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BIOELECTRICITY PRODUCTION EMPLOYING MICROBIAL FUEL CELL USING COMPLEX MEDIA AND WASTES

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Abstract:

A Microbial Fuel Cell (MFC) is a technique that converts the chemical energy of the chemical bonds in organic compounds to electrical energy by the catalytic reaction of microorganism under anaerobic condition. Due to recent energy crisis MFC shows reveal high efficiency regarding electricity production and waste water treatment. By breaking the complex molecule into simple molecule such as degradation of organic waste water can reuse successfully. Recent research is going on to reduce the cost and to increase the efficiency of energy production. In present study, complex media, dye waste, sugar industry waste had been used as substrates for bioelectricity production. It was found that all the reactors were run more than 20 days and maximum bioelectricity yield was 250mV.

Key words: Microbial fuel cell (MFC), Anode, Cathode, Salt bridge

Introduction

“Microbial Fuel Cell (MFC) is a technology; in which microbes are used to convert the energy stored in chemical bonds present in organic biodegradable compounds to electrical energy by its catalytic reaction.”(Reddy et.al.2010) Microbial fuel cells have operational and functional advantages over the technology for generating energy from organic matter. Other than electricity production, MFC participate in waste water treatment. MFC offers almost 90% possibility of extracting electrons from organic Compound. MFC is a multipurpose bioreactor in which electricity generation, dye degradation, decrease in COD level as well as toxicity of waste water can be done. (Reddy et.al.2010) The theoretical concept of Microbial Fuel Cell was given by M. Potter in 1911. He explained that most microbes can be potentially used as a biocatalyst in MFC. He also tried to demonstrate this concept by using *Escherichia coli* as microbes and platinum as electrodes. Although the experiment was not efficient but it is the basic concept on which the technology is based. However the efficient practical application of MFC was started almost after 70 years i.e. in 1980. It was discovered that current density and the power output could be generated in high amount. Since that day research is going on to increase the efficiency. Microbial fuel cell that treat domestic waste water were presented on 1991. The electrolytes used in MFC should be organic as well as biodegradable. Here bacteria used as catalyst which oxidise organic compounds and generate electrons. (Z. Du et.al. 2007). Along with the growing population and decrease in the natural non-renewable energy sources we need alternative source of energy. The use of fossil fuels, especially oil, gas and coal lead to global energy crisis as they are non-renewable energy source. Another alternative is to use positive potential energy of stored water as a source of electricity generation but it cannot fulfil all the requirement of energy. The energy source should be renewable so that we can also use the source for future use. The energy source should be pollution free or less pollutant so that global pollution can be reduced. Microbial fuel cell can fulfil all above requirement. Although it's efficiency to generate electricity is low as compare to other but research is going on to overcome this problem. (Z. Du et.al.2007)

Basically MFC consist of:

1. Anode (anodic chamber)
2. Cathode (cathodic chamber)
3. Salt bridge (proton exchange membrane PEM)

Bacterial community present on anode compartment uses organic substrates as fuel to produce electron and proton through biological process. These electrons are accepted by NADH in the electron transport chain and subsequently transferred to



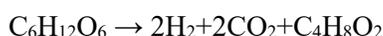
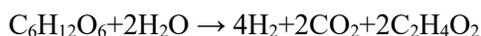
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terminal electron acceptors such as nitrate, sulphate, oxygen and then reaches to outer membrane proteins. Bacteria then transfer the electron to anode from where electron reach to cathode via an external electric circuit and produce electric current which can be measured by a voltmeter or ammeter.

Proton generated was diffuse through the salt bridge (PEM) to the cathode then combine with the electrons and oxygen to form water. The anode compartment is typically maintained in anaerobic condition as oxygen inhibits electricity generation where as the cathode is exposed to oxygen.

Reaction when glucose used as substrate:



On the other hand, dyes are widely used in different industries, especially in the textile manufacturing. Wastewater produced from dying process contains 10–15% of these dyes. Treatment of effluents containing dyes is indispensable due to their toxicity, carcinogenic impact and pollution effect on environment. Dyes also affect the clarity and oxygen solubility of water streams which has impact on aquatic life. Recently, several studies have focused on the treatment of dye containing wastewaters in MFC. Other than dye now experiment is going on by using sugar industry waste, Molasses, feather waste and iron rich media as electrolytes in MFC. (Z. Du et.al. 2007)

In order to understand and try to find out the solution for the major problem like pollution, energy requirement, increase in toxicity level of marine water following objectives has been followed:

1. Bioelectricity generation by using different complex media employing Microbial Fuel Cell.
2. To check decolourization of dye and toxicity analysis of metabolites.
3. Assessment of C.O.D. before and after dye decolourization.

The purpose of this literature review is to organize relevant information and apply the principles of a feasibility study to MFC technology. Theoretically, most microbes can potentially be used as a biocatalyst in MFC. The earliest MFC concept was demonstrated by Potter in 1910. Electrical energy was produced from living cultures of *Escherichia coli* and *Saccharomyces* sp. by using platinum electrodes (Potter, 1912). This didn't generate much interest until 1980s when it was discovered that current density and the power output could be greatly enhanced by the addition of electron mediators.

Unless the species in the anodic chamber are anodophiles, the microbes are incapable of transferring electrons directly to the anode. The outer layers of the majority of microbial species are composed of non-conductive lipid membrane, peptidoglycans and lipopolysaccharides that hinder the direct electron transfer to the anode. Electron mediators accelerate the transfer (Davis and Higson, 2007). Mediators in an oxidized state can easily be reduced by capturing the electrons from within the membrane. The mediators then move across the membrane and release the electrons to the anode and become oxidized again in the bulk solution in the anodic chamber. This cyclic process accelerates the electron transfer rate and thus increases the power output. Although a mediator with the lowest redox would in theory give the lowest anodic redox and thus maximize the redox difference between anode and cathode (i.e. give biggest voltage difference) it would not necessarily be the most efficient at pulling electrons away from the reduced intracellular systems (NADH, NADPH or reduced cytochromes) within the microbes.

Typical synthetic exogenous mediators include dyes and metalloorganics such as neutral red (NR), methylene blue (MB), thionine, meldola's blue (MelB), 2-hydroxy-1,4-naphthoquinone (HNQ), and Fe(III)EDTA (Park and Zeikus, 2000; Tokuji and Kenji, 2003; Veag and Fernandez, 1987; Allen and Bennetto, 1993; Ieropoulos et al. 2005a). Unfortunately, the toxicity and instability of synthetic mediators limit their applications in MFCs. Some microbes can use naturally occurring



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compounds including microbial metabolites (Endogenous mediators) as mediators. Humic acids, anthraquinone, the oxyanions of sulphur (sulphate and thiosulphate) all have the ability to transfer electrons from inside the cell membrane to the anode (Lovley, 1993).

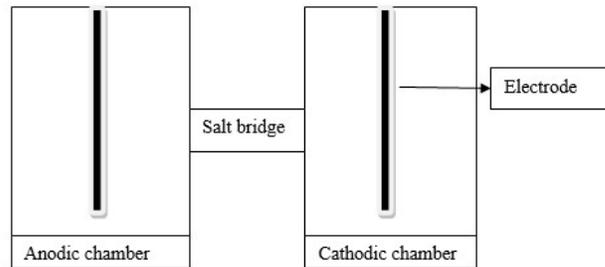
A real breakthrough was made when some microbes were found to transfer electrons directly to the anode (Kim et al., 1999a, Chaudhuri and Lovley, 2003). These microbes are operationally stable and yield a high Columbic efficiency (Chaudhuri and Lovley, 2003; Scholz and Schroder, 2003). *Shewanella putrefaciens* 466 Z. Du et al. / Biotechnology Advances 25 (2007) 464–482 (Kim et al., 2002), *Geobacteraceae sulfurreducens* (Bond and Lovley, 2003), *Geobacter metallireducens* (Min et al., 2005a) and *Rhodospirillum rubrum* (Chaudhuri and Lovley, 2003) are all bioelectrochemically active and can form a biofilm on the anode surface and transfer electrons directly by conductance through the membrane. When they are used, the anode acts as the final electron acceptor in the dissimilatory respiratory chain of the microbes in the biofilm. Biofilms forming on a cathode surface may also play an important role in electron transfer between the microbes and the electrodes. Cathodes can serve as electron donors for an MFC system that contained microbes in both anodic and cathodic chambers. *G. metallireducens* and *G. sulfurreducens* (Gregory et al., 2004) or other seawater biofilms (Bergel et al., 2005) may all act as final electron acceptors by grabbing the electrons from cathode as electron donors. Since the cost of a mediator is eliminated, mediator-less MFCs are advantageous in wastewater treatment and power generation (Ieropoulos et al., 2005a). Studies have shown that the MFCs using expensive solid graphite electrodes, but less expensive graphite felt and carbon cloth, can also be used (Bond and Lovley 2003, Tender et al. 2002, Chundhuri and Lovley 2003, Lui et al. 2004). PEMs such as Nafion are also expensive and if removed, can substantially reduce the overall cost of the MFC. Platinum is a critical catalyst at the cathode and no alternative metal has been proven to catalyze the combination of oxygen, the hydrogen proton, and electron in a more efficient manner (Oh et al. 2004). These design parameters set a limit on the overall cost reduction of the MFC. Many microorganisms possess the ability to transfer the electrons derived from the metabolism of organic matters to the anode. Marine sediment, soil, wastewater, fresh water sediment and activated sludge are all rich sources for these microorganisms (Niessen et al., 2006, Zhang et al., 2006).

A number of recent publications discussed the screening and identification of microbes and the construction of a chromosome library for microorganisms that are able to generate electricity from degrading organic matters (Logan et al., 2005; Holmes et al., 2004; Back et al., 2004)

MATERIALS AND METHODOLOGY

1. Microbial fuel cell (MFC) chamber preparation

MFC chamber prepared by joining two containers by a pipe (worked as salt bridge). Two carbon electrodes were rinsed with 70% ethanol and electrode used as anode was wrapped with cotton cloth. After that the whole chamber was wiped by 70% ethanol and UV treatment was given for 20 minute. After that preprepared autoclaved media poured in anodic chamber and electrolytic solution (phosphate buffer/ $K_2Cr_2O_7$) poured in cathodic chamber than 30% inoculums was inoculated in anodic chamber. A multimeter was externally connected, blue (negative) with anode and red (positive) with cathode. Small amount of media was extracted aseptically and bio electricity generation, absorbance, pH, spectrum was observed and noted down regularly.



Schematic representation of MFC

2. Measurement of chemical oxygen demand (c.o.d.) done by following the formula

Formula:

$$\text{C.O.D. (mg/L)} = \frac{8 \times C V_B - V_A}{V_S}$$

(Ref : Book of K. R. Aneja)

3. Toxicity check of extracted metabolite against waste media (control) by paper disc method.

4. Thin layer chromatography (T.L.C.) of control and metabolites has been performed.

Results and Discussion



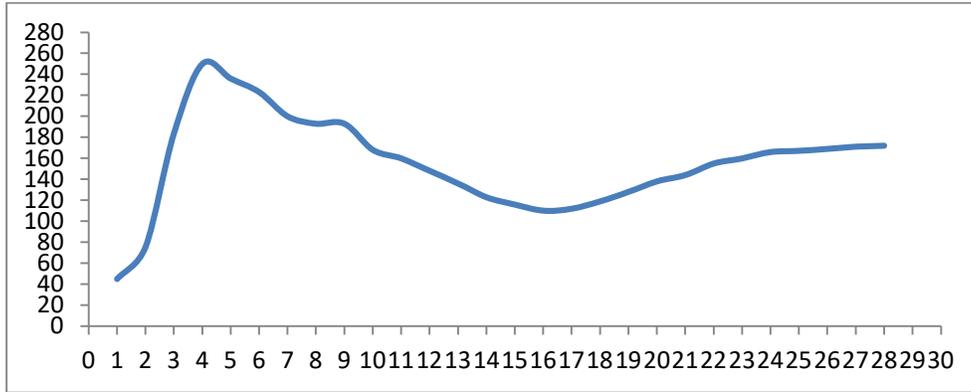
Initial stage of dye addition

In between stage of dye

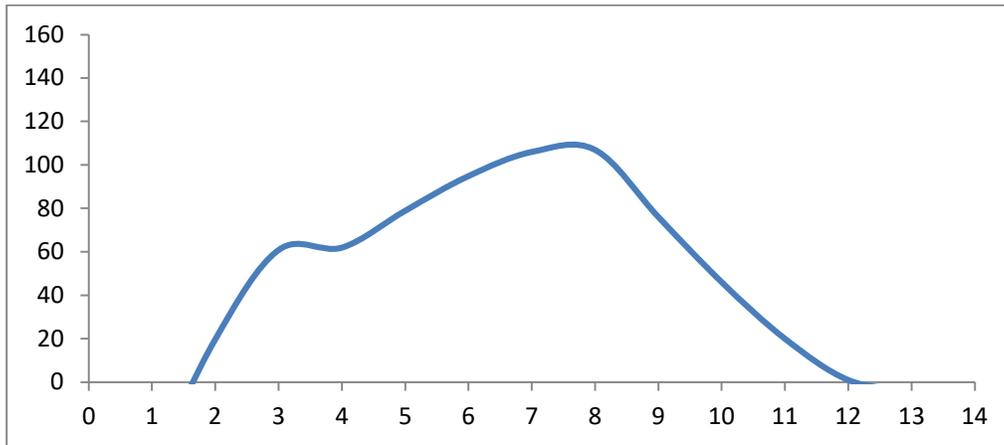
1. Bioelectricity generation (mV) by using different complex media.



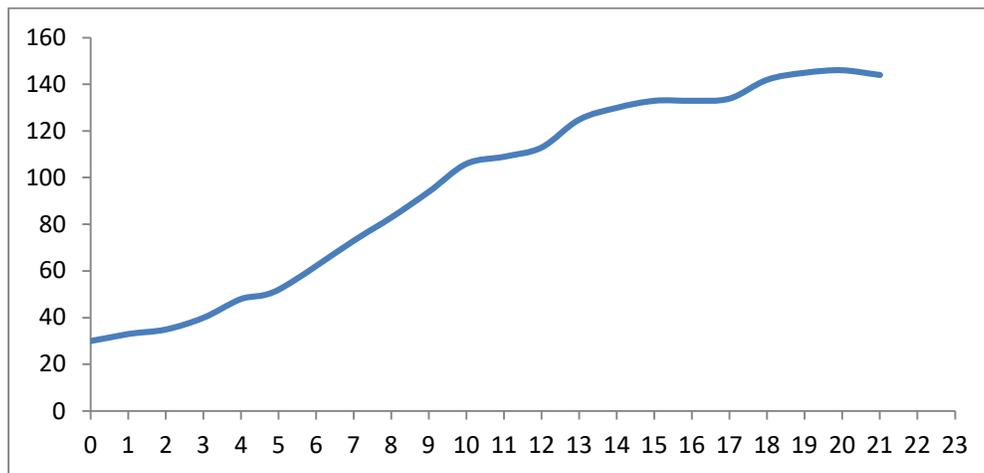
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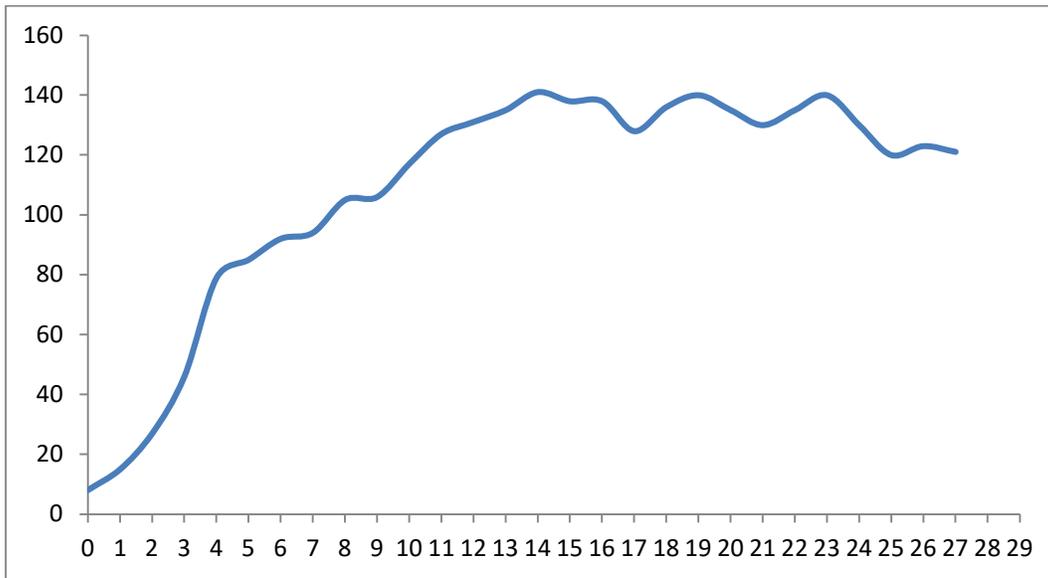
Bioelectricity generation in mV by using LB Media with MG



Bioelectricity generation in mV by using Iron Media

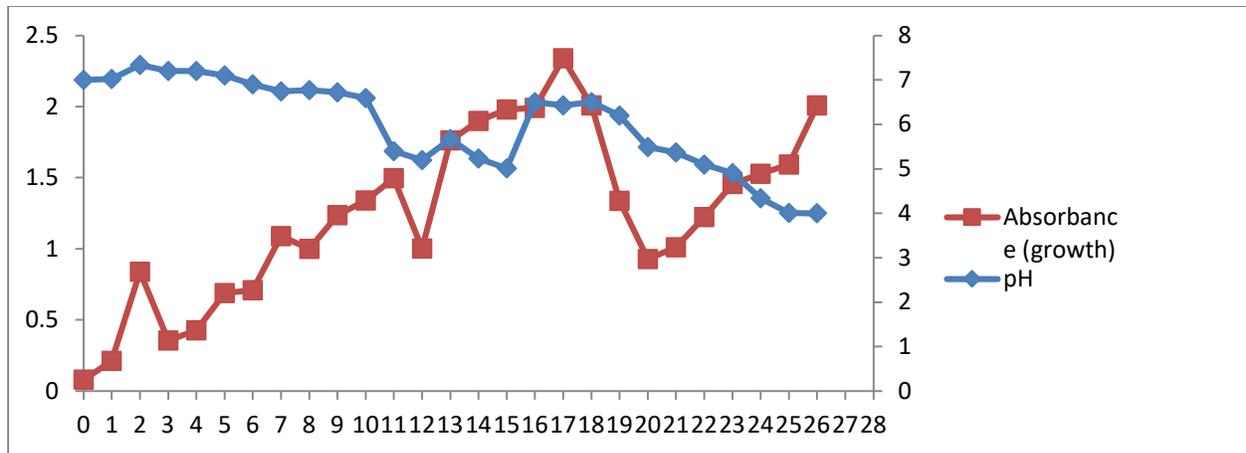


Bioelectricity generation in mV by using Molasses waste



Bioelectricity generation in mV by using FMB media

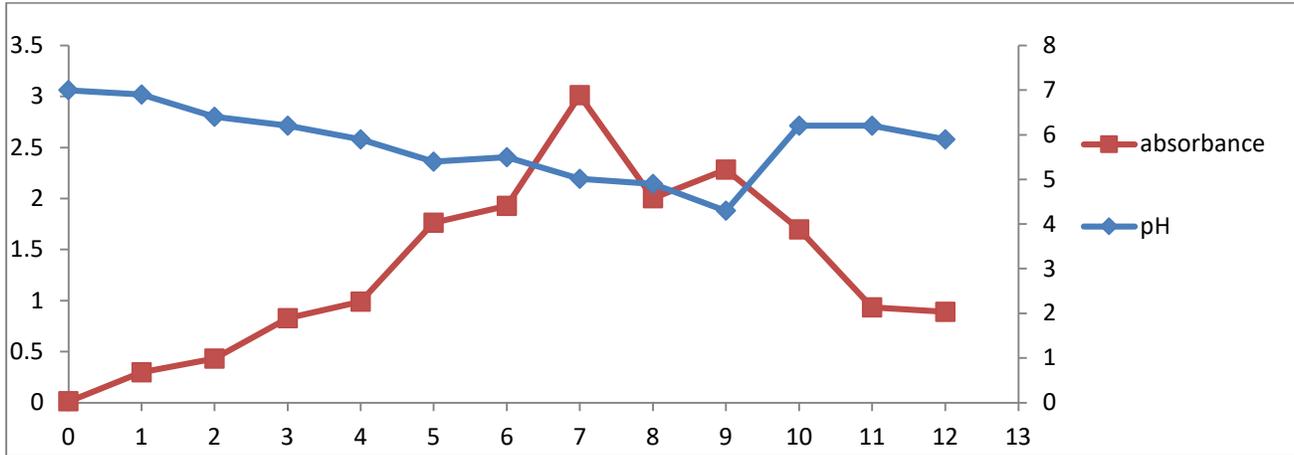
2. Growth of *Pseudomonas aeruginosa* (absorbance) and pH of media in MFC chamber.



Growth of *Pseudomonas aeruginosa* and pH of LB media containing MG

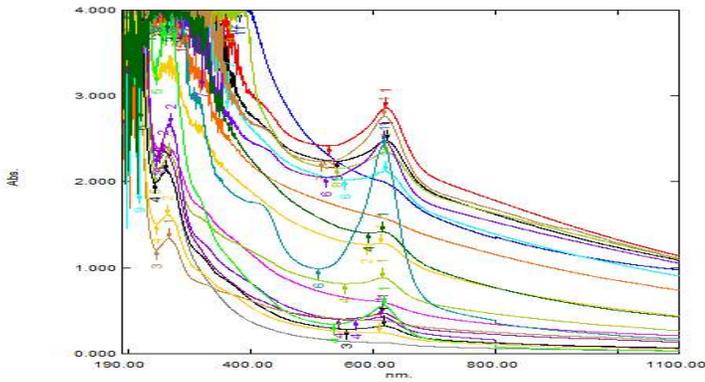


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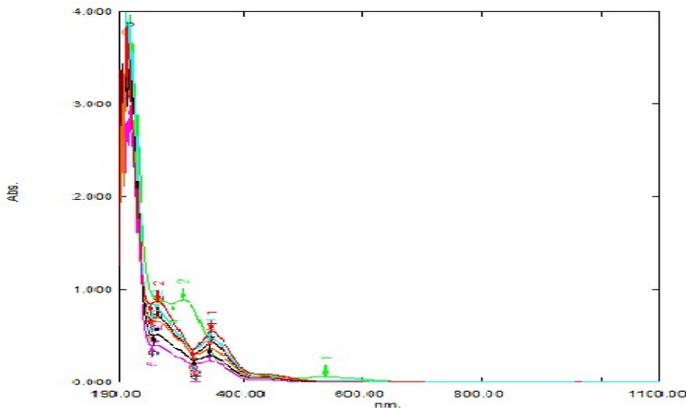


Growth of *Pseudomonas aeruginosa* and pH of Iron Media

3. Spectrum of different media (day wise)



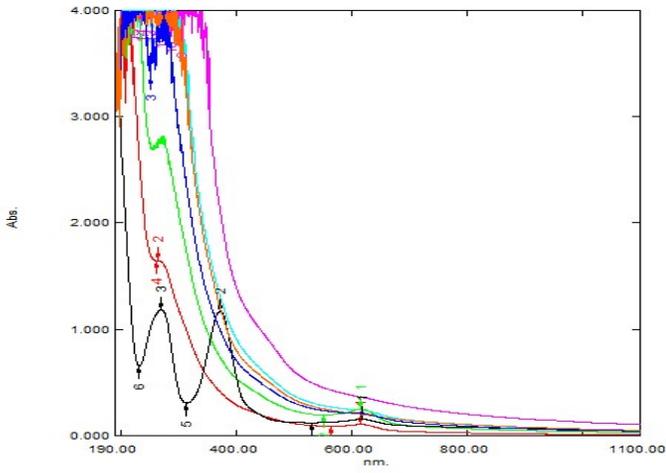
Spectrum of MG



Spectrum of $K_2Cr_2O_7$

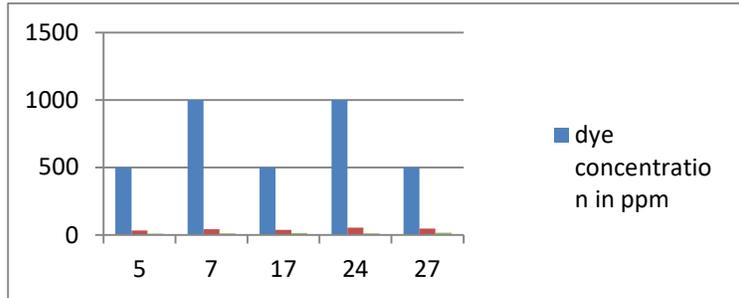


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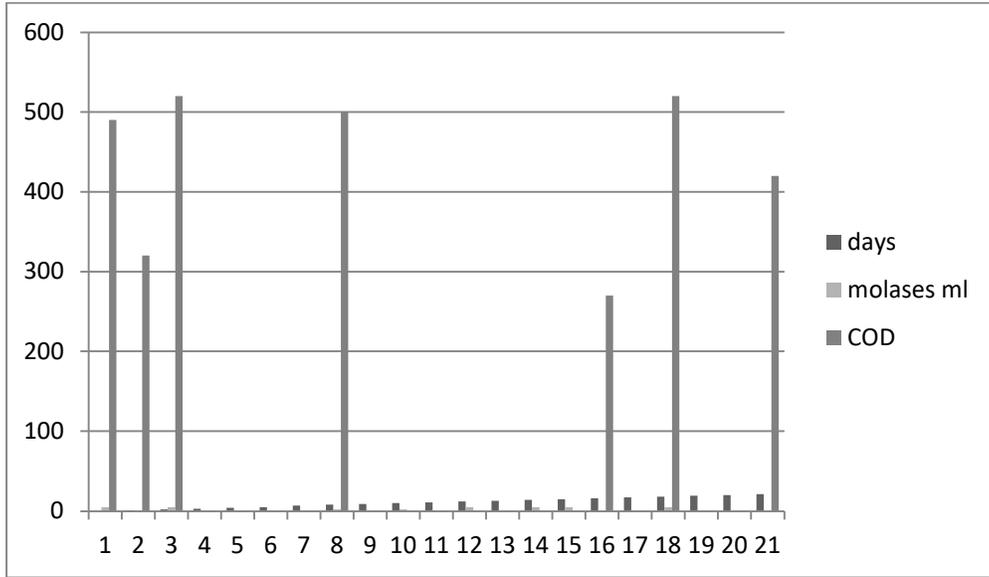


Spectrum of molasses

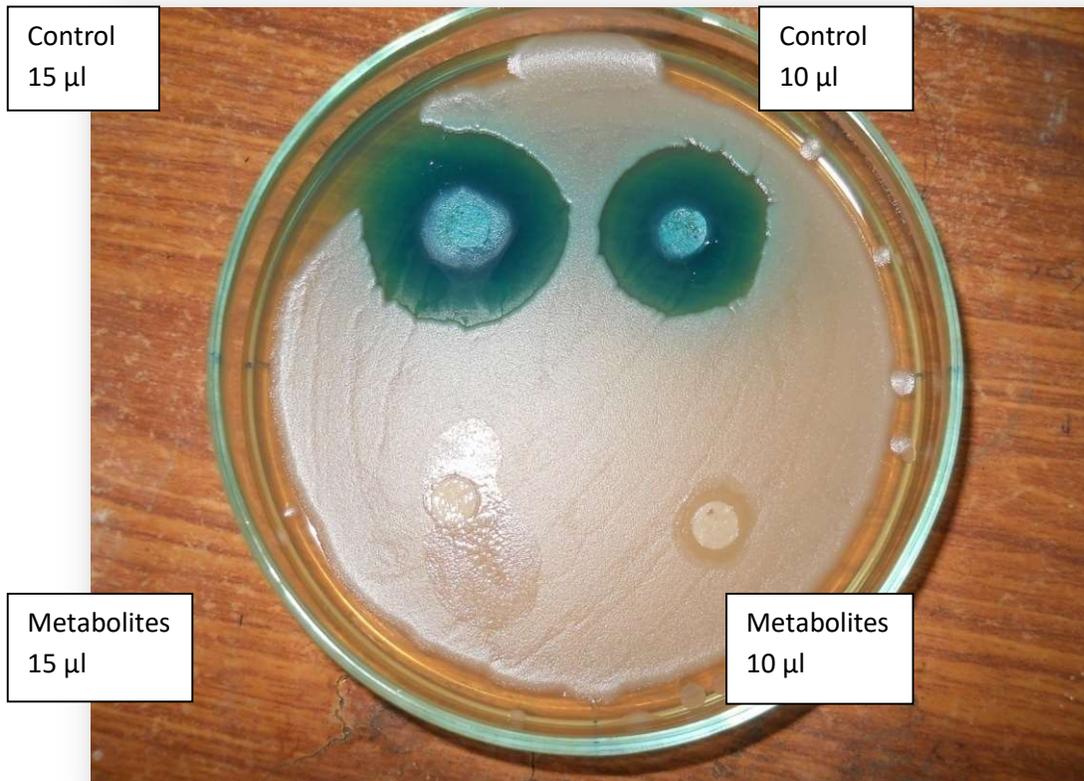
4. C.O.D. of media in different time interval



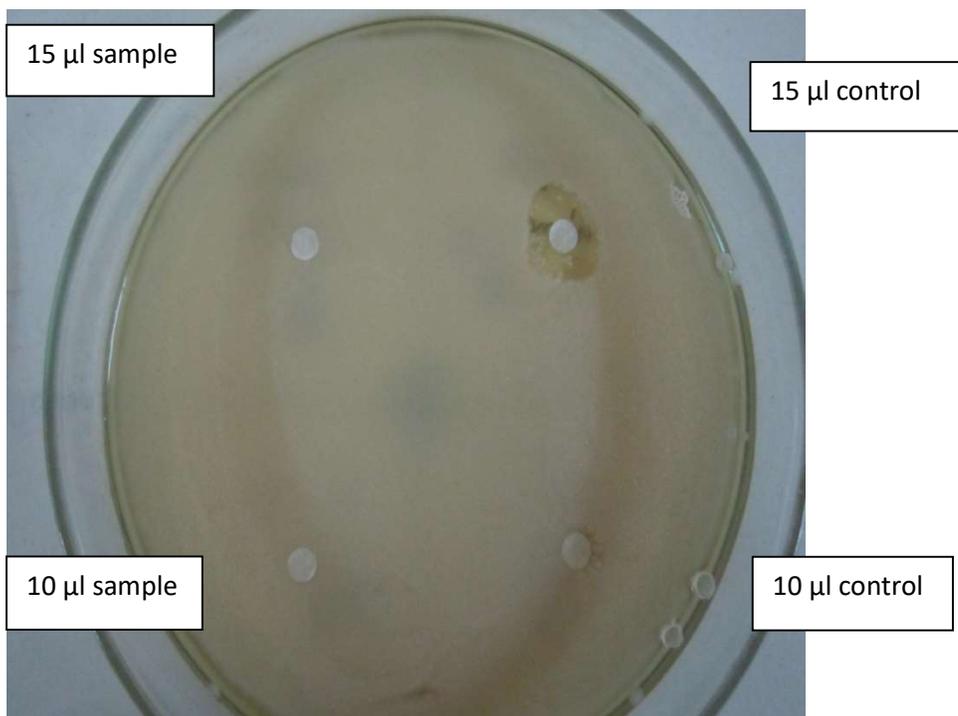
C.O.D. of LB Media containing MG



5. Toxicity check by paper disc method.

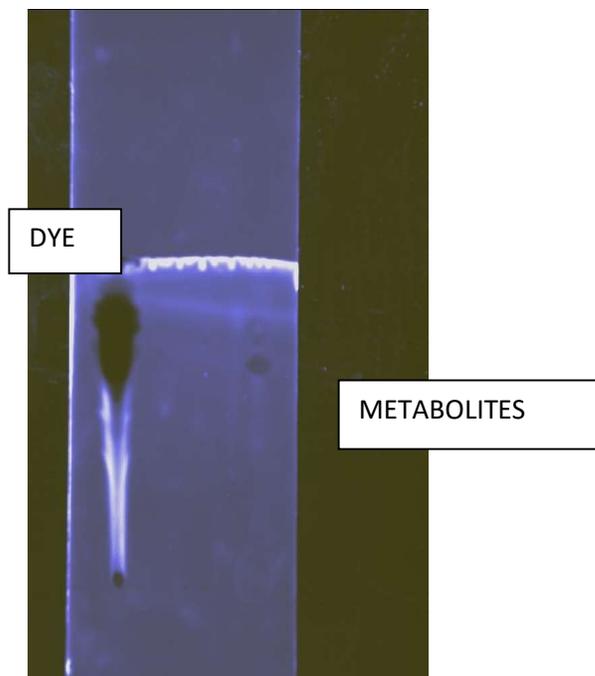


Toxicity check of metabolites of MG of anodic chamber (4000 ppm)



Toxicity of $K_2Cr_2O_7$ of cathodic chamber (40 ppm)

6. Thin layer chromatography of metabolites.





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DISCUSSION

1. Maximum productivity of MG, Iron, Molasses, Feather chamber was 250mV, 115mV, 145mV and 140mV respectively. However, MG rich chamber was run for maximum days (27 days). After a certain time period productivity got stationary then declined. Stability of chamber for more than 25 days increases the efficiency as well as decreases cost.
2. As growth of microbes increases it was observed that pH decreased. So, by maintaining pH optimum growth condition can be maintained which will increase the stability of chamber. As microbial growth increased bioelectric was also increased. By providing antifoaming agent, acid-base, proper agitation and temperature stability and yield of MFC chamber can increase tremendously. pH of all reactor decreases day by day (7.0 to 3.0).
3. Peak was decreased day by day showing degradation of MG, molasses and $K_2Cr_2O_7$.
4. COD level of media decreased spontaneously which shows that microbes degraded biodegradable organic waste so oxygen requirement for oxidizing chemical was reduced. After dye addition or molasses addition C.O.D. of media increases tremendously but after degradation it was come again to normal. It shows degradation of molecules took place.
5. In paper disc method zone of inhibition for control was clearly observed whereas for metabolites it was very small. It shows toxicity of corresponding organic compounds decreased tremendously.
6. Two clear spot was observed from TLC plate under gel doc, it indicate organic MG molecule broken down. Observed RF value for MG control was 0.77 whereas 0.75 and 0.65 for both metabolites.

Conclusion

Maximum bioelectricity productivity was found in malachite green (250mV) it indicates that crude MG and associated dye waste is beneficial for MFC. COD level of media decreases it indicates that molecules are degraded by breaking bonds which were confirmed by UV spectra and TLC. The toxicity study show that clear zone of toxic crude dye was large as compare to metabolites. This suggests that degraded dye metabolite was less toxic as compared to crude MG dye. Further studies can be performed to utilize MFC for large scale production and removal of organic rich waste from environment using sustainable approach for bioelectricity generation employing MFC.

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