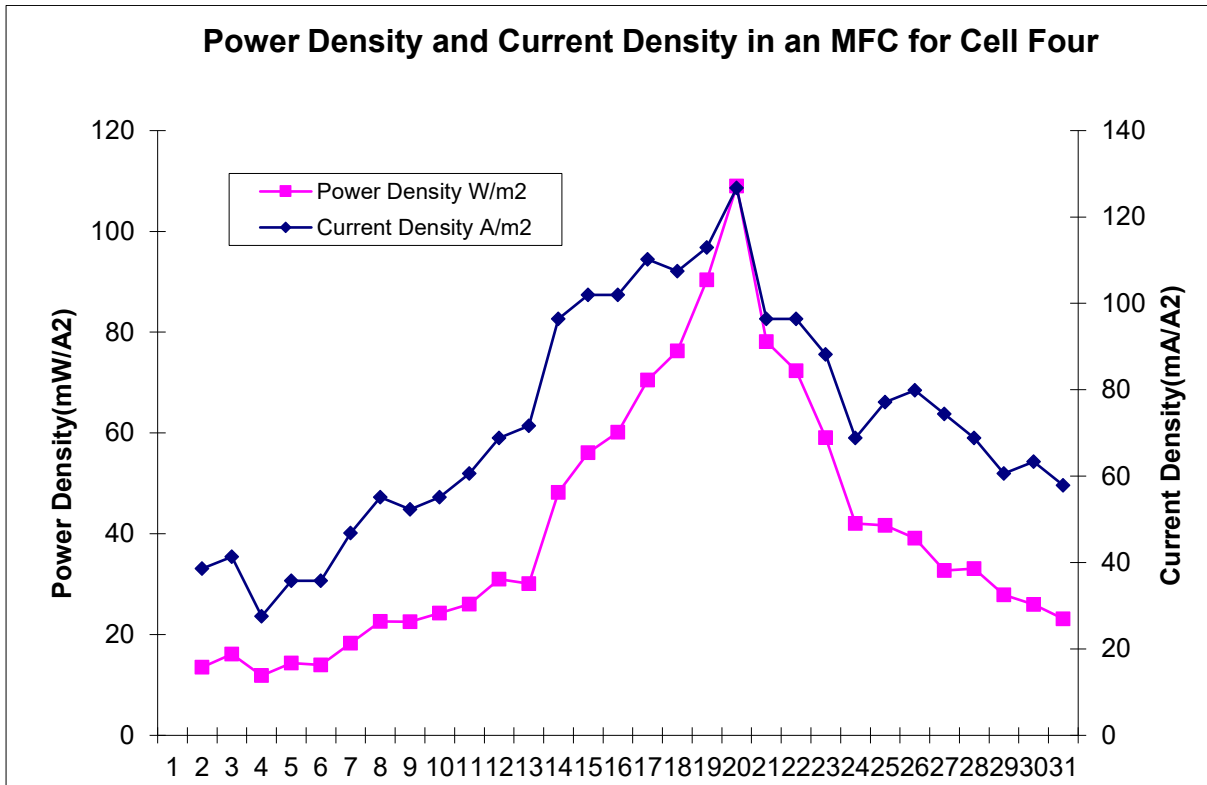


Fig.3.9 graph of Power and Current Density in an MFC for Cell Four

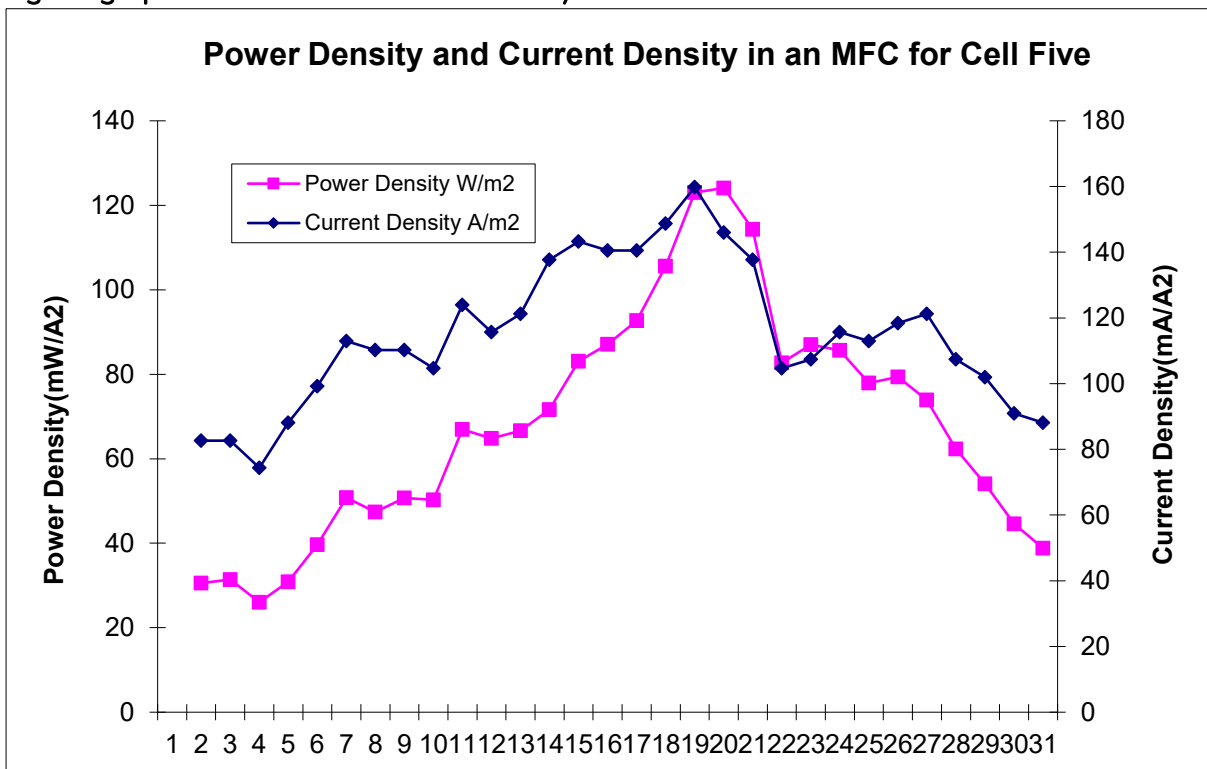


Fig.3.10 graph of Power and Current Density in an MFC for Cell Five

Analytical Calculations

Voltage and current were measured using a digital multimeter and converted to power density P (mW/m²) according to the equation:

$$P = IV/A$$

where:

I (A) is the current

V (V) is the voltage

A (m²) is the surface area of the projected anode The power density was expressed in mW/m², normalized to the projected surface area of the anode

A (m²) is the surface area of the projected anodeThe power density was expressed in mW/m², normalized to the projected surface area of the anode

$$P = \frac{\text{Current(mA)} \times \text{Volts(v)}}{\text{Surface area of projected anode(m}^2\text{)}} \quad \text{Eqn. (3.1)}$$

And current density C, expressed as:

$$C = \frac{\text{Current produced(mA)}}{\text{Surface area of projected anode(m}^2\text{)}} \quad \text{Eqn. (3.2)}$$

The Monod-type equation was used to model the voltage as a function of substrate concentration (S);

$$V = \frac{V_{\max} S}{K_s + S} \quad \text{Eqn. (3.3)}$$

Where V_{\max} = maximum voltage produced and K_s the saturation constant.

Table 3.3 Power density and Current density table

	Cell One		Cell Two		Cell Three		Cell Four		Cell Five	
Days	Power density (mW/m ²)	Current Density (mA/m ²)	Power density (mW/m ²)	Current Density (mA/m ²)	Power density (mW/m ²)	Current Density (mA/m ²)	Power density (mW/m ²)	Current Density (mA/m ²)	Power density (mW/m ²)	Current Density (mA/m ²)
1	3.9669	11.0193	24.8485	60.6061	37.6866	99.1736	13.4986	38.5675	30.5785	82.6446
2	9.6976	22.0386	22.3141	49.5868	30.7438	85.3995	16.1157	41.3223	31.4056	82.6446
3	17.8519	33.0579	25.1246	52.3416	31.1578	79.8898	11.8457	27.5482	26.0331	74.3802
4	15.4272	27.5482	29.1469	63.3609	37.1901	82.6446	14.3251	35.8127	30.8543	88.1543
5	17.7693	41.3223	26.9973	55.0964	38.1818	90.9091	13.9669	35.8127	39.6694	99.1736
6	22.921	44.0771	33.7197	66.1157	44.0771	110.193	18.2645	46.8325	50.8265	112.948
7	15.8135	38.5675	36.5014	68.8705	55.5372	115.703	22.5895	55.0964	47.3829	110.193
8	23.3611	44.0771	39.3939	71.6253	67.1625	126.722	22.5069	52.3416	50.6887	110.193
9	27.2738	49.5868	52.0661	96.4187	75.5923	134.986	24.2424	55.0964	50.2479	104.683
10	21.9833	57.8513	52.8928	88.1548	89.2566	148.766	26.0604	60.6066	66.9429	123.963

		2	6	3	2		6	1	2	7
11	32.507	55.096 4	60.495 9	99.173 6	97.465 6	159.78	30.991 7	68.870 5	64.793 4	115.70 3
12	42.424	60.606 1	58.512 4	99.173 6	112.72 7	170.79 9	30.082 6	71.625 3	66.666 7	121.21 2
13	87.273	99.173 6	57.575 8	104.68 3	134.54 6	181.81 8	48.209 4	96.418 7	71.625 3	137.74 1
14	98.072	110.19 3	73.057 9	107.43 8	110.19 3	137.74 1	56.060 6	101.92 8	83.085 4	143.25 1
15	120.33	132.23 1	84.848 5	110.19 3	105.17 9	126.72 2	60.137 7	101.92 8	87.107 4	140.49 6
16	100.41	123.96 7	82.562	101.92 8	99.393 9	121.21 2	70.523 4	110.19 3	92.727 3	140.49 6
17	89.063	146.00 6	100.52 3	112.94 8	93.663 9	110.19 3	76.281	107.43 8	105.62	148.76
18	47.273	107.43 8	97.135	118.45 7	82.562	101.92 8	90.358 1	112.94 8	123.03	159.78
19	30.303	55.096 4	92.562	115.70 3	89.228 7	112.94 8	108.98 1	126.72 2	124.10 5	146.00 6
20	38.678	49.586 8	105.17 9	126.72 2	84.710 7	112.94 8	78.099 2	96.418 7	114.32 5	137.74 1
21	37.163	52.341 6	113.05 8	148.76	82.920 1	118.45 7	72.314 1	96.418 7	82.699 7	104.68 3
22	54.656	88.154 3	96.942 2	140.49 6	72.727 3	110.19 3	59.063 4	88.154 3	87.024 8	107.43 8
23	60.606	110.19 3	89.063 4	146.00 6	63.856 8	104.68 3	42.011	68.870 5	85.619 8	115.70 3
24	50.413	82.644 6	89.393 9	162.53 4	46.969 7	85.399 5	41.652 9	77.135	77.933 9	112.94 8
25	34.545	60.606 1	74.049 6	154.27	55.922 9	96.418 7	39.146	79.889 8	79.366 4	118.45 7
26	34.38	66.115 7	70.247 9	140.49 6	51.983 5	101.92 8	32.727 3	74.380 2	73.939 4	121.21 2
27	31.074	66.115 7	64.462 8	143.25 1	44.022	93.663 9	33.057 9	68.870 5	62.314 1	107.43 8
28	24.077	63.360 9	49.697	121.21 2	36.143 3	88.154 3	27.878 8	60.606 1	54.022	101.92 8
29	16.226	52.341 6	35.674 9	96.418 7	30.578 5	82.644 6	25.978	63.360 9	44.545 5	90.909 1
30	13.085	52.341 6	26.446 3	82.644 6	27.272 7	82.644 6	23.140 5	57.851 2	38.787 9	88.154 3

Table 3.3: Power Density and Current Density

This table presents the power density and current density values for five microbial fuel cells (MFCs), labeled as Cell One to Cell Five, over a period of 30 days.

Power Density and Current Density Trends

- Variability: The power density and current density values show significant variability across the five cells and over the 30-day period.
- Peak Values: Some cells exhibit peak power density and current density values, indicating optimal performance.

Cell Performance Comparison

- a. Cell One: Shows a peak power density of 120.33 mW/m² and current density of 132.231 mA/m² on Day 15.
- b. Cell Two: Exhibits a peak power density of 113.058 mW/m² and current density of 148.76 mA/m² on Day 21.
- c. Cell Three: Displays a peak power density of 134.546 mW/m² and current density of 181.818 mA/m² on Day 13.
- d. Cell Four: Shows a peak power density of 108.981 mW/m² and current density of 126.722 mA/m² on Day 19.
- e. Cell Five: Exhibits a peak power density of 124.105 mW/m² and current density of 146.006 mA/m² on Day 19.

Key Observations

1. Performance Variability: The power density and current density values vary significantly across the five cells and over time, indicating differences in MFC performance.
2. Optimal Performance: Some cells exhibit optimal performance, with peak power density and current density values, while others show more variability

Table 3.4 Four weeks of substrate experimental analysis

S/no	Parameters	Week One	Week Two	Week Three	Week Four
1	pH	8.26	7.96	7.35	6.68
2	Conductivity	320µs	988µs	2763µs	3350µs
3	% Urea	298.5ppm	184ppm	102ppm	0.53ppm
4	% NH ₃	1375ppm	947ppm	458ppm	220ppm
5	BOD	712mg/L	598mg/L	326mg/L	263mg/L
6	COD	955mg/L	749mg/L	231mg/L	61.6mg/L
7	Temperature	26°C			

This table presents the results of a four-week experimental analysis of substrate parameters.

Parameter Trends

- a. pH: The pH decreases from 8.26 in Week One to 6.68 in Week Four, indicating a shift towards a more acidic environment.
- b. Conductivity: The conductivity increases from 320 µS in Week One to 3350 µS in Week Four, suggesting an increase in ionic strength.
- c. Urea and Ammonia Removal: The concentrations of urea and ammonia decrease significantly over the four weeks, indicating effective removal.
- d. BOD and COD Reduction: The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values decrease over the four weeks, indicating a reduction in organic matter.

Key Observations

- a. Effective Treatment: The results suggest effective treatment of the substrate over the four-week period, with significant reductions in urea, ammonia, BOD, and COD.
- b. Changes in pH and Conductivity: The changes in pH and conductivity may be related to the treatment process and the breakdown of organic matter

Empirical Analysis

The graphical presentations in Figures 3.1 to 3.10 illustrate the mode of voltage and current generation in the microbial fuel cells (MFCs). The measured values of voltage and current showed an inconsistent increase across the five set-ups, likely due to unsteady bacterial activity.

Voltage and Current Trends

- a. Initial Increase: The values of current and voltage increased until a maximum value was recorded between the 16th to 19th days across the five set-ups.
- b. High Internal Resistance: The low amount of current and voltage recorded resulted from high internal resistance in the cell, which could be mitigated by connecting a load to improve current and power density.
- c. Voltage and Current Drop: A drop in voltage and current was observed after the 20th day, attributed to continued degradation of the substrate by the bacteria.

Microbial Activity and Power Generation

- a. Non-Linear Relationship: The non-linear relationship between current and voltage produced was due to the unsteady rate of microbial activity, which often causes MFC operation to deviate from Ohm's law.
- b. Variable Power Source: The power source (microorganism oxidative activity) is not constant due to the effect of internal resistance in the system.

Power Density and Current Density

- a. Maximum Power Density: The power density increased with current and voltage up to a maximum value of 134.5455 mW/m² at 0.74 V and 0.66 mA.
- b. Maximum Current Density: The maximum current density obtained was 181.8182 mA/m².

This analysis highlights the complex relationships between voltage, current, and power density in MFCs, and the importance of understanding microbial activity and internal resistance in optimizing MFC performance.

Precautionary Measures

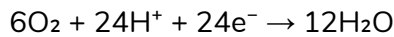
To achieve the desired results in the construction and operation of the dual-chambered microbial fuel cell, certain precautionary measures were observed. These measures include:

1. Leakage Test
 - a. Importance: The MFCs operate with liquid environments in the anode and cathode, making leakage a potential issue that could compromise the successful operation.
 - b. Procedure: To prevent leakage, the parts were properly fitted together during coupling. A leakage test was conducted by filling the empty chambers with clean water and allowing the system to stand for about six hours to ensure the absence of leakage before charging the electrolytes.
2. Anode Chamber
 - a. Anaerobic Environment: The anode chamber environment must be completely anaerobic to support the growth and activity of the microorganisms.
 - b. Precautions: Absolute care was taken to prevent oxygen from entering the chamber through openings or during inoculation. The bacteria were grown in a sealed container, and when the bacterial solution was added to the MFC, it was done quickly to limit oxygen exposure.
3. Cathode Chamber

- a. Aeration: The cathode chamber should be fully aerated to provide oxygen, which functions as the final electron acceptor.
- b. Solution and Aeration: The cathode chamber was filled with a solution like brine and aerated to provide oxygen to the cathode, serving as an ultimate "electron sink" or end point of the redox reaction.

Cathodic Equation

The cathodic equation is:



4. Maintenance of Stable pH

pH refers to the concentration of hydrogen ions (H^+) in a solution. An acidic environment has a high concentration of hydrogen ions, while a basic medium has a low concentration.

Importance of pH Control

The operation of a microbial fuel cell (MFC) is accompanied by the production of hydrogen ions at the anode, which can lead to a decrease in pH over time. This can threaten the growth and metabolism of the existing bacteria, as most microorganisms prefer a pH that approximates neutrality (pH 7.0).

pH Stabilization

To maintain a stable neutral pH in the anode chamber, a well-buffered solution was used to extract the substrate and charged into the anode chamber. This helps to:

- a. Regulate pH: Maintain a stable pH environment that supports the growth and activity of the microorganisms.
- b. Optimize Microbial Activity: Ensure that the microorganisms can thrive and perform optimally, leading to efficient electricity generation.

Summary of Experimental Study

The main focus of this study was to generate bioelectricity in a microbial fuel cell (MFC) using ammonia fertilizer plant effluent as a substrate, employing the general MFC principles. The study utilized a dual-chambered mediatorless MFC.

CONCLUSION

This study successfully demonstrated the feasibility of generating bioelectricity from ammonia fertilizer effluent using a microbial fuel cell, showcasing its potential as a sustainable solution for wastewater treatment and renewable energy production. The MFCs achieved a maximum power density of 134.5455 mW/m^2 and a maximum current density of 181.8182 mA/m^2 , highlighting the effectiveness of the system. The positive impact of the materials used on power generation highlights the potential for optimization and improvement in MFC design. This research contributes valuable insights to the field of MFC technology, paving the way for further innovation and development in sustainable energy solutions.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

1. Further Research on Optimization: Conduct further research to optimize the design and operation of MFCs for improved power generation and wastewater treatment efficiency.

2. Scaling Up: Explore the feasibility of scaling up MFC technology for practical applications in industrial wastewater treatment and bioelectricity generation.
3. Material Development: Investigate the development of new materials and electrodes that can enhance the performance and efficiency of MFCs.
4. Real-World Applications: Conduct pilot-scale studies to demonstrate the effectiveness of MFCs in real-world wastewater treatment scenarios.
5. Interdisciplinary Collaboration: Encourage interdisciplinary collaboration between engineers, microbiologists, and environmental scientists to advance the development and application of MFC technology.

These recommendations aim to promote further research and development in MFC technology, ultimately contributing to the advancement of sustainable energy solutions and wastewater treatment practices.

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