Technological Aspects of Microbial Fuel Cells and Soil Based Green Energy Conversion System

Anand Kumar K.S., Sachin Kumar, R.K. Saket* and R. Rajendran

Abstract— *This paper presents technological aspects, operating principle, and scientific applications of the microbial fuel cell (MFC). The MFC is a technology for the extraction of clean energy from biomass such as organic wastes; hence, comes under Green Energy Conversion System (GECS). The cell uses bacteria as biocatalysts to generate electricity by digesting biodegradable organics present in the organic waste material, through a catalytic reaction of microorganisms under an anaerobic condition. MFC has received considerable attention to offering the possibility of biological waste treatment and energy production simultaneous. Only in a few biosensors, the MFC is used practically, providing current for low power devices. Some researchers are uncovering that the importance of MFC technology is not only the production of electricity but the ability of electrode associated microbes to degrade wastes and toxic chemicals. This paper provides a platform to explore the possibilities of generating renewable power using biomass and the working principle of MFC technology with its applications like biological oxygen demand sensing, wastewater treatment, etc. Therefore, the paper has suggested the methods for electricity generation using a soil based MFC and water extraction from grass clippings using MFC. The experimental results showed better results than the previous research works.*

Keywords— **Biocatalyst; grass clipping; microbial fuel cell; organic waste; remote sensors; wastewater; soil.**

1. INTRODUCTION

MFC is a sustainable approach to harvest electricity through a natural path. It utilizes organic-rich wastes with predominate carbohydrates as an electrolyte and thereby, the paradigm has been shifted, as the decay continues to metabolized electrical energy [1]. The MFC couples the conventional electrochemical cell with the bio-catalytic actions of microbes to harvest the bio-electricity. The concept idea of metabolic electricity was first proposed by Potter in 1911 to draw power by utilization of bio-catalytic life concerning exoelectrogens [2, 18]. In recent years, and it has emerged as a multi-dimensional technology owing to its numerous advantages over both conventional energy resources and existing waste treatment system [3]. MFC technology has brought an increased number of researchers in recent years because of its potential, particularly for bioenergy production and waste treatment. Fig.1 reflects in the number of articles published in the last ten years that has been progressed successively from year to year. A number of publications in the last decade show an increase in interest of MFC technology among researchers. The data are based on the number of articles mentioning 'microbial fuel cell' in [43] to date.

Anand Kumar K.S. is with Electrical Division, CSIR-National Aerospace Laboratories, Bangalore-560017, India.

Sachin Kumar is with G. B. Pant Institute of Engineering and Technology, Pauri, Garhwal (Uttarakhand) India.

R.K. Saket is with Department of Electrical Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi (UP), India.

R. Rajendran is with Propulsion Division, CSIR-National Aerospace Laboratories, Bangalore-560017, India.

*Corresponding author: R.K. Saket, E-mail: rksaket.eee@iitbhu.ac.in.

Fig. 2 reveals a steep increase of interest in MFC research, reflected by an abrupt rise in the number of publications in the years from 2011 to 2018 as compared to the past years between 1981 and 2010.The Country-wise publications in MFC research, the top 20 countries concerning the number of articles published in the MFC research field is demonstrated in the pie chart of Fig. 3. Also, it is an eye-catching data that most of the researches are done in the field of energy and engineering as described in Fig. 4.

In India, 75.9 % (986,591 GWh) of the electricity comes from coal [4]. However, the coal-based thermal power plants in India are the least efficient, and therefore the most polluting in the world says a new study [5]. Carbon dioxide is the principal greenhouse gas that is causing climate change, which in turn is reducing farm output worldwide, raising sea levels and making droughts, storms, and floods more frequent and more severe. The study has to concentrate on renewable energy sources to ensure our energy security as well as to accelerate economic growth through green energy. In recent years, MFCs realize a most reassuring technology based on the turn of biochemical energy into bioelectrical energy via microbial catalysis [6, 7]. Amongst different kinds of fuel cells, MFCs defined as devices which directly converts microbial metabolism into electricity have attracted the researcher's attention [8]-[10]. MFCs are using soil micro-organisms represent the latest topic in the researches and developments [11]-[13]. MFCs are easy to fabricate and operate; these types of cells are based solely on the conversion of biochemical energy from the soil into bioelectricity [14]. Soils were having rich in complex sugars, and nutrients contain electrogenic microbes like Shewanella and Geobacter species [15]-[17]. The truth that these soil microbes live in abundance in all soils makes them an exciting prospect to examine their ability to release electrons and notice how with varying parameters are affected. Thus, this paper explores this phenomenon with the soil mixed with biomass and speculates the use of the produced power. Also, this work is extended in the production of water from grass clippings using MFC.

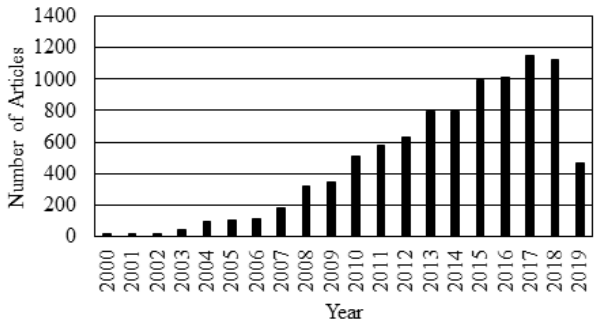


Fig. 1. The Number of Articles on Microbial Fuel Cells.

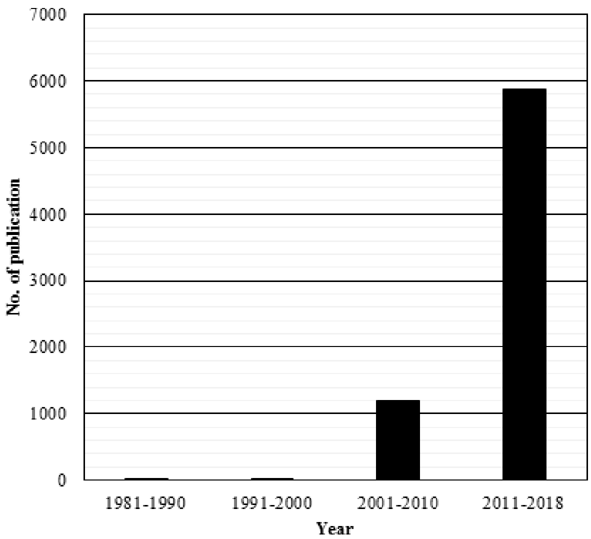


Fig. 2. An Abrupt Rise in Number of Articles on Microbial Fuel Cells.

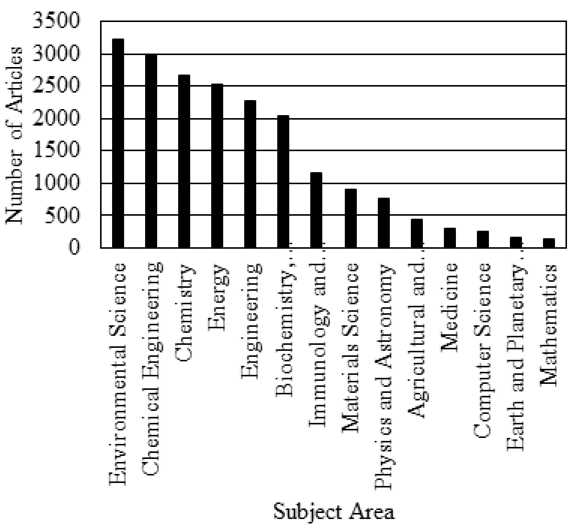


Fig. 3 The countries with their Researches on Microbial Fuel Cell.

MFCs are an innovative addition to the record of alternative energy sources having minimal or no net-CO_2 emission. Electricity production using microbial cultures obtained first reported early in the last century [18]. MFCs have been described as "fuel cell that converts the energy in the chemical chains of organic compounds into electrical energy through the catalytic activity of micro-organisms under anaerobic conditions" [19]. MFC technology describes a novel approach of using bacteria for the generation of electricity by oxidation of organic waste and renewable biomass [20]. The importance of this technology comes under the ambit of environmental engineering and bioremediation. MFC technology is thus multi-disciplinary, in the genuine sense of the term and provides scope for strengthening research across disciplines.

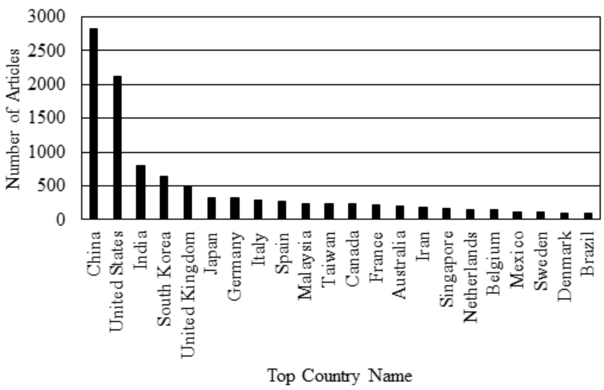


Fig. 4 Subject-wise Research Publications on Microbial Fuel Cell.

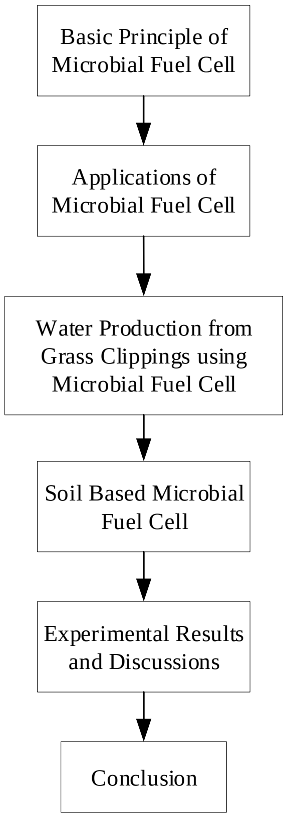


Fig. 5 Flow chart showing steps of present work.

This paper is organized as follows. Section 2 of this paper explains the working principle of MFC with its applications in Section 3. The application like water extraction from grass clippings using MFC is done experimentally in Section 4. Also, the straight conversion of organic matter of the biomass to bioelectricity using bacteria is possible in Soil Microbial Fuel Cell (SMFC). Such technology can be used even for rural and urban waste management and the production of electricity simultaneously which is discussed theoretically and experimentally in Section 5 and 6. The workflow of this paper is shown with the help of a block diagram in Fig. 5.

2. WORKING PRINCIPLE of a MICROBIAL FUEL CELL

The principle of operation of MFCs is based on the tenets of microbial physiology coupled with electrochemistry. The architectural design of MFCs brings the distinctions of electrical and materials architecture to the fore. Wherewith do microorganisms derive nutrition for their sustenance? Chemotrophic microbes use organic and additional biodegradable syntheses, following diverse states. The electrons produced from the oxidation are transported across relevant transports depending on the final electron acceptor ion. In aerobic bodies, this terminal acceptor is oxygen which catches up the electrons and makes reduced to water. The chemiosmotic theory states that electron transfer chains of bacteria stay linked to the translocation of protons across the layers which are in turn associated to ATP (ATP synthase is an enzyme that creates the energy storage molecule 'adenosine triphosphate') synthesis by the proton electrochemical potential across the energy transducing layer [21]. The bacterial cell membrane uses as an energy transducing membrane functioning according to the chemiosmotic system. This translocation of protons towards the outside of the layer appears in the proof of a proton electrochemical inclination. The pH gradient adds up to this layer potential and effects into the proton motive force. The re-entry of those protons across the ATP-synthase enzyme does arrive by ATP structure. The ATP synthesized thus is used by these bacteria for their continuation [22]. Keeping this theoretical background in mind the MFC functions are defined here.

A typical MFC consists of two sections - one anodic and cathodic half-cell; which continue accomplished through a selectively porous, cation-specific layer or a salt-bridge as shown in Fig. 6. The anodic cell comprises from microbes suspended under anaerobic requirements in that anolyte, plus single cathodic chamber receives the electron acceptor (oxygen). In principle, the electron donor involves substantially separated from the terminal electron acceptor across the two sections. Utmost of the electrons released from the process of oxidation continues transferred to the anode. Electron transfer to the anode can be succeeded by electron mediators or shuttling agents [23], directly by the cell [24] or using 'nanowires' [23]. Those electrons move conducted into the cathode crossed an external circuit, and for each particle carried, a proton is transferred across the membrane to the cathode for completing the reaction and sustaining an electric current [24].

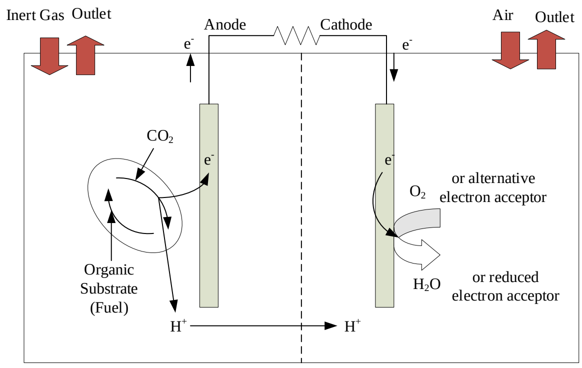


Fig. 6 Microbial Fuel Cell showing its working principle.

The MFCs have some operational and practical benefits such as: (a) organic waste materials are used as fuel in MFCs; (b) MFC does not require controlled circulation as it is required in Hydrogen-based fuel cells, and (c) To gather the maximum 90% of electrons from bacterial electron transfer process, the MFC has high transformation efficiency than Enzymatic based fuel cell.

3. TECHNOLOGICAL ASPECTS of MICROBIAL FUEL CELL TECHNOLOGY

Although MFCs have done investigated as an alternative energy source, their application is limited to certain niche areas. With further improvements in design, cost-effectiveness and performance efficiency based on these near-term applications, it would be possible to scale-up and use MFCs as a renewable energy resource.

3.1 Wastewater Treatment

The Micro-organisms present in the wastewater oxidize the organics of the water and electrons are released which allows the flow of steady electric current. Reference [25] has mentioned that if MFC electrical power generation capacity is increased then it may provide a method to reduce the running cost of wastewater treatment (WWT) plants and makes cost-effective WWT in industrial and developing nations. The schematic of MFC for WWT is shown in Fig. 7 in which WWT with a chemical cathode used to develop useful chemicals or remove pollutants in the environment while the anode chamber is flourished with wastewater resources. Also, reference [26] has described that the MFC generates less sludge than the aerobic treatment process.

3.2 Powering Underwater Monitoring Equipments

The sensors which are placed to recognize the data from the actual situation require electrical power for their proper operations. Thus, MFC is used to provide energy to such devices which are particularly situated inside the water where the arrangement to restore batteries on regular intervals is very difficult. So, to counteract such type of situations a Sediment MFC is available to monitor the natural systems such as rivers, oceans, and creeks [27]. But due to the low concentration of organic materials and high internal resistance, the power density is very low in sediment MFC. However, reference [28] has described that to release data to central censor the low power density is being an offset by energy storage systems. A simple SMFC is applied in the hot lake with Remote Sediment MFC Tester (RSMFCT) is shown in Fig. 8 (a) and (b).

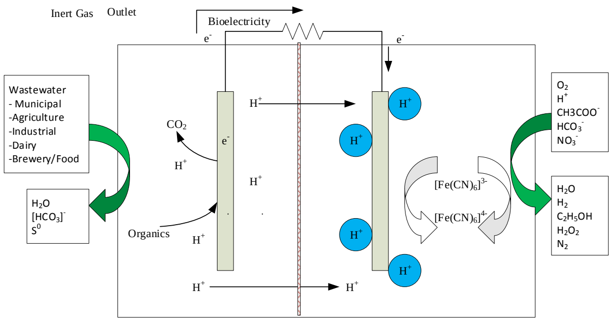
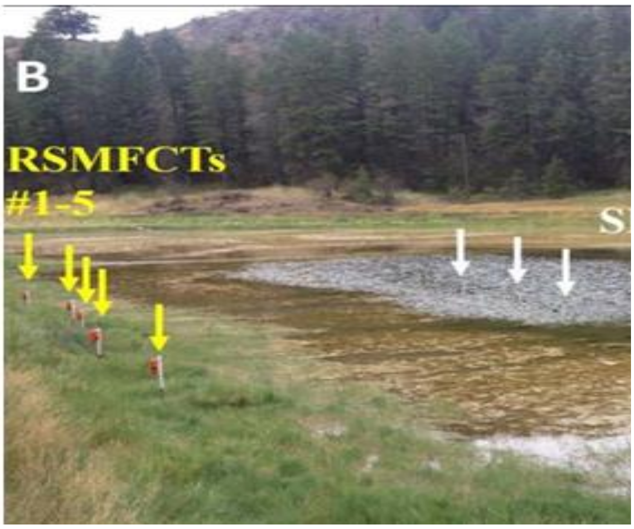
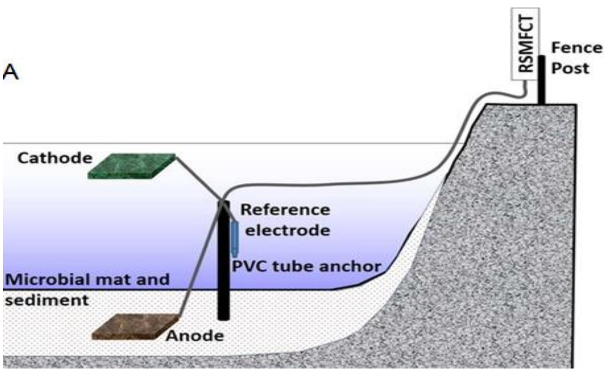


Fig. 7. Microbial fuel cell for wastewater treatment.



(a)



(b)

Fig. 8(a) Picture of SMFCs 1-5 Deployed in the hot lake and the Connection to RSMFCTs 1-5 on the Shore, (b) Schematic of Sediment Microbial Fuel Cell Connected to the RSMFCT at the Deployment Site.

3.3 Sensing of Biological Oxygen Demand

The MFC technology is used as a sensor for pollutant analysis and in situ method monitoring and handle. Biological Oxygen Demand (BOD) is the quantity of dissolved oxygen needed to meet the metabolic requirements of aerobic organisms in water deep in the cellular body, such as excrement. The proportional relationship between the coulombic yield of MFCs and the collection from comparable organic contaminants in wastewater perform MFCs potential usable as BOD sensors. MFC type BOD sensor is kept operational for over five years without extra maintenance far continued in service life span than other types of BOD sensors reported in the literature [28, 29]. Fig. 9 shows a schematic diagram of MFC and the mechanism for MFC-based BOD monitoring. Increased BOD input provides more organic fuel for the MFC, which in turn increases current output. Also, the mechanism for MFC based toxicity monitoring is done if increased toxin input isinhibited the cellviability and metabolic activity, which directly reduces the current output [29].

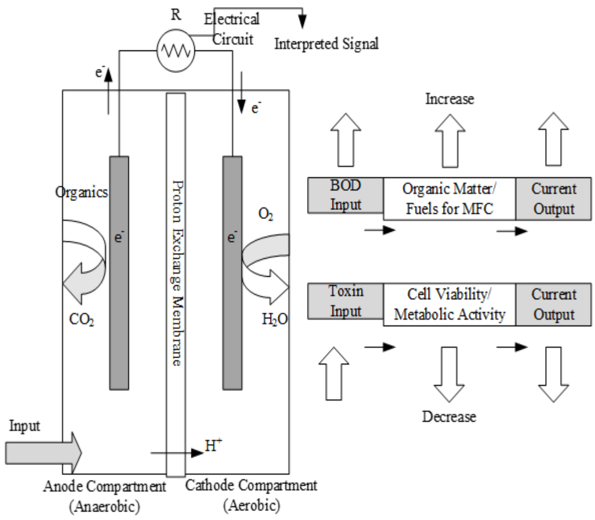


Fig. 9 Microbial Fuel Cell for BOD Sensing.

3.4 Power Supply to Remote Sensors

The power demand for electronic devices has drastically decreased with the development of microelectronics and related systems. Typically, batteries do utilize to power chemical sensors and telemetry operations, but in any applications replacing batteries on a periodic basis is expensive, time-absorbing, and impractical. A potential solution to this obstacle is to use standalonerenewable energy supplies, such as MFCs, which can operate for a prolonged period using local natural resources. Extensive research toward developing reliable MFCs to this effect is focused on selecting suitable organic and inorganic substances that could hold explored as sources of energy [3]. Fig. 10 (a) and (b) show a typical diagram of MFC as to power the remote sensors.

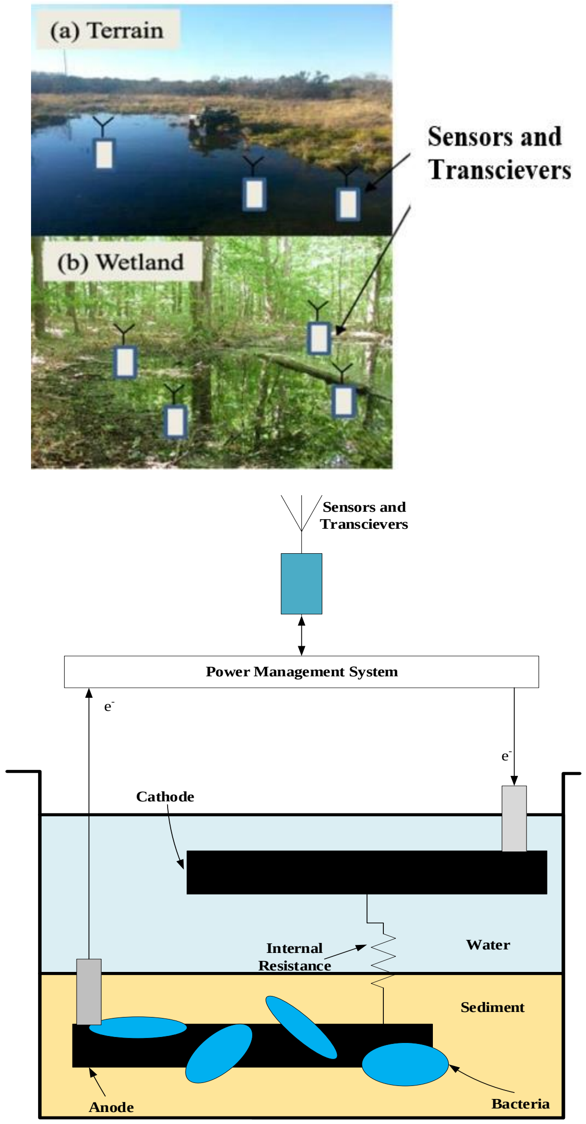


Fig. 10(a) Schematic of Microbial Fuel Cell for Remote Sensors. (b) Schematic of Microbial Fuel Cell for Power Supply to Remote Sensors.

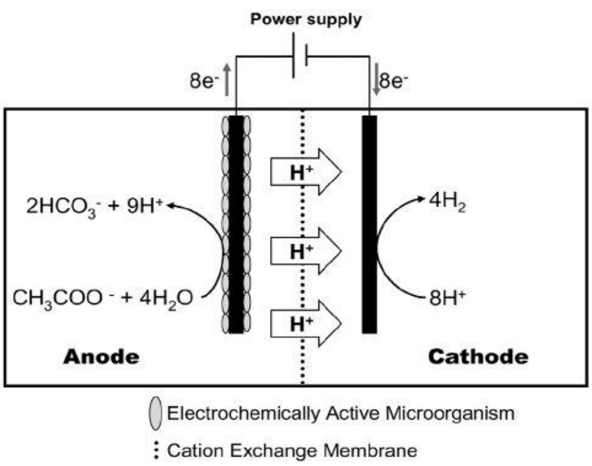


Fig. 11 Microbial Fuel Cell for Hydrogen Production.

3.5 Hydrogen Production

The modified MFCs are also used in Hydrogen production and an anaerobic provision exists in this type of device. An additional voltage of about 250mV is continuously required to the cathode and under these situations; hydrogen is produced from proton at the cathode. This type of MFC is named as BEAMR; Bio-electrochemically assisted Microbial Reactors [30]. Fig. 11 shows a schematic diagram of external power assisted MFC based hydrogen production during the bio-catalyzed electrolysis of acetate.

3.6 Generating Electricity

The conventional electricity generation hence, the green energy generation from microbes of organic wastes comes in picture and the electricity generation from MFC is an effective, clean and recyclable without any toxic product production [32].

The two electrodes cathode and anode are present in the MFC where the redox reaction takes place from an organic material and bacteria, which produces electrons and protons and thus, electricity generates. At present, MFC with the dual chamber (DCMFC) and single chamber (SCMFC) [31] is applied in the extraction of metals and nutrients from industrial effluents along with wastewater treatment. A schematic of electricity generation by using MFC is shown in Fig. 12.

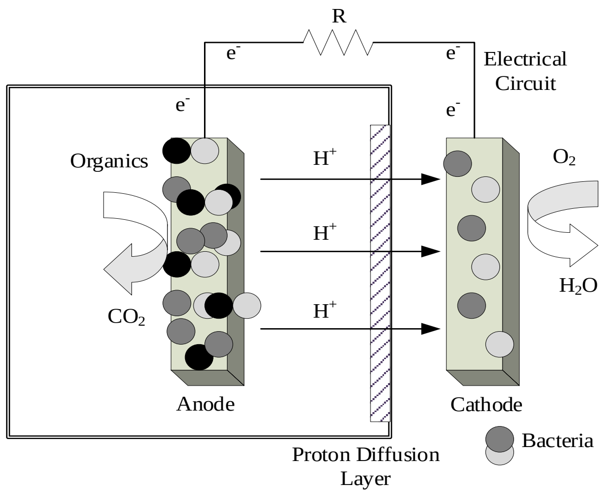


Fig. 12 Microbial Fuel Cell for Electricity Generation.

4. WATER PRODUCTION FROM GRASS CLIPPINGS USING MFC

Grass clippings are the good potential of water (85% to 90 %) and contain approximately 4% nitrogen, 0.5% phosphorus, and 2% potassium nutrients. The present research study deals with the conversion of grass clippings' wastes which are generated from farmland into the water through a Microbial Fuel Cell technology. The grass clippings waste continuously processed in a closed container along with the addition of Bokashi powder in an anaerobic condition where after 72 hours, the grass clippings convert themselves into the water and the by-products such as manure and electricity are produced.

Table 1 compares the agriculture waste generated by the selected Asian countries in metric tons per year [44]. India is the first in Asia and the second massive producer of rice and wheat in the world, two crops that usually produce a large volume of residue.

Table 1. The available amount of Crops

Country	Crops available (in metric tons/year)
India	500
Bangladesh	72
Indonesia	55
Myanmar	19

4.1 Study Area

Council of Scientific and Industrial Research (CSIR) campus is in Bhruhat Bengaluru Mahanagar Palike (BBMP) with a covered area of 300 hectares; where a small, medium and large agriculture farmland with urban forest spread over in 120 acres divided into 7 sectors are present. The basic experimental setup used is a bioreactor, which is the GECS assembly purchased from the local market, Bengaluru, India. The components include a separator, tap, an airtight vessel, and other secondary materials, as shown in Fig. 13.

Fig. 13The separator (Blue color), Tap (Blue color), grass clippings, the airtight vessel and the bioreactor unit experimental setup.

5. SOIL MICROBIAL FUEL CELL

5.1 Soil Characteristics

The soil used for the experiment was Red loamy soil taken in January 2019 from Tumakuru, Karnataka, India (13 20°19′ N; 77 6° 4′ E) as given in Fig.14.It is located close to the range of hills extending to nearly 4,000 feet (1,200 m) crosses it from north to south, creating the watershed between the systems of the Krishna and the Kaveri rivers. The soil iscollected from the surface layer (0–20 cm) of an agricultural meadow which is used for haymaking.

Before MFC construction, soil was described by physical-chemical analyses for the moisture percentage (drying samples at 105 °C for 24 h), Water Holding Capacity (WHC) in a stainless-steel pressure chamber (SP.S.P. Soil search Equipment, India), pH and redox potential (E_h) (Hach Lange and Radiometer potentiometric equipment), and total organic carbon content (TOC) by an automatic analyzer Shimadzu TOC-V_{CSH}. Also, the levels of nutrients were examined in fresh soil samples by Olsen P extraction (as an estimate of plant available P), NaCl-extractable ammonium, and water extraction by a flux analyzer AA3 Bran Luebbeauto analyzer [33].

Fig. 14 Location of the soil sampling area in India (January 2019).

WHC 41.93 %, TOC 30.7 %; pH 6.019; E_h 446.4 mV; N-NO_3 0.0267 mg g−1; N-NH_4 0.0081 mg/g and P-PO_4 0.0053 mg/g). The soil was stored at 4°C before the MFC construction.

5.2 Soil based MFC Construction and Operation

The construction of MFCs with soil micro-organisms is done by blending with biomass. Three combinations of MFCs differing from each other in the water content (100 % WHC, flooding) and the carbon source available for soil microorganisms (from kitchen waste) are assembled. The MFCs are arranged in the vessel contains a transparent enclosure made of clear Polyethylene terephthalate (PET) (height 46cm, diameter 10cm, and capacity 1000cm^3).

The vessels remained filled with the soil (1.14 kg) to a height of 37.5 cm, corresponding to a capacity of 1000 cm^3. Fig. 15 represents the MFC designed combinations which are as follows:

(1) Organic waste including Nutrient 1 (mixture): {1.14 kg of Red loamy soil+100 ml of water+potato peels (50g)+banana peels (100g)+orange peels (50g)+mango peels (50g)}, and is referred as MFC-A

(2) Organic waste including Nutrient 2 (mixture): {1.14 kg of soil + Water (10 mL) + tomato paste (34.5mL) + sugar (2 g) + liquid glucose (10 mL) + iodized salt (2 g) + onion peels (4 g) and garlic peels (4 g)}, and is referred as MFC-B

(3) Organic waste including Nutrient 3 (mixture): {1.14 kg of soil + Water (10 mL) + tomato paste (34 mL) + sugar (2 g) + edible common salt (2 g) + onion peels (2 g) and garlic peels (2 g)}, and is referred as MFC-C

Stainless steel mesh electrodes for the anode and air cathode (50 mm x 50mm in length and width, 0.2 mm thickness), are inserted into the prepared MFC combinations. Bottom electrode called anode is located at a depth of approximately 30 cm from the vessel surface (anode space), while the upper electrode called air cathode held positioned on the granular activated carbon layer at a depth of 5 cm from the neck of the vessel (cathode space). The laboratory experiment lasted for 15 days and is conducted at room temperature of 20°C. The external circuit is fixed with the 1000 μF capacitor for getting smooth dc output. Water loss via evaporation during the operation is routinely replenished with tap water to maintain a constant condition of 100 % flooding (5 cm^3 of stagnant water on the soil surface).

5.4 Experimental Analyses

The voltage (mV) produced by MFC is recorded every day or at 2 days intervals, using a Fluke 8845A/8846A 6.5 Digit Precision Multimeter. Moreover, current intensity (mA) is metered by a dual range 0-50/0-500 mA DC ammeter. The current and power densities are calculated based on the footprint area of the anode [34]. After observing the experimental values of voltage, current, and power, the graphical analysis of the experiments based on the voltage generated isdiscussed in section 5, which demonstrates the fact that soil microbes in this region of Karnataka are capable of producing electrical energy across terminals using the soil as an electrolyte.

6. RESULTS and DISCUSSION

6.1 Water production from Grass clippings using Microbial Fuel Cell

The nitrogen, phosphorous and potassium (NPK %) are analyzed in water and manure. The chemical characteristics of the water and compost comprise are presented in Table 2.

Table 2. Characteristic of produced water and manure

Parameters	Water (in %)	Manure (in %)
Nitrogen	1.15	0.39
Phosphorous	0.308	0.159
Potassium	0.77	0.51

6.1.1 Toxicity Test

The produced water and manure are used to evaluate the toxicity of plants depicted in liquid compost, and the various dilutions are prepared by adding distilled water. The absorptions are made by adding collected liquid of various collections as 0.60 ml, 1.25 ml, 2.50 ml, and 5.00 ml and 25 ml of distilled water produced from the GECSare added to all the concentrations uniformly. A 1000 ml plastic pot is used which is having ten mustard seeds distributed in pots at compatible diameter. Seeds are grown, under an aerated system, adding the various concentrations of liquid manure. Germination of seeds is doneafter seven days, later the length of the plant was measured by using a ruler. The toxicity test experiment continued conducted in triplicate. The toxicity results are obtained and it is observed that the mustard seed germination and length of the plant are good when produced water and manure are used in several concentrations. The preliminary toxicity test with all collections has shown seed germination noted greater than 90%.

The rising prices of chemical fertilizer in the market and water scarcity in the agriculture resembling for an idea to overcome someone else to meet the needs of the crops they planted. Also, a chemical fertilizer if used continuously can make microorganism in the soil becomes dead and causing the farmland to be infertile [45]. The utilization of grass clippings waste as water and manure is supposed to solve these difficulties and can help to increase the economy by farmers and housekeepers in the community. Price of chemical fertilizers so as Urea prices 25 USD per kg, SP-36 USD 300 per kg, ZA USD 200 per kg, NPK USD 350 per kg. The pricesarenot only hiked continuously but the influence of chemical fertilizer used may degrade soilquality in contrast to the organic liquid compost that is environmentally friendly and very safe. The financial cost to prepare the water and manure is presented in Table 3, which is economical and viable for farmers without any environmental impact [46].

Table 3. Cost details of water production from Grass clippings using MFC

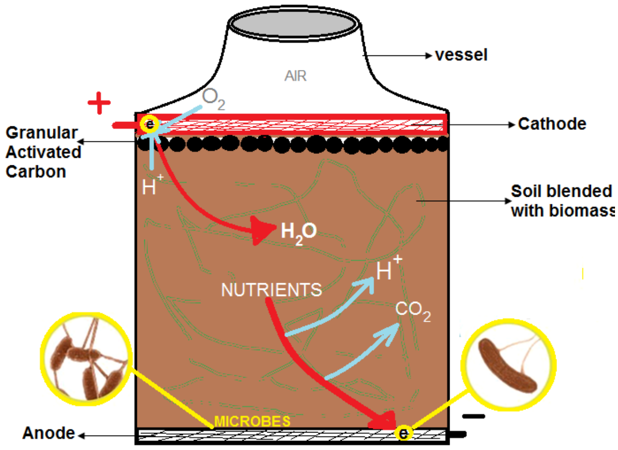
Materials	Quantity	Price (in$)
Bioreactor unit	1 no.	10
Grass clippings	1.5 kg	-
Bakashi powder	0.5 kg	1
Granular activated carbon	1 kg	1
Plastic bottle (used)	2 nos.	-
	Total	12

6.2 Soil Based MFC

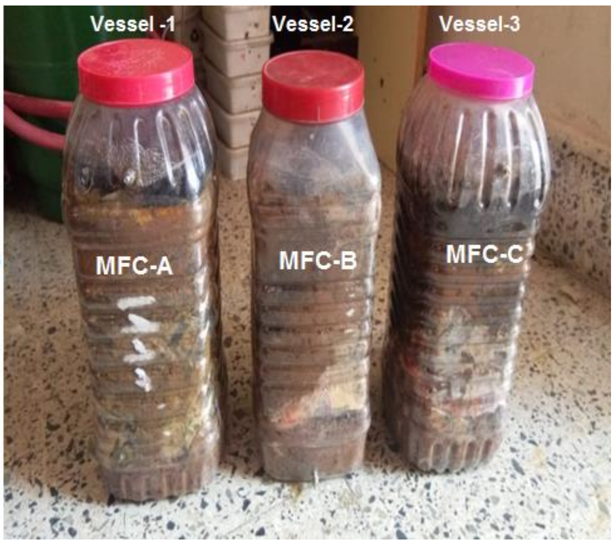
Electricity Generation from the Soil Results for voltage generation from four different combinations of the tested soil MFC is presented in Fig. 15.

MFC-A is the fastest MFC from the 4^{th} day and the most effective in voltage generation (600±5 mV). Aforementioned results from the fact that glucose is a readily available source of carbon for soil microorganisms, which by having easy access to this source straight transform the energetic potential included in the organic substances like Glucose; into electricity, which constitutes the essence of MFC.

Generally, it can act affirmed that the MFC-A was described by the highest and most stable potential, as the registered voltage generation values remained at a high level of 550-590 mV throughout the experiment. Only after 9 days, a decrease in the measured potential to the state of 550±3 mV obtained recorded, and simultaneously, it was the lowest potential level achieved in the MFC-A. Probably, the noted decline is the consequence of depletion of the available carbon source and a decrease in the microbial activities. A natural source of carbon is straw, which decomposes very slowly, typically for natural materials, such as wood, paper, or stable textiles in cotton. What is significant, after hydrolysis, cellulose is a natural source of carbon for microorganisms; therefore, we used it as a substrate in the MFC-C combination.



(a)



(b)

Fig. 15 (a) Schematic diagram of the MFC design (b) Soil bio-electrochemical remediation system.

In contrast to the glucose treatment, the efficiency of the MFC-C was noticeable already after two weeks of the experiment. Undoubtedly, this fact remained linked to the process of a long run of natural carbon stocks contained in cellulose, which became available for soil microorganisms only after hydrolysis of polysaccharides. Throughout the first week of the experiment, the bioelectricity generation from the MFC-B was quite low and remained at the level of 520±2 mV. On days 9 and 13 of incubation, equalization of potentials between the anode and cathode space continued noted. An intensive increase in voltage generation after ten days was recorded with the maximum (620±4 mV) on day 15. On subsequent days, voltage variations in the range of 500-590 mV are observed.

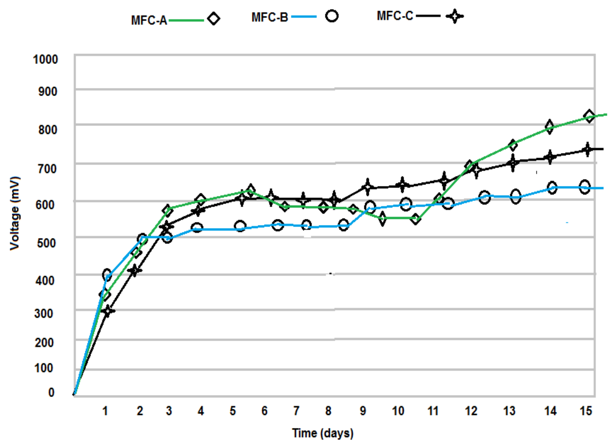


Fig. 16. Voltage Generation from Different Soil MFC Combinations during the 15 Days of Operation.

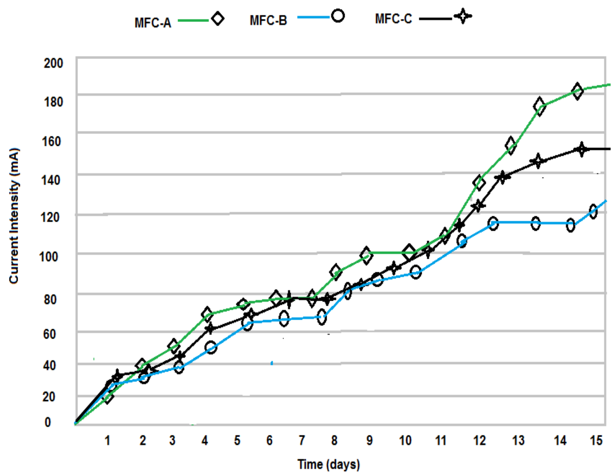


Fig. 17 Current Intensity Generated from Different Soil MFC Combinations During the 15 Days of Operation.

The lowest effectiveness held remarked in the MFC-B combination, with a layer of stagnant water on the soil surface. In that case, throughout the experimental period, the generated voltage did not exceed the level of 610±2 mV, with one exception on day 15 when it reached the value of 620.4±3 mV. The energy of the MFC-B was different from the others because it decreased quickly due to oxygen depletion in the role of the electron acceptor. Also, the mass transfer limitation in the electron donor that reached the anode might be the cause of this phenomenon [35]. Reference [36] highlighted that voltage production from a single wastewater MFC is on an average of about 500 mV, which entails a serial connection of several MFCs to achieve the required level of voltage and current. Reference [13] reported that the initial redox potential of a compost soil MFC freshly inoculated with a glucose solution (5 g l−1) ranged between 350 and 400 mV, analogically to our data from the MFC-B after the fourth day of the experiment. In the case of the presented study, all soil MFC combinations revealed a slightly lower efficiency, as the maximum voltage generations of 732.2 and 819.3 mV were achieved by the MFC-A and

MFC-C, respectively. Nonetheless, it should do directed into consideration that our experiment did carry on a small amount of soil (1.14 kg) and that no mediators were used to support the MFC work as if often practiced by other researchers. In the course of our experiment, in parallel to voltage generation as shown in Fig. 16, the current intensity is also monitored and shown in Fig.17.

At the beginning of the study, the current in all the MFC combinations remained at a similar level 42-65 mA. A substantial increase in the current intensity was observed between the 8th and 10th day when it reached a value of approximately 80-138 mA. Progressively, from day 13, the rapid growth of the current intensity was noted in the MFC-A, reaching values of up to 182 mA. In contrast, the lowest current intensity values comprised found in the MFC-B (24–106 mA). The power and current densities can also be determined for each of the examined soil MFC combinations as shown in Fig.18.

It is found that the MFC-A achieved individual single highest power density (P_{max}=80 mW/m^2) at a current intensity (CD) of 100 mA/m^2. For lower values of P_{max} from 60.6 to 70.8 mW/m^2 are noted in the case of the MFC-C at CD of 60–80 mA/m^2, respectively. It is found that particular maximum power density (P_{max}=80 mW/m^2) is achieved by the MFC-A at a CD of 100 mA/m^2.

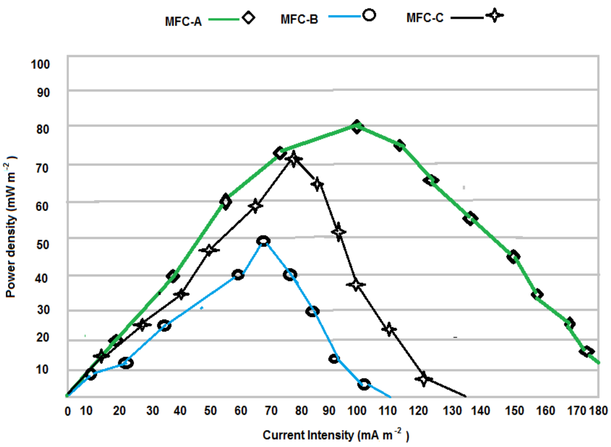


Fig. 18 Power Density as a Function of Current Density for Soil MFC Combinations during the 15 Days of Operation.

The lower values of P_{max} from 40.6 to 50.8 mW/m^2 are noted in the case of the MFC-B at CD of 60-80 mA/m^2, Sequentially, on the other hand, the lowest power density occurred found in the MFC-C (P_{max}=70 mW/m^2 at 80 mA/m^2). It is very complicated to compare directly the power output with the consequence of other MFCs reported in the literature due to different operating conditions and substrate additions, types of applied electrodes, and various species of microorganisms establishing the MFC. However, it is found in [35] that the data are compatible with those who noted similar P_{max} (31.6 mW/m^2 at 100 mA/m^2) in the case of a wet-sediment MFC constructed with carbon nanotubes. The same authors also noted a decrease in P_{max} to the level of 10 mW/m^2 which is analogical to MFC-C; in the wet sediments, MFC prepared with stainless steel net. In [37], it is noted that P_{max}=30 mW/m^2 at 85.49 mA/m^2 in a wastewater MFC with acetate addition as a substrate. Additionally, [38] indicates that acetate, in particular, is well known to generate low anode potentials and highpower densities [39]. The value mentioned is close to our data obtained from the MFC with glucose as a substrate, which confirms the ability of soil to generate bio-energy at a comparable level as in the case of wastes. Likewise, [40] is demonstrated that in the case of an aerobic-enriched wastewater MFC, the maximum power density amounted to 179 mW/m^2 for acetate, 174 mW/m^2 for glucose, and 175.4 mW/m^2 for ethanol. However, these values still cannot meet the requirements of many applications, i.e., lighting lamps or pumping water, which require a power output larger than 100 kW/m^2 [41]. Rather than boost conversion, in situ application of this electricity, it would be a better way as it avoids energy consumption [38]. Consequently, only large-scale treatment is the application closest to the manufacturing accomplishment and is the domain of much current in MFC research [42].

7. CONCLUSIONS

The MFC technology has continued employed for various applications. However, there are remarkable hurdles that need to be addressed to make the technology economically viable. The first prime hurdle is a feasible design for scaling up the MFC. Though this aforementioned technology is considerably encouraging as a source of renewable energy, it will be any time ere considerable-scale which is highly effective MFCs to start the commercial use as explained in section 3. Additionally, the direct electron transfer process, hence no cost related to the use of chemicals, the concept of microbial fuel cells is used in places lacking proper electricity, and the study which shows that the generated electricity in MFCs is also useful in water purification.

The paper studied and shown experimental analysis on Grass clippings waste in agricultural farmland which has endless potential if it is processed into water and manure using GECS. The organic liquid compost is expected to help the economy of farmers or just used in their owned farm. The present investigation reveals that the nutrients value of ordinary grass clippings waste exists are converted into two highly useful products which are water and manure without offering any further environmentally damaging yields. This technique can empower and is supposed to defeat the difficulty on the farmers gently and could get more revenue from this water and manure. The organic liquid compost is very affordable and if calculated from the total expenditure to be incurred during the manufacture of organic fertilizers is economical.

The paper has also shown that how the power generating capabilities of soil bacteria is nourished as there is no such literature available on Indian soils for it. This work is examined material in that it has confirmed that specific electrogenic bacteria which can serve in a microbial fuel cell exist here as well. For this work, a particular location in India, in Karnataka, at Tumakuru was taken for the soil samples. For sample sizes of 6cm

× 6cm × 3 cm, this MFC system is produced a peak voltage of 0.83 millivolts so that it can continue analyzed with higher sample size, i.e., scaling up this system can generate significant energy. Also, it is mentioned that because of time limitation most of the investigations in this work are restricted to a maximum of four weeks, so the spectrum of possibilities is wide open for this kind of renewable energy technology to grow, as this work has shown that the system works. Besides, once the power is maintained for the system, small electronics can do connected into the Booster Board and can implement continually. The system shows some limitations such as water build up over the cathode, and the power production is low if the temperature is below 24°C but having said that this work is fully demonstrated the topsoil use and also defines the use of the salt solution, chemicals like sodium acetate, and tomato pulp. There is literature available, as discussed earlier, which shows the use of vermicomposting, which makes the soil further enriched with Nutrients.

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