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Bioelectricity Generation Using Groundnut Oil Cakes In Microbial Fuel Cells: The Optimization Of Parameters

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Abstract
Microbial fuel cell (MFC) is state of art technique to produce electricity from organic waste. This ecofriendly way of producing electricity affected by many parameters like type of electrogene, electron acceptor, pretreatment of substrate, electrode size, electrode etc. Here we had optimised electrogene, electrode acceptor for groundnut oil cake (GOC). In current work influence of fly ash addition in anodic chamber on electricity production was also studied. Here salt bridge which is used as the anodic and cathodic chamber separator is reused and checked for electricity generation. The study reveals that MFCs containing Escherichia coli generate an optimum electromotive force of 136mV, compare to those with Pseudomonas aeruginosa and native organisms as electrogene. The maximum power density achieved by the E. coli MFC is 249mW/m². Physical and chemical pretreatments enhance bioelectricity production by approximately 1.5 and 2 times, respectively, and their combined application results in a threefold increase, indicating superior biodegradation. NaCl and $KMnO_4$ prove effective catholytes and NaCl is eco-friendly too against the use of $K_3[Fe(CN)_6]$, $K_2Cr_2O_7$. Additionally, the inclusion of fly ash in the MFC substantially boosts voltage and accelerates power generation, achieving a maximum power density of 480mW/m². The findings suggest that fly ash facilitates the breakdown of organic materials, enhancing cost-effectiveness. Salt bridge which is used as separator when reused first time enhances electricity generation but when reused second time its efficiency deteriorates severely. Further optimization of pretreatments and electrode materials is recommended to maximize MFC performance.
Key words: *Groundnut oil cake, bioelectricity, Microbial fuel cell, Pretreatment, Electron acceptor, salt bridge, electrogene*

1. INTRODUCTION

Microbial fuel cells (MFCs) are bio-electrochemical transducers that convert microorganism metabolism-produced microbial reduction power into electrical energy (Rojas-Flores et al., 2023). In small-scale applications, they offer a substitute for conventional power generation techniques. In the modern world, energy, in all its forms, is the most important component. A representative investigation of the solid waste of many developing countries found that organic waste, which usually receives less attention for recycling or resource recovery, accounts for the majority (more than 80%) of the total solid trash (Hassan et al., 2023; Jalili et al., 2024; Moqsud et al., 2013a).

In MFC anode and cathode sections are normally separated with help of a cation-specific membrane that exchange proton or salt bridge in microbial fuel cells. Microorganisms oxidize organic substances in the anode compartment to produce protons and electrons. When aerobic microbes eat a substrate like sugar, they release carbon dioxide and water. However, in the anaerobic condition, they produce protons, electrons, and carbon dioxide, as follows (Bennetto, 1990; Roy et al., 2023):

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^- \quad (1)$$

Conversely, when airborne oxygen is introduced to the cathode, the subsequent chemical reaction takes place:

$$6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O \quad (2)$$

In an MFC, microorganisms at the anode chamber oxidize organic substrate, releasing electrons.

Microbial fuel cells (MFCs) have already been the subject of some study in an effort to produce bioelectricity from wastewaters or organic wastes (Apollon et al., 2023; Daniel et al., 2009; Hakeem et al., 2015; Jiang et al., 2010; Luste & Luostarinen, 2011). Numerous investigations on the analysis of MFC utilizing synthetic organic wastes have been reported globally. MFCs have also been utilized by researchers to recover electricity from rice paddies and oilcake (Kaku et al., 2008; Thapa & Chandra, 2019).

Using locally accessible substrates, a reconstructed form of MFC was used for the current investigation. However, this work used natural substrates like oil cake and an MFC system. After oilseeds are recovered, a valuable byproduct known as oilseed cake, sometimes called oilseed meal, is created. It can be utilized for a number of purposes, such as animal feed, organic fertilizer, energy production, soil amendment, and as a solid substrate for industrial fermentation (Wainaina et al., 2020). Depending on market demand and costs, producing electricity from oilseed cake could be more profitable than utilizing it as animal feed (Shanmugaprakash et al., 2018). By generating revenue from the sale of power, bioenergy production can provide farmers and oilseed processors with an extra stream of income. Through the production of renewable energy from organic waste sources, oilseed cake bioelectricity generation can increase resource efficiency. This promotes environmental sustainability by aligning with the concepts of sustainable resource management and the circular economy. To generate bioelectricity from oil cake will be a step toward green solution of national and international problem of greenhouse gas emission (Group, n.d.; Kudnie Sahari et al., 2022; Moqsud et al., 2013a; Thapa & Chandra, 2019; Ujai et al., 2024).

When we use complex organic substrate like oil cake which is rich in lignocellulose and cellulose microbial degradation becomes difficult and delayed. The higher lignocellulosic content work as recalcitrant for anaerobic microbial degradation (Ewunie et al., 2021). To make it faster and easier we've used a novel strategy of pretreatment of which makes ease in availability to the microbes. Pretreatment techniques can be classified into four categories based on the type of lignocellulosic material they are applied to: physicochemical, chemical, physical, and biological. Pretreatment modifies the structure of various feedstock materials at every level of the fibre, opening the door for hydrolysis, which releases the cellulose embedded in lignin and hemicellulose by breaking down their constituent parts (Ewunie et al., 2021). Radiation has the power to break the glucoside linkages in cellulose, resulting in the formation of oligosaccharides, brittle fibres, and even cellobiose from cellulose chains. With wavelengths ranging from 1 mm to 1 m, microwave energy is a common form of radiation energy found in the electromagnetic spectrum. The biomass is immediately exposed to radiation when it is microwaved, which results in quick heating and little temperature gradient(Abu Tayeh et al., 2020). Due to how quickly the heating process happens, the most common inorganic alkali solution used in this procedure is sodium hydroxide (NaOH). It results in increased hemicellulose dissolution by inducing both cellulose swelling and hemicellulose hydrolysis. As a result, high-purity hemicellulose is extracted (Barlianti et al., 2015; Manyi-Loh & Lues, 2023).

Electrogenic organisms are also playing crucial role in generation of electron and thereby electricity. These electrogenicity is dependent on substrate utilization efficiency, mediator formation, sustainability in MFC environment etc. Electrogenic bacteria produce electrical currents through their metabolic activities, transferring electrons from their metabolism to an external electrode. One application is microbial fuel cells (MFCs), which generate sustainable energy from organic waste (Pisciotta & Blessing, 2022; Rabaey & Verstraete, 2005; Rahimnejad et al., 2015; Sydow et al., 2014). Extracellular electron transfer (EET) allows certain bacteria, like some Escherichia coli, Pseudomonas aeruginosa, Pseudomonas putida to move electrons to external acceptors, such as electrodes. This process involves cytochromes, membrane-bound proteins that facilitate electron movement across the cell membrane.

A Ward et al., 2014 found that P. aeruginosa can transfer electrons to an external electrode using an electron mediator, showcasing its electrogenic properties. A Feng studied the mechanics behind E. coli's capacity to produce electrical current and using glucose as the substrate E. coli could produce a maximum power density of 430mW/m^2 in an MFC (Baruch et al., 2021; Feng et al., 2020; Ward et al., 2014). So, we have checked these two organisms with indigenous flora for electricity generation (Aiyer, 2021).

Oxygen has extremely slow reduction kinetics on graphite, it serves as a restriction agent in MFCs (Dange et al., 2022). To address this issue, most studies used potassium permanganate ($KMnO_4$), potassium dichromate ($K_2Cr_2O_7$), potassium ferricyanide ($K_3[Fe(CN)_6]$) and NaCl as oxidizing agents (Logan et al., 2006; Pham et al., 2008; Rahimnejad et al., 2015) . A two-chambered mediator less MFC using glucose as a substrate and three different electron acceptors, potassium permanganate ($KMnO_4$), potassium ferricyanide ($K_3[Fe(CN)_6]$), and potassium dichromate ($K_2Cr_2O_7$), was examined. The salt bridge-connected MFC was reported to yield a maximum potential of 1.04V with $KMnO_4$. MFC performance with $K_2Cr_2O_7$ and $K_3[Fe(CN)_6]$ were significantly lower, with maximum potentials of 0.56 V and 0.71 V, respectively (Sanju Sreedharanand, 2016). Potassium Ferri-cyanide ($K_3[Fe(CN)_6]$) was replaced with $KMnO_4$ as the oxidizing agent in the cathode chamber at varying concentrations due to its toxicity and dependence on power output.

The anode and cathode compartments in the microbial fuel cell should be electronically isolated. Due to high-cost salt bridge was used instead of Proton exchange membranes (PEMs) which were frequently used as separator of anode and cathode chambers. Shahi et al., 2017 obtained 0.504 V nafion membrane as separator from a dual-chambered microbial fuel cell with that they reported nafion membrane and salt bridge give similar output. Chae et al., 2008 reported that using a salt bridge as a separator is more economically possible than using a pricey nafion membrane (Singh et al., 2020). Here, we used a salt bridge for separation, and repeated use of the separator was tested for MFC performance in terms of power generation. Cyclic utilization of salt bridge as separator adds on to the cost-effectiveness which was shown 61% with comparison of nafion membranes (Chae et al., 2008; Mukherjee et al., 2021).

The MFC's performance of organic waste with different admixtures as well as a number of electrical characteristics were established. One of them is that fly ash is rich in several nutrients as well alkaline in nature so it was selected to be mixed in with the organic trash in anodic chamber. In compost if we mix alkaline material like lime improve degradation (Moqsud et al., 2013b).

When we want sustainable use of large scale MFC for electricity production, we have to optimize many factors that affect the amount of electricity production (Nawaz et al., 2022). Some parameters are type of substrate, electron acceptor, type of anodic electrogene, size and material of electrodes, additives, mediators etc. The goal of this work is to create a microbial fuel cell that produces energy by breaking down organic waste (Groundnut oil cake) and treating it beforehand. It also aims to maximize electricity by optimizing parameters like type of electrogene, catholyte, pretreatments and additives in anodic chamber.

2. MATERIALS AND METHODS

2.1 Characterization of substrate: Physicochemical characterization of sample was done as following. All measurements were made in triplicates, and the results are expressed as mean values. CHNS analysis were done with help of autoanalyzer at CSMCRI, Bhavnagar. Dry matter (Total solid), ash contents, moisture content, volatile solid were determined according to the standard procedures of the Association of Official Analytical Chemists (Nawaz et al., 2017). Estimation of celluloses was done by acetolysis followed by hydrolysis to form glucose units. These glucose units were then dehydrated and reacted with anthrone to give a green colored product, absorption of which was measured at 630 nm (Bauer et al., 2014). Lipid content was estimated by conventional Soxhlet extraction method (Jabłoński et al., 2016). Groundnut oil cake characterization is presented in table 1.

Insert table 1.

2.2 Experimental setup of MFC: The current investigation was carried out in batch mode utilizing a traditional "H" type two chambered mediator-less MFC system with identical plastic Pipes (Deval & Dikshit, 2013). In a microbial fuel cell, a salt bridge serves as a separator between the anode and cathode. These electrons need to flow to the cathode to complete the circuit and generate electricity. The salt bridge facilitates this transfer by conducting protons from the anode chamber, where they are oxidized to produce water and hydrogen peroxide. A salt bridge, consisting of an agar slurry created by combining 30% KCl with 6% agar, was used to divide two chambers. The slurry was placed inside a 4 cm-long PVC pipe (Khan et al., 2013). The anodic and the cathodic chamber was kept anoxic during the operation with a total working capacity of 150ml. In anodic chamber we used 10% ground nut oil cake as substrate for microbial growth. And in cathodic chamber 150ml catholyte were added. There was no need for intermediates because the biofilm and electrode made direct contact, facilitating the transmission of electrons. Then graphite rods were placed in it and placed under anaerobic condition at room temperature. A multimeter connected to the circuit was used to measure the voltage output as the amount of electricity generated. After each 24 hours we checked its electricity (voltage) with a digital multimeter till 15 days (Wei et al., 2012). All experiments were performed in triplicate. To remove the metal fouling, the graphite electrodes were first soaked in IPA (isopropyl alcohol) for 30 min., then washed with 1N HCL and 1N NaOH (Ravandeh et al., 2017). The dimensions of the graphite electrodes used in both chambers were 15 cm long by 1.5 cm wide.

2.3 Optimization of different parameters: There are many parameters like the kind of substrate, electron acceptor, anodic electrogene, electrode size and composition mediators, and so on. Here by optimizing variables including electrogene type, catholyte and pretreatments, studied the production of electricity. Table 2 summarize the experiments involved in optimization.

2.3.1 Pretreatment of substrate: To the best of the information we have, this study is the first where the pretreatment is given substrate (GOC) in the MFC system. Three different types of experiments were carried out for pretreatment of organic materials-oil cake. In the first experiment, 10 min 160watts microwave treated oil cake was used as organic waste. In the second experiment, 30 min 1N NaOH treated oil cake was used. In the third case we used both treatments (Jabłoński et al., 2016; Manyi-Loh & Lues, 2023). These pretreated 10% oil cakes are then added in an anodic chamber. The cathodic chamber was filled with distilled water.

2.3.2 Anodic electrogene: MFC systems were tested for anodic electrogene optimization for three variants, Escherichia coli, Pseudomonas aeruginosa and indigenous flora. Because they are potential electrogenic characteristics with less hazard reported, E. coli and P. aeruginosa were chosen as the experimental microorganisms in this study. These blending will promote fermentation of complex substrates. In experiments anodic chamber was inoculated with 3 % inoculum of active cultures of E. coli and P. aeruginosa. with 10% GOC. The third MFC system without the inoculum was maintained to check the efficiency of indigenous flora as control. Cathodic chamber was filled with distilled water. Bacterial cultures were grown on a coagulate mixture consisting of 3 gm of beef extract, 10 gm of peptone, 5gm of sodium chloride, and 1000ml of distilled water. The pH 7 was adjusted and the E. coli and P. aeruginosa culture's temperature was kept at 37 degrees Celsius. A fresh 16 hrs old culture of these organisms were used in anodic chamber.

2.3.3 Cathodic electron acceptor: Using oil cake as the substrate and four distinct electron acceptors—potassium dichromate ($K_2Cr_2O_7$), potassium ferricyanide ($K_3[Fe(CN)_6]$), potassium permanganate ($KMnO_4$) and NaCl—different mediator-less MFCs were tested. In this experimentation, we used 10% Groundnut oil cake (GOC) to make up 150 ml with distilled water in an anodic chamber. In these sets, cathode chamber we filled different catholytes 150ml of 10mM concentration against the 150ml distilled water as the control (Wei et al., 2012).
Insert table 2

2.4 Influence of admixture (fly ash): The MFC's performance of organic waste with different admixtures as well as a number of electrical characteristics were established. According to Moqsud et al., 2013a, adding alkaline materials like lime to decomposition accelerates the breakdown of organic waste. Coal-fired power facilities produce fly ash as a byproduct. Fly ash is rich in several nutrients as well alkaline in nature so it was selected to be mixed with the organic substrate in anodic chamber. In this study, fly ash produced from GOC was used in 20%w/v. Anodic chamber of 10% GOC was tested with and without fly ash in the form of voltage generation in MFC. Cathodic chamber was filled with 150ml distilled water. The blended sample including fly ash had a pH of 8.4, while the sample without fly ash had 7.5 pH in a microbial fuel cell.

2.5 Influence of reuse of salt bridge: Due to high-cost salt bridge was used instead of Proton exchange membranes (PEMs) which were frequently used as separator of anode and cathode chambers. In these experiments anodic chamber contain 10% GOC and distilled water is used as catholyte. Here salt bridge was used three times repeatedly, where the anode and cathode content in the dual chambered MFC system after completed run was replaced with fresh anodic and cathodic content (Mukherjee et al., 2021).

2.6 Evaluation of electricity produced: At the time of data acquisition, the anode and cathode were connected with multi meter and an external resistance (10Ω). The laboratory test was conducted in a mesophilic range. Electrode output was measured in volts (V) against time (Venkata Mohan et al., 2008). The current I in Amperes (A) was calculated using Ohm's law,
$I = V/R$,

where V is the measured voltage in volts (V) and R is the known value of the external load resistor in Ohms.
From this it is possible to calculate the power output P in watts (W) of the MFCs by taking the product of the voltage and current
$P = I * V$.

3. RESULTS AND DISCUSSION:

3.1 Optimization of different parameters

3.1.1 Pretreatment of substrate: The voltage changes with duration in various pretreatments utilizing the same biomass (oil cake) is depicted in Figure 1. The maximum voltage was obtained when microwave and alkali treatments were combined; this voltage reached 401±5 mV, which is a very good value. Alkali pretreatment led to the succeeding increased voltage value, after three days, the voltage reached 189±4 mV and only microwave treatment gave 152±3 mV compared to untreated produces 91±5mV. When compared to the untreated condition, the single physical treatments show average 1.5 times higher voltage production and chemical treatment alone displayed average 2 times higher voltage during the test. But when both treatments gave in combination it showed 3 times higher result. It may be due to increase digestion of substrate and releasing more sugar as described by Ibrahim et al., 2015. According to Ibrahim et al., 2015, the alkaline pre-treatment of oil palm empty fruit bunches (OPEFB) with 2% NaOH resulted in about 32 g/L of sugar. Additionally, oil palm de-oil cake OPDC has been tested with alkaline pre-treatment, which increased sugar production from less than 1 g/L (untreated) to about 6 g/L with pre-treatment using 1% of NaOH (Amalina et al., 2022; Razak et al., 2012). Figure 2 present Power density (PD) and Current Density (CD) variation when both pretreatments were given simultaneously.
As nowhere in MFC researchers had used pretreatment of substrate so comparative literature is not available but Ewunie et al., 2021, discovered that pre-treating the Jatropha press cake (JPC)for biogas production with 7.32% NaOH at 35.86 °C for 54.05 hours was optimum to increase digestion and even more effective than codigestion with crude glycerol.
Insert Figure 1
Insert Figure 2

3.1.2 Anodic electrogene: Figure 3 demonstrates the way voltages vary over time in the MFC test as a result of various electrogene. It is evident that each MFC's voltage raised gradually over time, approaching its maximum value in three to five days. When several organisms were used as the electrogene of the MFCs, higher voltage was obtained in the order of E. coli, native flora, and P. aeruginosa. For the MFC with 3% E. coli as electrogene in 10% GOC, the maximum power per anode area is 264mW/m^2 and Pseudomonas give 220mW/m^2. Figure 4 presents the variation of PD and CD with different electrogene tested here.
Jahnke et al., 2021 checked the behaviour of E. coli strains on gold electrodes was investigated in 40 mL U-tube MFCs and small-scale (240 µL) MFCs. In the small-scale MFCs, there is a conspicuous relationship between a strain's affinity for a gold surface and the peak voltage generated during MFC operation; strains exhibiting peptides with high affinity for gold produce potentials greater than 80 mV, while strains displaying peptides with minimal affinity for gold produce potentials surrounding 30 mV.
Where as in our work E. coli generate 136mV and P. aeruginosa generate 124mV. High-affinity gold-loving E. coli strains in the bigger MFCs reach power densities of up to 0.27mW/m^2. According to research by Aiyer (2021), pure cultures of P. aeruginosa and E. coli produced power densities of 158.76 and 139.24mW/m^2, respectively, while the co-culture produced an improved power density of 190.44mW/m^2. Subsequently, the cathode chamber was injected with the photosynthetic alga Chlorella vulgaris. Co-cultures with C. vulgaris increased the mean power density by 41.7%, from 175mW/m^2 to 248mW/m^2. When C. vulgaris was combined with the co-cultures, a synergistic effect was seen. These suggest possibility of future work of co-culture study but without this also single electrogene give comparable fare power generation though these are non-genetically engineered strains.
Insert Figure 3
Insert Figure 4

3.1.3 Cathodic electron acceptor: The anodic chamber was fixed with 10% oil cake and in cathodic chamber the catholyte was changed with $KMnO_4$, $K_2Cr_2O_7$, $K_3[Fe(CN)_6]$ and NaCl which was compared with distilled water. In this two-chamber MFC catholyte is in the 10 mM aqueous solution which were adjusted at pH 7.0. It was observed that sodium chloride permanganate induced higher OCP of 142mV and146mV respectively, compare to $K_2Cr_2O_7$ 119mV and $K_3[Fe(CN)_6]$ 101mV were achieved. Figure 5 shows how altering the catholyte materials causes the voltage to vary over time. For $KMnO_4$ and NaCl, the higher power densities were about 291mW/m^2 and 279mW/m^2. The power was around 211mW/m^2, 137mW/m^2, 104mW/m^2 for $K_2Cr_2O_7$, $K_3[Fe(CN)_6]$ and distilled water, respectively. As a catholyte, $KMnO_4$ and NaCl performed significantly better than $K_2Cr_2O_7$, $K_3[Fe(CN)_6]$ and pure water. Here figure 6 shows variation of PD andCD with use of NaCl and $KMnO_4$.
According to research by You et al., 2006, utilizing permanganate as the cathodic electron acceptor for a two-chamber MFC resulted in a maximum power density of 115.60mW/m^2, which was 11.3 and 4.5 times higher than that of utilizing oxygen (10.2mW/m^2) and hexacynoferrate (25.62mW/m^2). This may be explained by the MFC's permanganate's increased open circuit potential (OCP).
Of the four electron acceptors, potassium persulfate was found to be more appropriate; it had a higher open circuit potential (OCP) but maintained the voltage for a significantly longer amount of time than permanganate. Voltage and power generation by Potassium permanganate, potassium persulfate, potassium dichromate and potassium ferricyanide are 1.11V; 116.2mW/m^2, 1.10 V; 101.7mW/m^2, 0.76 V; 45.9mW/m^2, 0.78 V; 40.6mW/m^2 respectively (Pandit et al., 2011).
Insert Figure 5
Insert Figure 6

3.2 Influence of admixture (fly ash): Fly ash is very alkaline and includes a variety of nutrients. Fly ash is consequently thought to encourage the organic matter's breakdown in MFC. Figure 7 displays the voltage variation over time for the MFCs with and without fly ash. The MFC with fly ash had a lot greater voltage for the same amount of time than the one without fly ash, and it grew much more quickly. While the MFC without fly ash peaked on the seventh day, the MFC with fly ash mixture peaked on the third day. It is believed that combining fly ash accelerates the breakdown of organic materials (Moqsud et al., 2013). Specifically, the addition of fly ash enhanced the MFC's ability to generate power. The highest power per cathode area was 341mW/m^2 for the MFC by mixing fly ash and without fly ash was 114mW/m^2. Figure 8 presedts variations of PD and CD with use of fly ash and without use of it.
The voltage with and without fly ash by oil cake MFC are 159±7mV and 92±8mV respectively. Tremouli et al., 2023 showed that bio circular economy addition of fly ash can be noteworthy solution. Moqsud & Khong, 2020 observed that due to blending of fly ash voltage production was increased up to 350mV.
Insert Figure 7
Insert Figure 8

3.3 Influence of reuse of salt bridge: Microbial fuel cells (MFCs) use microbes to convert organic materials into power. Salt bridges in MFCs assist in moving ions between the anode and cathode compartments in order to maintain electrical neutrality. The functionality of the MFC may be impacted by reusing these salt bridges. Apart from the electrogene, pretreatment, catholyte, admixture, we also looked into the effects of newly constructed and reused salt bridges. Fig. 5 illustrates the voltage generation in three repeated use of salt bridge up to 15 days. It was seen that maximum power reached about 571mW/m^2 by reusing salt bridge first time compare to fresh utilization of salt bridge (340mW/m^2). Repurposed salt bridges may initially generate twice as much electricity due to acclimatization. The second reuse show decrease in value of power (39mW/m^2) due to its fouling or degeneration of material may eventually cause a decrease in ionic conductivity. This shows excessive reuse decreases the potential, through decreasing proton transfer and increasing oxygen diffusion, adversely affects voltage generation. A higher internal resistance brought on by decreased ionic conductivity may restrict the effectiveness of electron transfer and lower MFC performance as a whole. Because salt bridges are exposed to extreme chemical conditions in the MFC environment, they may deteriorate over time. Salt bridges that have aged or sustained damage should not be reused since this may reduce their longevity and increase maintenance requirements for the MFC. The highest stable voltage output observed with

new salt bridge employed for the first time was 0.16 V. Upon usage for the second and third times, the MFC demonstrated a maximum output of 0.21V and 0.11V. The current density measured from the salt bridge's first, second, and third usage systems was 2142mA/m^2, 2775mA/m^2, and 728mA/m^2, in that order. Results showing lower power density and current density on second reuse suggested that salt bridge reuse can be advantageous only up to second time usage (Chae et al., 2008; Chiu et al., 2016).
The Mukherjee et al., 2021 study. Using 5 mM sodium benzoate, a maximum power density and current density of 18.15mW/m^2 and 370.37mA/m^2 with the reuse of the salt bridge in MFC investigation, demonstrating that it is a cutting-edge technology for the development of bio-based circular ecosystems.
Insert Figure 9 The voltage generation in three repeated use of salt bridge

4. CONCLUSIONS

The following are the primary findings of this paper:
Groundnut oil cakes as other organic wastes can be used to directly produce power using a microbial fuel cell as well produce higher electricity that low carbon waste. When physical and chemical pretreatments are given that improve bioelectricity production by nearly 1.5 and 2 times respectively. But when these treatments were given in combination it improves electricity production by 3 times, it shows combined pretreatment does more biodegradation compared to working alone. About 140 mV is the electromotive force of MFC containing E. coli than it comes to P. aeruginosa and native organisms. For the MFC with E. coli, the maximum power per cathode area is 264mW/m^2. When four electron acceptors, $KMnO_4$, $K_2Cr_2O_7$, $K_3[Fe(CN)_6]$ and NaCl were compared with control for electricity generation, NaCl and $KMnO_4$ works well as catholyte, as well NaCl is also healthy for the environment. The MFC with fly ash generate higher voltage than the one without fly ash. The maximal power per cathode area for the MFC using fly ash mixture is 340mW/m^2. It is believed that combining fly ash accelerates the breakdown of organic materials. Higher power generation from first reuse is more cost-effective. To maximize power output in the MFC, additional pretreatments and cathode and anode materials can be done in future.

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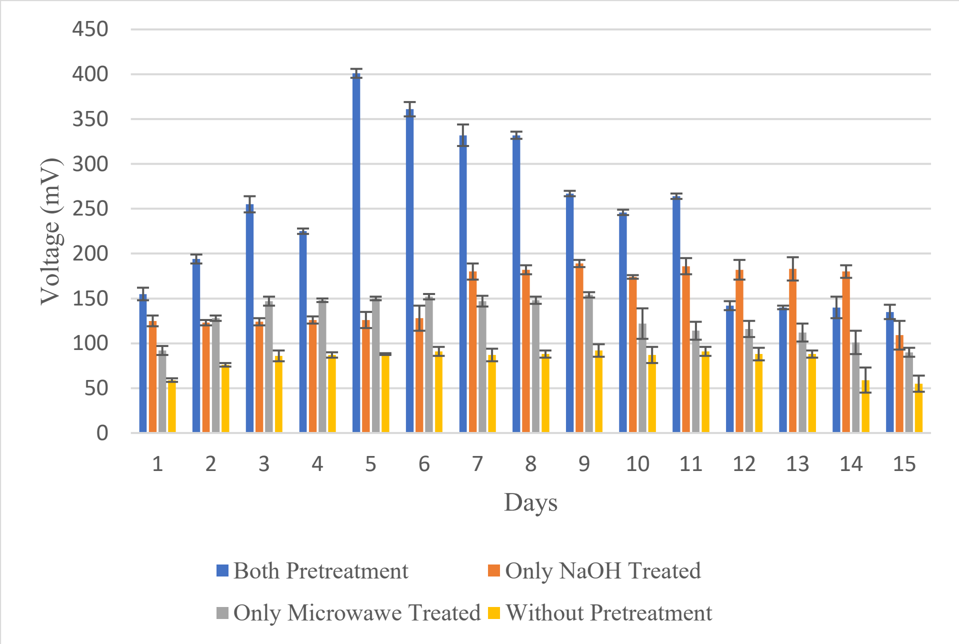

Figure 1 The variation of voltage with different pretreatment of GOC

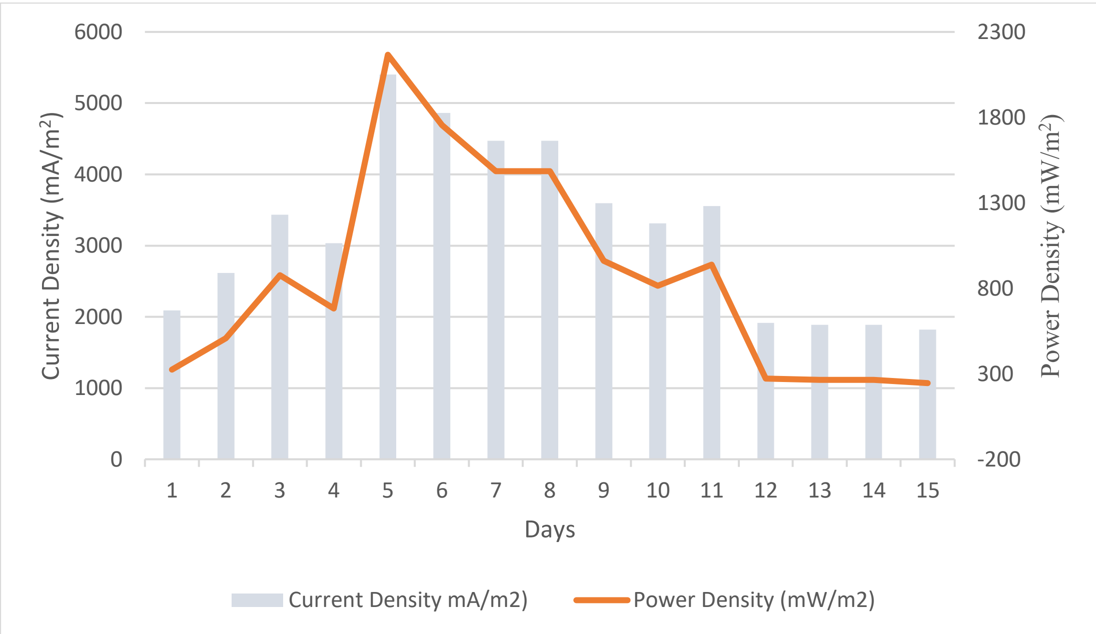

Figure 2 Variation of PD and CD when both pretreatments were given

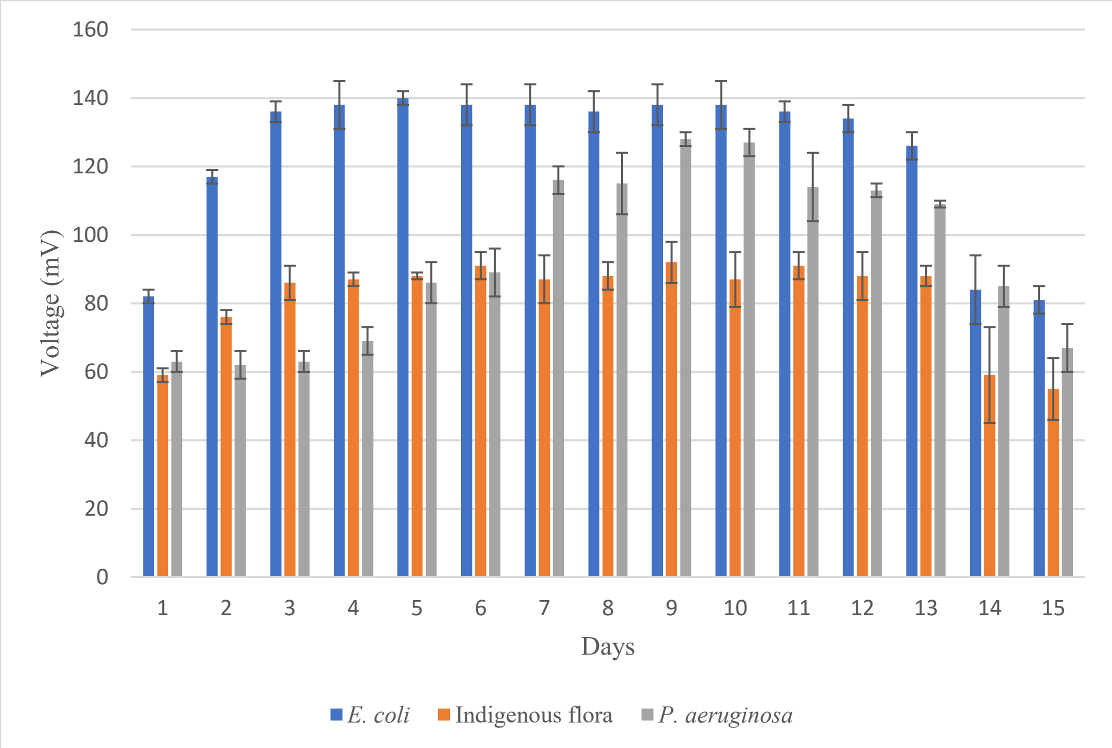

Figure 3 The voltage generation from different electrogene (E. coli, indigenous flora and P. aeruginosa)

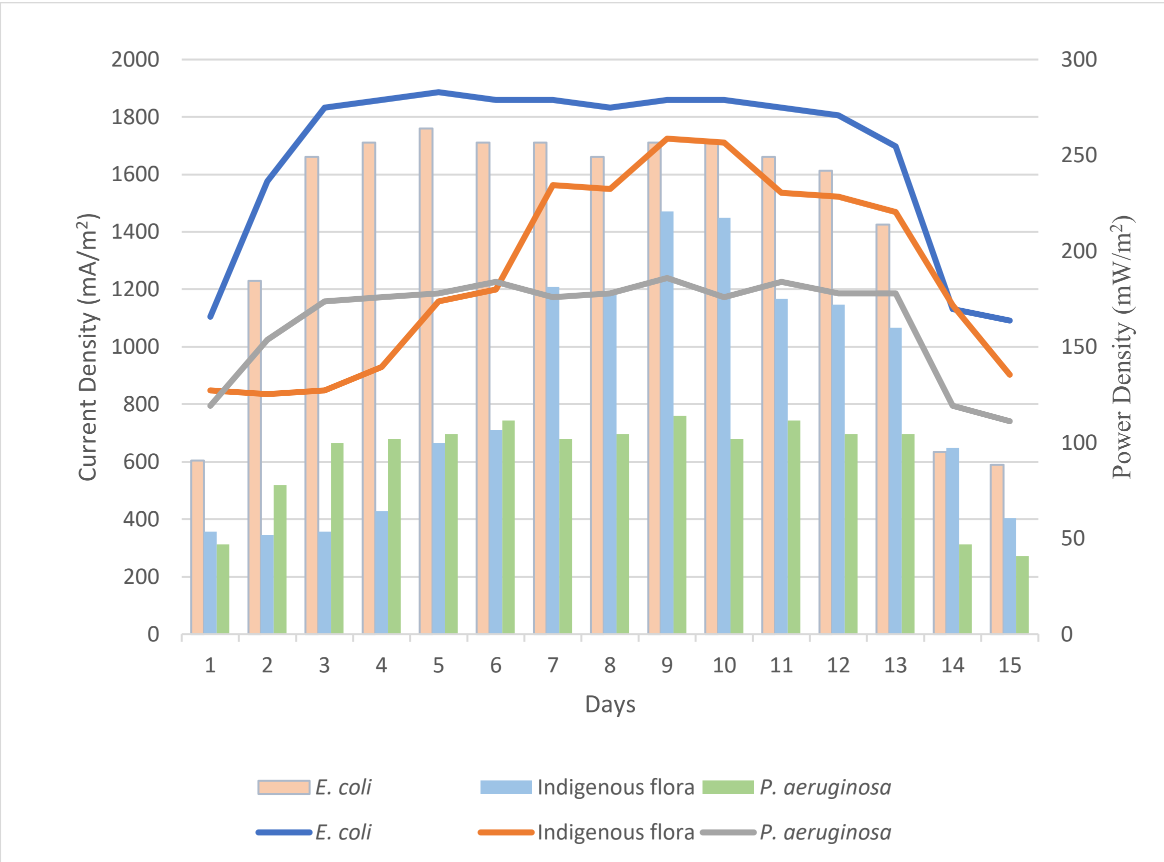

Figure 4 Variation of PD and CD with different electrogene

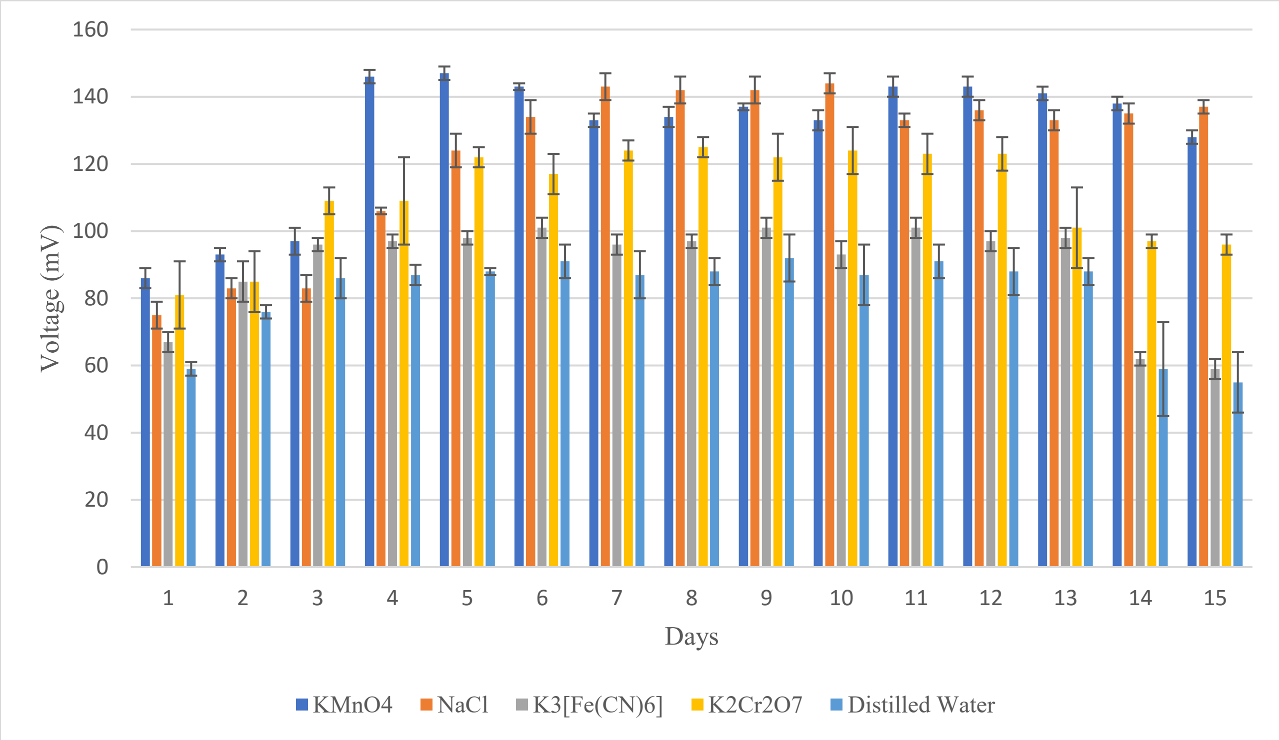

Figure 5 The variation of voltage with different electron acceptors

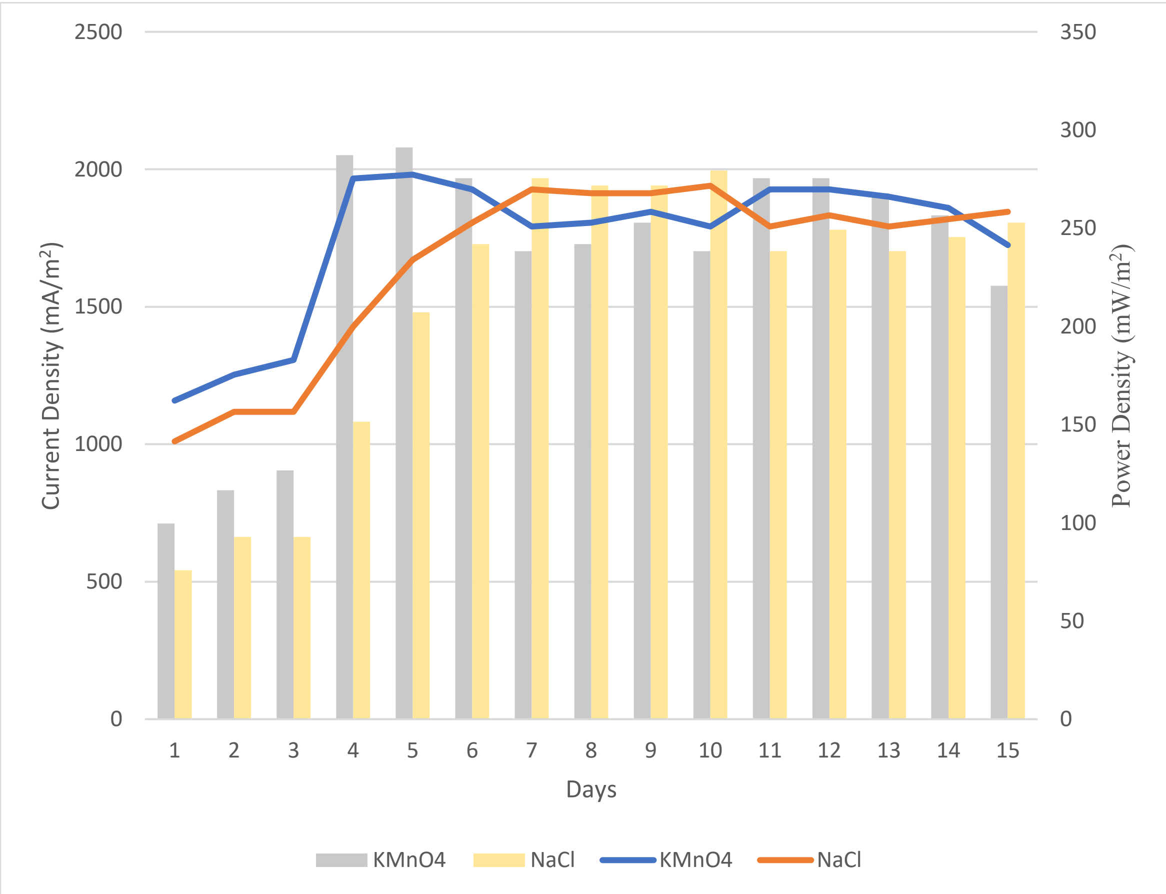

Figure 6 Variation of PD and CD with use of NaCl and $KMnO_4$ as electron acceptor

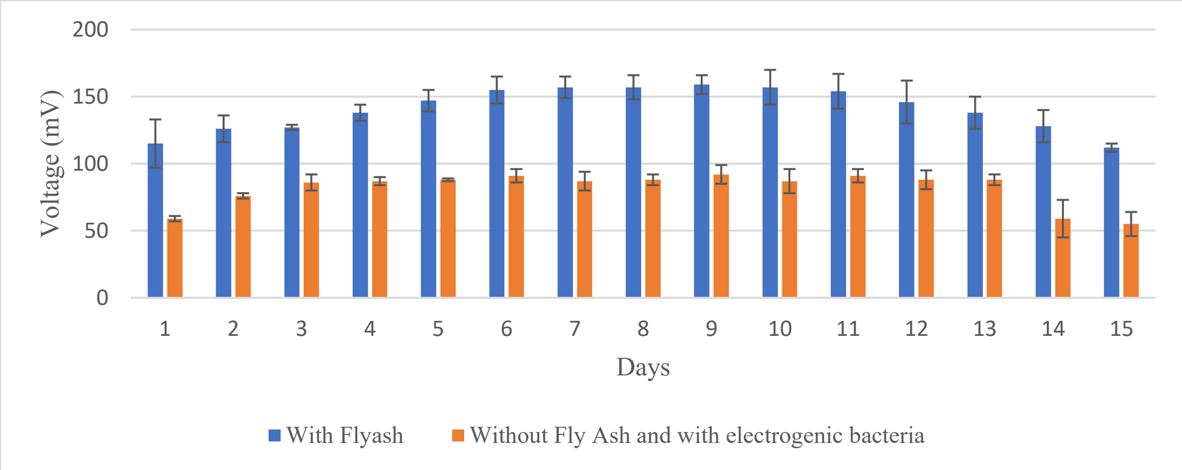

Figure 7 The comparison of voltage generation with and without using admixture (fly ash)

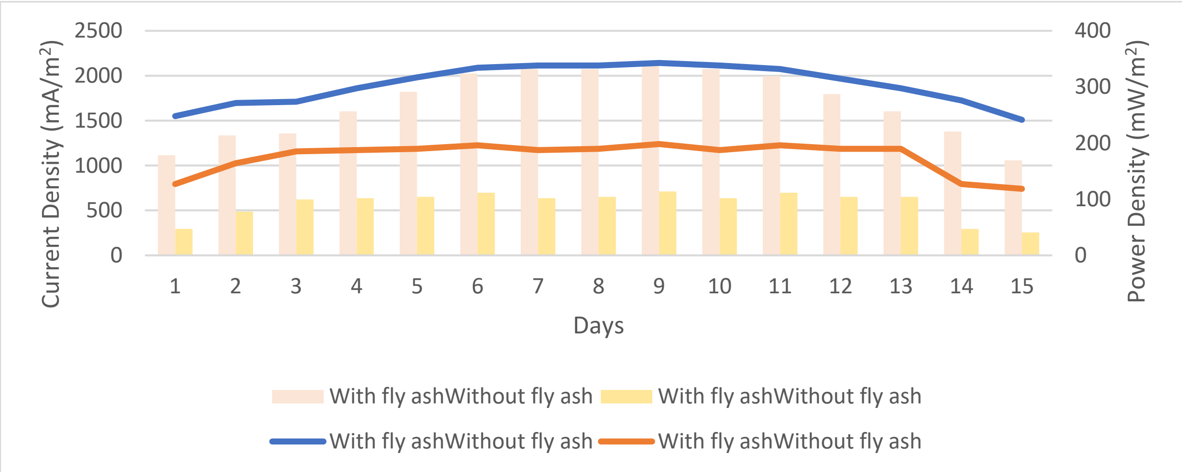

Figure 8 Variation of PD and CD with and without using admixture (fly ash)

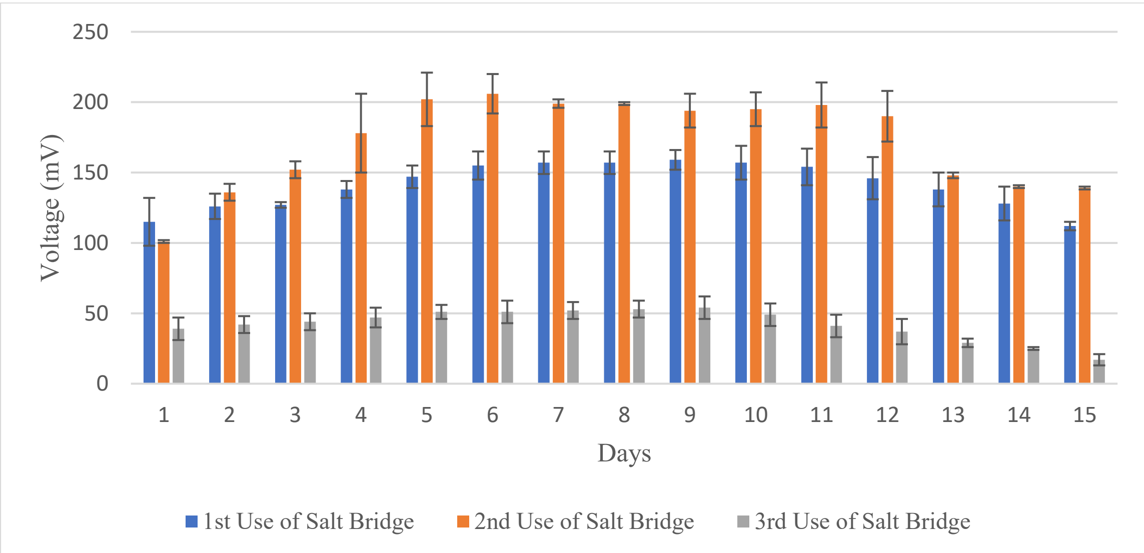

Figure 9 The voltage generation with three repeated use of salt bridge

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Table 1 Characterization of GOC

Table 2 Design of optimization experiments

Table 1 Characterization of GOC

C%	H%	N%	S%	cellulose	Lipid	Organic matter	Total solid	
42.93±0.6	4.5±0.27	7.3±0.46	0.38±0.04	0.66±0.39	15.2±1.83	94.77±0.67	86.6±0.44	Present study
42	5.8	6	0.31				5.8	L.J. Wang 2013
46.37	7.015	6.86	0.287		4.18	83		Agrawalla et al., 2011

Table 2 Design of optimization experiments

Aim of Experiment	Set	Anodic Chamber	Cathodic Chamber
Optimization of anodic electrogene	A	3% E. coli culture +10% GOC	Distilled Water
	B	3% P. aeruginosa culture +10% GOC	Distilled Water
	C	10% GOC	Distilled Water
Optimization of electron acceptor	A	10% GOC	10mM NaCl
	B	10% GOC	10mM $KMnO_4$
	C	10% GOC	10mM $K_2Cr_2O_7$
	D	10% GOC	10mM $K_3[Fe(CN)_6]$
	E	10% GOC	Distilled Water
Optimization of pretreatment of substrate	A	10% GOC 1N NaOH Treated	Distilled Water
	B	10% GOC (Microwave Treated)	Distilled Water
	C	10% GOC (Both NaOH and Microwave Treated)	Distilled Water