Nature Environment and Pollution Technology *An International Quarterly Scientific Journal*	p-ISSN: 0972-6268 e-ISSN: 2395-3454	Vol. 16	No. 2	pp. 433-439	2017

Original Research Paper **Open Access**

Electrical Power Generation with Himalayan Mud Soil Using Microbial Fuel Cell

Debajyoti Bose and Amarnath Bose
Department of Electrical, Power & Energy, University of Petroleum & Energy Studies, Dehradun-248 007, India

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 21-05-2016
Accepted: 16-07-2016

Key Words:
Renewable energy
Top soil
Microbial fuel cell
Power generation

ABSTRACT

Topsoil microbial community primarily consists of bacterial species that can generate electricity if a microbial fuel cell is incorporated with it. Since such electron producing bacteria are abundant in nature, microbial fuel cells can be considered as clean source of electricity generation and a prospect for renewable energy growth. Here, the authors have shown experiments with a real microbial fuel cell, investigating electrical power production from it using the Himalayan top soil of Dehradun in Uttarakhand, India. A two week study revealed a peak power of 0.99 mW and voltage across the terminals rise up to 1.54 V; also various nutrients were added to the soil, like kitchen wastes and acetate to see the power producing capacity of the soil microbes. At the smallest level, it can help remote rural areas to power lamps or other less energy intensive devices. Using a setup that includes anode, cathode, and related electrical fittings this work has utilized these bacteria over time and observe the power they produce. The setup brings together the concept of energy, electronics and microbiology under one framework and is in line with issues relating to climate change, energy security and sustainability. An attempt has been made to explore the spectrum of scenarios and speculating the possibility of generating renewable power using the Himalayan top soil.

INTRODUCTION

During the 1900s the inception of the idea to use microbes to produce electricity started taking shape, which eventually led to the use of Microbial Fuel Cell (MFC) technology. This relatively unexplored territory has, however gained attention as alternate energy sources and are entering the society. Topsoil is filled with bacteria species that decompose organic matter and release electrons as a part of the natural process, and since these soil microbes are abundant in nature, these become an exciting prospect for renewable energy as no toxic chemicals are used and the process employs locally sourced material. The MFC setup includes an electrochemical cell with its two electrodes (anode and cathode), and a membrane. For MFCs, fuel enters through the anode and leaves from the cathode.

Bacteria that can convert organic matter in the soil to electricity are mainly from the proteobacteria phylum: *Shewanella* (Family: *Shewanellaceae*) and *Geobacter* (Family: *Geobaceraceae*). *Shewanella* appeared in a comic book as "Shewy, the Electric Bacterium", in educational kits that are available for students and hobbyists to understand how microbes contribute to charge density in the soil by giving out electrons after consuming organic matter from it (Hofstetter et al. 2002). The fact that these soil microbes live in abundance in all soils make them an interesting prospect to study their ability to release electrons (Amann et al. 1995) and see how with varying parameters it is affected. We explore this phenomenon with the Himalayan soil of Dehradun in India and speculate the use of the power it produces.

The present work focuses on the following areas:

1. Study the sub-Himalayan soil available in Dehradun with a microbial fuel cell and see if it is capable of producing any power.
2. Observe and record, if any power is produced, the peak power, and when it starts to drop.
3. Adding nutrients and secondary chemicals (example: sodium acetate) to the soil and check how it affects the microbial growth (positively or negatively).
4. Speculate the possibility of scaling up the present system in an efficient manner which can then be sold to villagers at an easily affordable price and they can power their own small scale utility devices just by using the local soil.

This work is considered important as it shows that the electrogenic bacteria which can work in a microbial fuel cell exist in Uttarakhand, i.e. Indian soil as well. Through our investigation, we have opened a plethora of possibilities to experiment and collect more data about the soil in the Himalayan ranges of Uttarakhand. The power of the MFC can be increased by putting the MFC in stacked form.

Renewable and clean forms of energy are one of society's greatest need. The direct conversion of organic matter to electricity using bacteria is possible in MFC; use of compost is a future prospect. Expensive and toxic chemicals are not needed for mediated electron transfer. Such technology has the possibility to be used even for rural and urban waste management, which includes cleaning of river, and production of electricity simultaneously.

There is no literature available on this topic for the soil of Uttarakhand, or strictly speaking the soil in this region. There was some interaction with associates from Forest Research Institute (FRI) and Wadia Institute of Himalayan Geology, and it is seen that they have data on soil profiles, but no studies on microbial profile of the soil. This gives the project an added significance as it would contribute to increase the sphere of knowledge of the soil in terms of power production capacity of microbes in the soil (if any).

BACKGROUND

At Pennsylvania State University, Prof. Bruce Logan, one of the most eminent names in MFC research is working on developing MFCs that can generate electricity while accomplishing wastewater treatment. In a project supported by the National Science Foundation (NSF), they are researching methods to increase power generation from MFCs while at the same time recovering more of the energy as electricity (He et al. 2016). A study conducted by a group at Steven Institute of Technology in New Jersey, USA observed the relationship between organic matter and electrical capacity of MFC fuelled by the sample. High percentage of organic matter in the sample resulted in higher electricity production of MFCs powered by that sample (Li et al. 2013). Hisham et al. (2013) showed that an MFC has the ability to generate electricity from the wastewater, while simultaneously removing carbon and nitrogen.

A study by Pranab Barua (Barua & Deka 2010) demonstrated that the first order derivative of voltage generated from an MFC with respect to time is a negative constant. Hence, the change in voltage with respect to time is independent of time. The key finding of this work has been the mixture of bio-wastes used that resulted in high potential current than any single component. The study used specific quantities of cow dung, sewage water, rice washing water individually and combined with slurry. Cell life decreased after addition of slurry, but increased after adding vermicompost, thus confirming to the organic matter consumption of the microbes.

Fuel cell is considered a technology which is of need for the 21st century and a potent tool to tackle problems from the combustion technologies. Due to their high efficiency and very little environmental impact, they have emerged as a potent alternative. Space exploration already uses fuel cells and with MFC its use to generate renewable power (Arulmani et al. 2016) from soil can be speculated. The work presented in this project highlights an initiative, though small, but if implemented in the right direction can be scaled up to industrial processes working entirely with microbial action. Also, it will not be restricted to top soil/mud, but waste to energy and other biochemical disciplines as well.

There has been an emphasis on the production of fuels through biochemical processes in recent years, to name a significant one would be at IIT-Kharagpur, where a group under Prof. Debabrata Das is working on the production of bio-hydrogen and optimizing the process essentially to bring it from R&D phase to commercialization (Das & Veziroglu 2001). The project has the financial support of ONGC and research collaborations from European countries as well. Photo-bioreactors are studied with microbes as part of the carbon sequestration initiative, cultures of *Chlorella*, at UPES (Sharma et al. 2015) at bio-diesel lab and also at Abellon clean energy, a bio-energy company (Patel et al. 2011) based in Gujarat (to name a few). It must be mentioned that almost all bio-energy projects are in R&D phase nationwide and are yet to reach commercial viability.

If we look back at the history of soil microbes or simply put bacteria in the soil, they go back all the way to early life (cyanobacteria), these primitive life forms, made our planet green through oxygenic photosynthesis, and set the stage forever more complex life forms to arrive. These microbes, millions of years ago figured out how to run those complex cellular processes and they do it even today, and hence are an integral part of nature and life as we know it.

The cyanobacteria made this planet green and today when we are suffering from pollution problems from combustion technologies and looking for green alternatives/ energy, what better than microbe species to explore and make part of this initiative. The only limitation of such processes is that they take time, as almost all natural processes do. The findings of this work also reported the same. For results, the time sometimes include a week or sometimes more than a week.

Limitations are coupled with all scientific investigations and it is believed that over time they become part of the process, given the work develops into a scalable and usable utility. Although it must be mentioned the system, that has been used in this work, experienced over acidification in the soil between the anode and cathode which is a rare occurrence, yet happened and during that time power output became significantly low, such has been discussed later in this work.

PROSPECTS FOR MFC IN UTTARAKHAND

In the remote locations of the foothills of the Himalayas, there are still many villages with little or no access to electricity. The reason sometimes is extending grid power to remote location comes with a significant price, or otherwise the geopolitical scenario. This work reported by the authors ambitiously takes into account the study of Himalayan soil available in a particular region within Uttarakhand and primarily checks the soils capability, i.e. if it can produce power and if so what is the peak power it can produce, which is done by exploiting the microbes in the soil.

The secondary task being to speculate, if enough power is produced, and if so whether it can power small lamps, or less energy intensive utility devices. It is proposed to test MFC on Himalayan soils of Uttarakhand, district Dehradun, situated in NW corner of Uttarakhand State and extends from N latitude 29°58' to 31°02'30" and E longitude 77°34' to 78°18'. In this work we have tested the soil from Bidholi, Dehradun and reported the voltage it generates between the anode and cathode and also the power characteristics.

As for international research on similar topic, Prof. Bruce Logan at the Pennsylvania State University in the US is working on production of hydrogen from microbial fuel cell and also in the same apparatus, purification of water; primarily working on making water infrastructure energy sustainable in the next 20 to 25 years. There are many researches going on with MFCs (Kim et al. 2007) but specifically understanding the soil microbes and enhancing the process has not gone through significant feats. Hence, this work with the local Dehradun soil is considered to lay a ground for such work, especially in developing nations.

MATERIALS AND METHODS

The basic setup used is a microbial fuel cell, which is the MudWatt™ assembly purchased from Keegotech, USA. The components include an anode, cathode, an air tight vessel and other secondary materials, as given in Fig. 1.

It must be mentioned that the anode and cathode are made of conductive fibres, which can cause electrical short circuits, to prevent any damage they must be kept away from other electronic devices. The cathode assembly has two parts: cathode felt and the cathode wire which is made of titanium. Similar is for the anode assembly: anode felt and the titanium wire.

The vessel will be filled up with a specific quantity of soil, the anode will be placed in the mud where the microbe species can grow, while the cathode will be on top of the soil layer exposing it to oxygen in the space between the container lid and the felt. Both cathode and anode are made of grapheme connected to titanium wires. This is explained in Fig. 2.

At point 1: As the microbes around the anode take up the nutrient in the soil/mud, they deposit electrons onto the anode in one of the three ways:

- **Mediated transfer:** using electron-shuttling bio-molecules.
- **Nanowire transfer:** using connected appendages developed by the bacteria.
- **Direct transfer:** from the cell wall of the bacteria and directly to the anode surface.

At point 2: Electrons travel through length of the wire to the board with the power electronics, where they power the small energy intensive devices.

At point 3: After passing through load, electrons go down through the wire via the cathode.

At point 4: At the cathode, electrons interact with oxygen inside the closed vessel to form water.

This cycle happens over and over, trillion of times every second. This continuous flow of electrons is the generation of electricity, which power the small electronics. The Blinker Board (part of the electronics, refer to Fig. 1) gives a visual indication that the microbial community is producing power, All Blinker Board electronics use lead-free solder. The function of the components:

Hacker board: The hacker board takes the low voltage and low current coming from the system and converts into short bursts of higher voltage and higher current. It contains voltage-boosting microchip and 8-pin hacking socket.

Capacitor: Energy storage component, it is able to build up energy as power comes in from the system, and discharge that energy in a quick burst to blink the LED.

LED: The light emitting diode takes the electrons being discharged by the capacitor and converts the electron's energy into light energy. The LED will start glowing only when the voltage generated across the terminals is greater than 0.35V.

The vessel contains a transparent enclosure made of clear PET (Polyethylene terephthalate), white ABS (Acrylonitrile butadiene styrene).

The power can be calculated directly using the multimeter and for taking power measurements and assessing the health of the microbial community. Seven resistors were used as shown in Fig. 3, with values of 47Ω, 100Ω, 220Ω, 470Ω, 1kΩ, 2.2kΩ, and 4.7kΩ respectively.

To find power output (including maximum power), power for each resistor is calculated using Ohm's law.

$V = I.R$ and, $P = V.I$

Therefore,

$P = V^2/R$

Where power is in watts, voltage is in volts, resistance is in ohms, and current is in ampere.

As far as analogies are concerned, it can be deduced that only when voltage difference exists between terminals, current will be flowing, similar to pressure drop allowing fluid to flow. Early experiments investigated the possibility of generating power from the local soil available at Bidholi, Dehradun. The geographical details are mentioned in Table 1.

Sample size for all experimental data is:

1. For sample below anode: 6cm × 6cm × 2cm (weighing around 84 g on average).
2. For sample below cathode and above anode: 6cm × 6cm × 3cm (weighing around 91 g on average).

Detailed graphical analysis of the experiments based on voltage generated will be discussed now, which demonstrates the fact that soil microbes in this region are capable of producing voltage across terminals using the soil as an electrolyte, now throughout all experiments there were some limitations which will be discussed later.

RESULTS AND DISCUSSION

For the graphs given in Figs. 4(a, b) the voltage developed is studied over time, the soil is prepared, and the whole setup is kept under observation, for the first batch the primary target was not to check power production but to investigate if any voltage is generated across the electrodes. This study was started from 14th January 2016 and was done up to 16th January 2016. A 48 hours period was the total duration of the first experiment.

Now it must be remembered that soil microbes, especially bacteria, prefer temperatures above 28°C but less than 60°C, at this time of the year in Bidholi, temperature stays around 24°C during the day and drops to around 8°C at night, so this attributes to a limiting factor hence it is assumed that voltage generated (if any) would be significantly low for this study, as temperature is on the colder side and the time given to the microbes to generate electrons is only 48 hours. But, however, it must be remembered that this experiment is not for investigating peak power but to see if any voltage is generated in this setup by the soil bacteria

Table 1: Details of the geographical location of Bidholi.

Name	UPES, Bidholi
Type	Locality
Latitude	30°31'65"
Longitude	78°03'22"
State	Uttarakhand
District	Dehradun

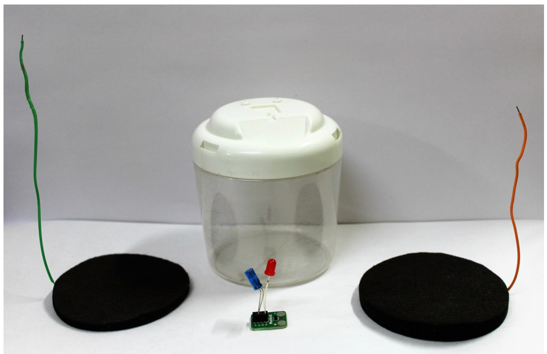


Fig. 1: The anode (with green wire), cathode (orange wire), the vessel and the electronic setup.

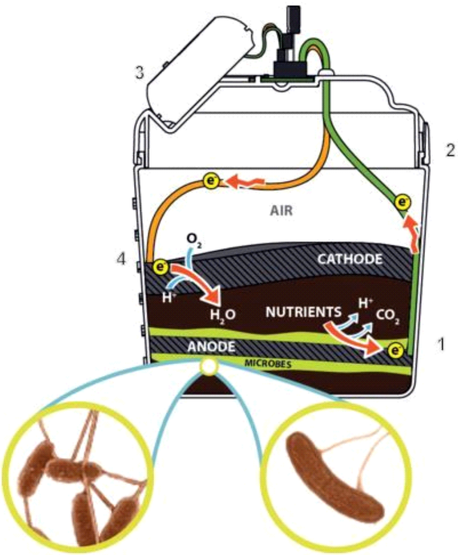


Fig. 2: The flow of electrons through the system.

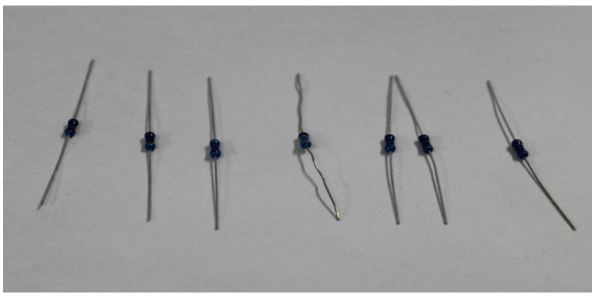


Fig. 3: Seven different resistors (47-4700 Ωs), value can be found by connecting the multimeter.

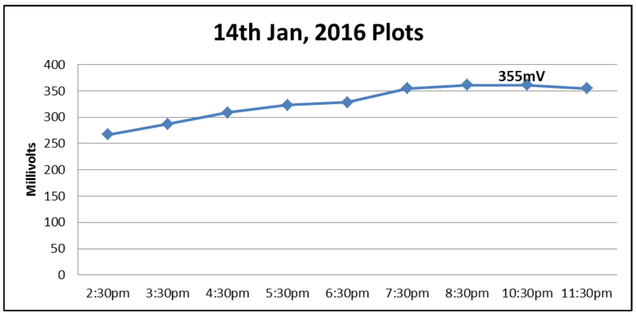


Fig. 4 (a): For the first 12 hour study, the peak voltage was 361mV.

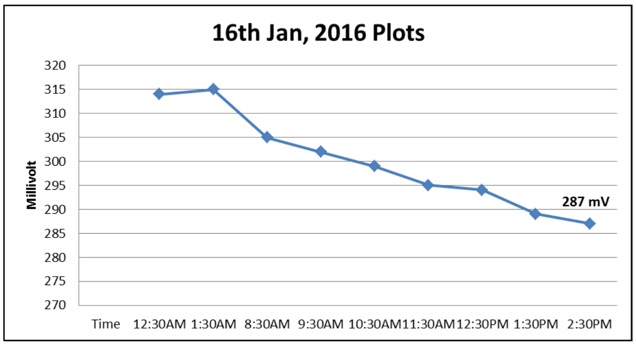
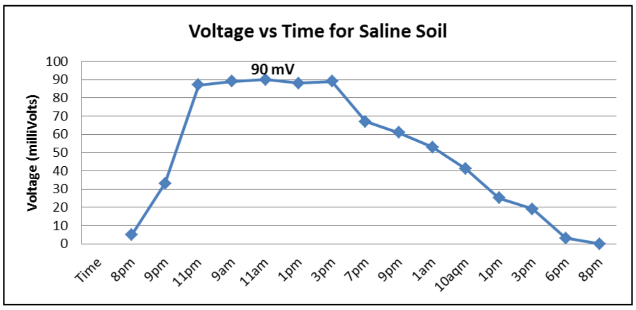
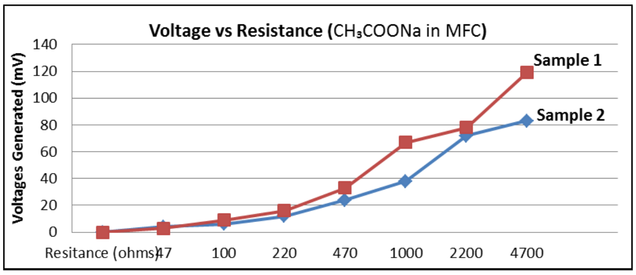


Fig. 4 (b): For the last 12 hours, peak value was 299 mV.



(a)



(b)

Fig. 5: (a) Voltage variation over time in a saline soil system; (b) Voltage variation with resistance over time for two samples of soil with fixed amount of sodium acetate added to it.

via the process we have suggested.

Fig. 4(a) confirms that the potential can exist with the local soil here between the anode and cathode, one hour after charging the system, the value shot up to 267 millivolts (mV). Over time this value increased and for that day the peak voltage value was 361 mV. From Fig. 4(b), it is reported that the value of voltage starts dropping, now for this there is a very good explanation.

Ideally, this system can develop a big community of microbes and can work for a month or even a year, but since in this investigation we only wanted to see the voltage generated across the terminal, we kept it open circuit, i.e. the cathode and the anode were not connected to the pins on the Blinker/Hacker board. And the value of voltage was taken by connecting the multimeter with alligator clips and the other end of the clips directly to the titanium wire of the anode and cathode.

Before going on to experiments to see peak power produced and its characteristics, it is of interest to see how the soil bacteria react to certain materials. For this investigation we have considered two substances, salt and sodium acetate (CH_3COONa), both 25 g respectively.

Sodium chloride or table salt is the most commonly available material in soil and water, we made an investigation where saline water is mixed with the soil and response of the microbes are recorded, in terms of voltage over time, while for sodium acetate, some literature from a University in Boston (United States), who made a similar soil based experiment with MFC, found that bacteria loves consuming acetate (Villarrubua & Wuillma 2011). This triggered us to make a study with our local soil and see how the soil microbes react to it.

For Fig. 5(a), the peak voltage recorded 90 mV and then it started dropping within the 24 hours, thus showing that bacterial species in the soil are highly salt intolerant and cannot produce power where the salinity concentration in the soil is high. For this experiment 25 g of salt was added to the soil. This outcome was somewhat expected, as salinization of the soil is recognized as one of the most pressing environmental challenges. It is reported that elevated sodium (Na^+) decreases plant growth. For Fig. 5(b), some literature has suggested that MFCs running with soil as electrolyte has a remarkable influence on the power produced by soil microbes, but the given sample taken for this investigation reports poor microbial growth. Two separate samples were taken and they both peaked up to 83 mV and 119 mV respectively in a 72 hours study.

Fig. 6(a) represents the second system which was setup in the mid of February 2016, when temperature was between

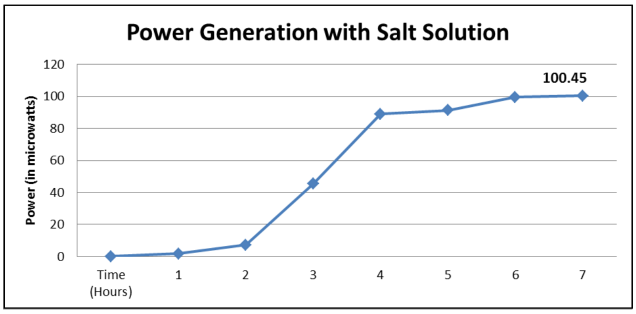


Fig. 6 (a): Power output for saline soil using one resistor (220 ohms).

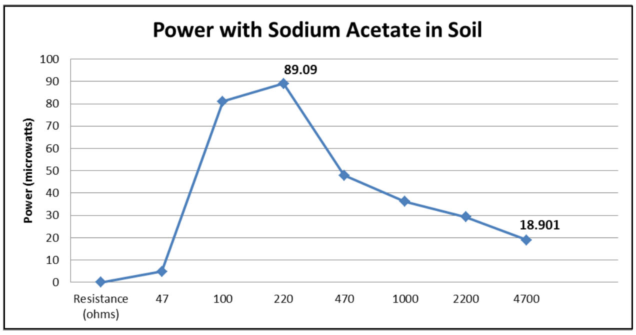


Fig. 6 (b): Power output variations with use of sodium acetate in the soil of MFC.

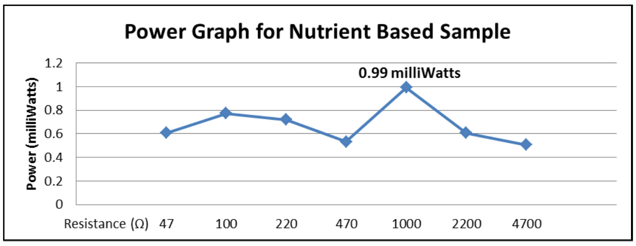


Fig. 7(a): Power versus resistance.

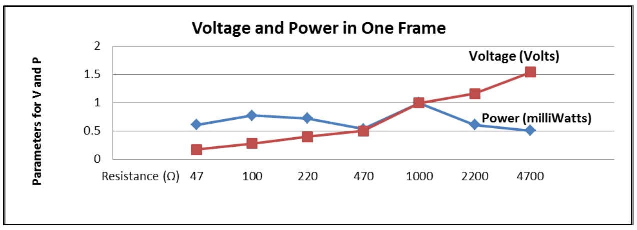


Fig. 7(b): Bringing voltage and power in one framework to deduce nature of the current produced.

28°C in the morning to 15°C at night. The setup with salt solution was observed for few hours because from previous graphical analysis, voltage vs. time plot, it was concluded that saline condition do not allow much microbial growth, hence this study was completed within 24 hours. This investigation for generating power with salt solution showed that the power stabilized around 100 µW. Fig. 6(b), shows power production with sodium acetate (CH_3COONa) solution, now this has been very interesting, in the previous case it is reported that power continued to increase very slowly after 100 µW, in this case it is seen that after reaching a peak value of 89 µW the power production started dropping all the way up to 18 µW, and then it was discontinued.

This behaviour was somewhat unexpected, the authors deduce that Himalayan soil or simply soil microbes in this region do not consume acetate the way some literature suggested. And since acetate is expensive, it should not be considered for large scale use.

Now the following discussion will show the maximum power output reported from Himalayan soil using the MFC system, for this system there was significant enrichment of the soil that was done. For the anode, the soil sample was mixed with nutrient 1 and the sample below cathode was mixed with nutrient 2. The details of them are as follows:

Nutrient 1 (mixture): Water (10 mL), tomato paste (34.5 mL), sugar (2 g), liquid glucose (10 mL), iodized salt (2 g), onion peels (4 g) and garlic peels (4 g).

Nutrient 2 (mixture): Water (10 mL), tomato paste (34 mL), sugar (2 g), edible common salt (2 g), onion peels (2 g) and garlic peels (2 g).

For the graph in Fig. 7(a), we see that the peak power produced by the system in two weeks time is 0.99 millivolts, and then it drops, the value fluctuates because different resistors are used to record the voltage which then fed into the equation: $P = V^2/R$, gives the power produced. This investigation could have been continued further to see how much power can it produce and given the observation made, it is very clear that power value will again increase.

In the study explained graphically in Fig. 7 some very interesting observations are reported. Referring to Fig. 7(b), it is seen that voltage generated across the terminals increases rapidly up to 1.54 volts, the study was discontinued after that to see the power production. However, the graph given demonstrates the capability of the soil microbes to produce voltage not in the range of milli to micro, but a higher range and if this is allowed to continue (say for a month), there can be some remarkable current produced from the system which we can then speculate to help light less energy intensive devices at rural levels where electricity is still not available. The microbial fuel cell generates DC or direct current, and with increasing resistance the value of power produced goes down as both are inversely related to each other. Given the vessel size, nutrients, both 1 and 2, were adjusted accordingly and no specific strongholds were considered for the mixtures. It was considered an agglomerate of kitchen wastes.

CONCLUSION

This work investigated the power producing capabilities of soil bacteria, because there was no such literature available on Indian soils for it. This work is considered important in that it has shown that the electrogenic bacteria which can work in a microbial fuel cell exists here as well. For this work a specific location in India, Uttarakhand, in Dehradun at Bidholi was taken for the soil samples. For sample sizes of 6cm × 6cm × 3cm this MFC system has produced peak power of 0.99 millivolts, so it can be speculated with bigger sample size i.e., scaling up this system can produce significant power. Also it must be mentioned that because of time limitation most of the investigations in this work were restricted to maximum of two weeks, so the spectrum of possibilities are wide open for this kind of renewable energy technology to grow, as this work has shown that the system works. Furthermore, once the power has stabilized for the system we have used, small electronics can be plugged into the Blinker Board and can be operated. The system did show some limitations such as: water build up over the cathode, and the power production is low if temperature is below 24°C but having said that this work has demonstrated the top soil use and also showed the use of salt solution, chemicals like sodium acetate, and tomato pulp. There is literature available, as discussed earlier, which shows use of vermicompost, which makes the soil further enriched with nutrients. Also present work went with direct electron transfer process, hence no cost related to use of chemicals.

The concept of microbial fuel cells can be used in places lacking proper sanitation and electricity. There are studies which have shown generating electricity in MFCs in different setups can also purify water (Bruce Logan Web 2016).

ACKNOWLEDGEMENTS

Present work has been funded by the Department of Chemistry at University of Petroleum & Energy Studies, Dehradun, India. We thank them for their inputs and allowing us to carry out this investigation. We would like to acknowledge the continuous support of Dr. Pankaj Kumar, HOD, Chemistry Department and Dr. Kamal Bansal, Dean, CoES, UPES for the RISE initiative which allowed this investigation to meet its goal.

REFERENCES

Amann, Rudolf I., Wolfgang Ludwig and Karl-Heinz Schleifer 1995. Phylogenetic identification and *in situ* detection of individual microbial cells without cultivation. Microbiological Reviews, 59(1): 143-169.

Arulmani, S.R.B., Jayaraj, V. and Jebakumar, S.R. 2016. Long-term electricity production from soil electrogenic bacteria and high-content screening of biofilm formation on the electrodes. Journal of Soils and Sediments, 16(3): 831-841.

Barua, P.K. and Deka, D., 2010. Electricity generation from biowaste based microbial fuel cells. International Journal of Energy, Information and Communications, 1(1): 77-92.

Bruce Logan, Web, Website: http://www.engr.psu.edu/ce/enve/logan/bioenergy/research_mfc.htm (Accessed: 04/22/2016)

Das, Debabrata and T. Nejat Veziroçlu 2001. Hydrogen production by biological processes: a survey of literature. International Journal of Hydrogen Energy, 26(1): 13-28.

He, W., Zhang, X., Liu, J., Zhu, X., Feng, Y. and Logan, B.E. 2016. Microbial fuel cells with an integrated spacer and separate anode and cathode modules. Environ. Sci. Water Res. Technol., 2: 186-195.

Hisham, N.S.N., Zain, S.M., Jusoh, S., Anuar, N., Suja, F., Ismail, A. and Basri, N.E.A., 2013. Microbial fuel cells using different types of wastewater for electricity generation and simultaneously removed pollutant. Journal of Engineering Science and Technology, 8(3): 317-326.

Hofstetter, T., Pecherl, K. and Schwarzenbach, R.P. 2002. Bioavailability of clay-adsorbed U(VI) to Shewanella putrefaciens. Environ. Sci. Technol., 36: 1734-1741.

Li, Jessica 2013. An experimental study of microbial fuel cells for electricity generating: performance characterization and capacity improvement. Journal of Sus. Bioenergy Systems, 3: 171-178.

Patel, Beena, Bharat Gami and Hiral Bhimani 2011. Improved fuel characteristics of cotton stalk, prosopis and sugarcane bagasse through torrefaction. Energy for Sustainable Development, 15(4): 372-375.

Kim, J.R., Cheng, S., Oh, S.E. and Logan, B.E. 2007. Power generation using different cation, anion, and ultrafiltration membranes in microbial fuel cells. Environmental Science & Technology, 41(3): 1004-1009.

Sharma, R., Tiwari, A.K., Kumar, G.S. and Lamba, B.Y. 2015. Cost effective and economic method for cultivation of chlorella pyrenoidosa for the simultaneous treatment of biogas digester wastewater and biogas production. International Journal of Pharma Sciences and Research, 6(2): 318-321.

Villarrubua, Narváez, and Claudia Wuillma 2011. Integration of composite nanomaterials into anode and cathode designs. Doctoral dissertation.