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Production of Bioelectricity from Vegetable Waste Extract by Designing a U-shaped Microbial Fuel Cell

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Authors' Contribution
MMJ conceived and designed the study. MAN and MUA wrote the manuscript and participated in field work. BM provided field support and logistics.

Key words
Vegetable waste extract, Polypropylene Random (PP-R), Electrochemically Active Bacteria (EAB), Designed Synthetic Waste Water (DSWW), Anode chamber.

ABSTRACT

The microbial fuel cell (MFC) was constructed from polypropylene random (PP-R) pipes jointed in U-shaped manner with a cation exchange membrane. The MFC constructed was subjected for the bioelectricity production by using vegetable waste extract as substrate. The power production was analyzed for three days. Maximum power density of 88990mW/m^2 with a current density of 314.4mA/m^2 was observed on the second day of process with minimum internal resistance comparatively *i.e.* 123.23Ω. The higher power density shows efficiency of this U-shaped design compare to other dual chamber MFCs.

INTRODUCTION

Microbial fuel cells (MFCs) are one of the alternatives for the production of electricity. It is just like any other fuel battery having electrodes and chemicals to react *i.e.* electrolysis but in case of MFCs the chemical reaction is more like biochemical that involves the microorganisms to carry the process. The whole process is carried out by the oxidation of the substrate with the help of microorganisms in well-designed manner (Du *et al.*, 2007). MFCs are the devices which have been used for the production of bioelectricity with the help of microorganism utilizing the various organic matters (Lovley, 2012). These are the emerging environmental friendly and renewable sources for the production of energy. MFC technology involves many disciplines such as biological, electrochemical and physical process. Because bacteria are mostly preferred which utilizes the substrate *i.e.* organic matter and acting like a bioremediation agent and degrading biologically the organic waste. Municipal waste, agriculture and industrial waste are ideal because of rich microflora, cheap source and rich organic energy source for the microorganisms (Logan *et al.*, 2006; Zhou *et al.*, 2013). Gul *et al.* (2012) reported the production of industrially important end-products by converting hazardous industrial effluent with microbial cell factories. Inoculum microbial cells in MFCs transport electrons exogenously to electrodes without using artificial mediators. Various studies proved relation of bacterial specific genes or proteins for their bioelectricity potential in MFCs. Examples of such certain genes reported as redox-active compounds (*e.g.*, pyocyanin), outer membrane multiheme cytochromes (*e.g.* OmcZ), conductive pili predominantly in the members of *Shewanellaceae* and *Geobacteraceae* family (Kumar *et al.*, 2015). Whereas, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Aeromonas hydrophila* subsp. *hydrophila*, co-culture of *Clostridium cellulolyticum* and *Geobacter sulfurreducens etc.* have been reported microbial inocula in various studies as efficient producers of bioelectricity in MFCs (Ren *et al.*, 2008; Kalleary *et al.*, 2014; Shen *et al.*, 2014).

The MFCs have two portions in their design *i.e.* the anode portion, where the microbial action produce electrons and protons, and the cathode portion where the electrons and protons from the anode produced by microorganism are transferred and form water by a chemical reaction with oxygen which act as electron acceptor (Oh *et al.*, 2004).

Electrons produced from the bacteria may transfer from bacterial cell to electrode with the help of mediators like thionine, methyl viologen, and methylene blue *etc.* (Delaney *et al.*, 2008). It could also be without the use of mediators, which makes them mediator-less MFCs, by the utilizing of the electrochemically active bacteria (EAB). EAB has the potential of transferring the electrons to the

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electrode via its cell wall by making biofilm over electrode (Rabaey and Rozendal, 2010; Logan and Rabaey, 2012).

Different kinds of the substrates have been used so far in the MFCs for the bioelectricity production which includes: food, agriculture and domestic waste water (Nimje *et al.*, 2012), rice straw (Hassan *et al.*, 2014), glucose, fructose and sucrose (Jafary *et al*., 2013) and many others. Besides all these, food waste extract is also been reported for the bioelectricity production which is a major portion of urban municipal waste (Venkata *et al*., 2010; Goud *et al*., 2011; Li *et al*., 2013). It has been studied that the use of mix microbial culture give a potentially better power output as compare to the pure cultures (Rabaey *et al*., 2004).

In present study, vegetable waste was utilized as a substrate and source of energy for mix microbial culture for the production of bioelectricity through a microbial fuel cell designed by simple local market materials.

MATERIALS AND METHODS

Construction of microbial fuel cell

Microbial fuel cell was constructed from combining two PP-R pipes of 12 inches length in a U-shaped manner with the help of a union at the bottom joining the two elbows on either side (Fig. 1). A cation exchange membrane (CMI 7000, from membrane international) was placed in between the joint of the union. Three graphite rods serving as electrodes (anode and cathode) each with 5cm length, 0.81cm in diameter and surface area of 0.0015m^2 were placed inside the anode and cathode chambers, further these were fixed with aluminum wires to get the power output. In present study, U-shaped microbial fuel cell was used instead of H-shaped, because H-shaped design is mostly used for basic parameter research like analyzing the power production from new substrate materials or microbial cultures, or checking the degradations of some toxic substances.

Preparation of vegetable waste extract

Household vegetable waste including cabbage, spinach leaves, potato peels, cucumber peels and carrot was collected (100g of each) from a local market. They were washed properly and converted to smaller pieces, and blended in a blender with 0.1M phosphate buffer solution (PBS). The slurry was filtered and extract was separated for further use. NaCl (50mM) was added to the final volume of this extract and the pH was adjusted to 4.5 by using acetic acid.

Inoculum enrichment

Sample of sewage waste water was collected from Hall Road, Lahore. Sample was enriched in designed synthetic waste water (DSWW). The composition was: glucose, 3g/l/; NH_4Cl, 0.5g/l; K_2HPO_4, 0.25g/l; KH_2PO_4, 0.25g/l; $MgCl_2$, 3g/l; $ZnCl_2$, 11.5mg/l; $CoCl_2$, 25mg/l; $CaCl_2$, 5mg/l; $CuCl_2$, 10.5mg/l; $FeCl_3$, 25mg/l; $MnCl_2$, 15mg/l; $NiSO_4$, 16mg/l and vitamins 5g/l (Venkata et al., 2010). DSWW media was purged with nitrogen before sterilization to reduce the oxygen level inside the media. pH of the medium was checked to be 7.0. Sample was

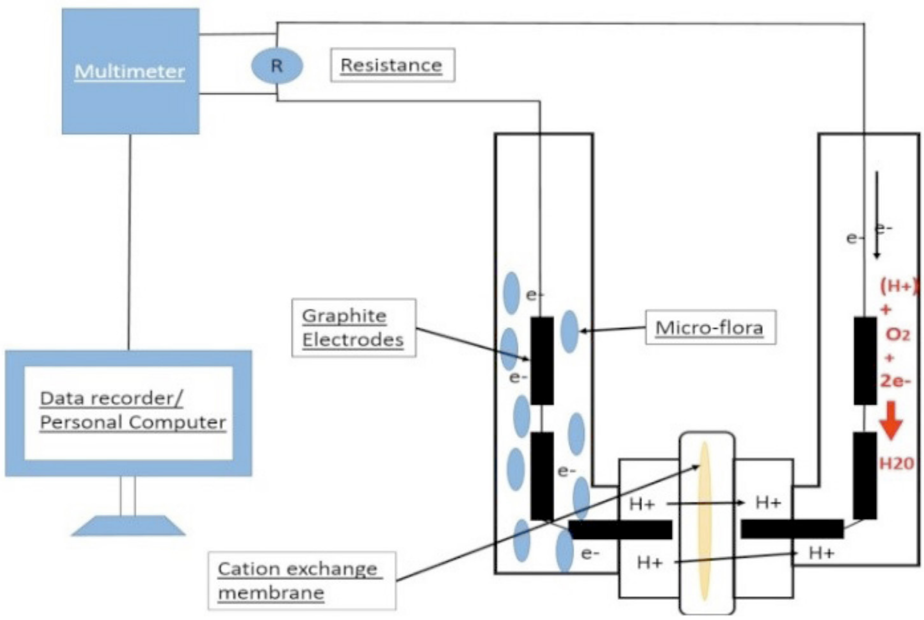

Fig. 1. Diagrammatic scheme of the U-shaped MFC design and set up.

inoculated and incubated at 37°C for 48 h. This enriched mix microbial culture (composed of anaerobic bacteria) was then centrifuged at 5000 rpm, 20°C. Pellet was washed several times by centrifuging it with saline phosphate buffer solution (PBS with 0.85% NaCl).

Pellet obtained from the centrifugation of enriched mix microbial culture was used as inoculum. Prepared vegetable waste extract was also purged with nitrogen and was added in the anode chamber. Cathode chamber of the MFC was filled with saline water (50mM NaCl). Both chambers were separated from each other through a cation exchange membrane at the center. The opening of anode chamber was closed and the MFC setup was connected with a variable resistance in parallel with the multimeter (UNI-T UC- 60A) with personal computer (PC) interface. After 24 h, the voltage production was analyzed under steady state condition.

Data analysis

Results were analyzed by checking voltages across variable resistance (5-4000Ω). Electric current was calculated by following the ohm's law *i.e.,* I=V/R and the power was calculated by the relation P=VI. Electric current density and power density were calculated by dividing the total surface area of anode electrodes to current and power respectively. Surface area of the graphite rods was calculated with the help of formula $2\pi r^2+2\pi rh$. Internal resistance was calculated from the slope (-ΔV/ΔI) of the linear zone of the plot between the voltage (obtained from 200-5000 Ω) and current (Logan *et al.*, 2006).

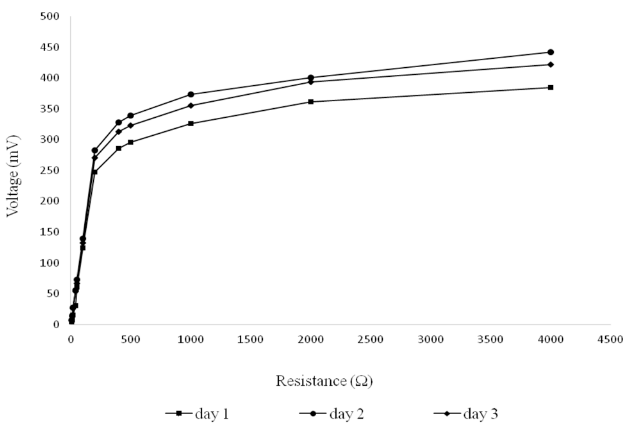

Fig. 2. Graph between voltage and resistance.

RESULTS AND DISCUSSION

Voltage was analyzed with variable resistance and straight line graph was obtained up till 100Ω for all three days of data analysis. Highest voltage with respect to 100Ω was detected on day-1 of process which was 139mV (Fig. 2). The voltage from the open circuit *i.e.*, without any external load was also in support of the voltage with resistances. Highest voltage (566.3mV) was observed on day-2, while the average voltage on day-1 and day-3 was 498.2mV and 541.3mV respectively (Fig. 3). Maximum power density was obtained at 200Ω with external load for three days; highest power density (88990mW/m²) was obtained on day-2 of the process with current density of 314.4mA/m² (Fig. 4).

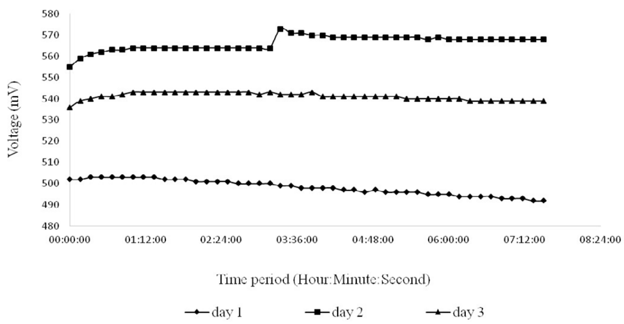

Fig. 3. Open circuit voltage of three days.

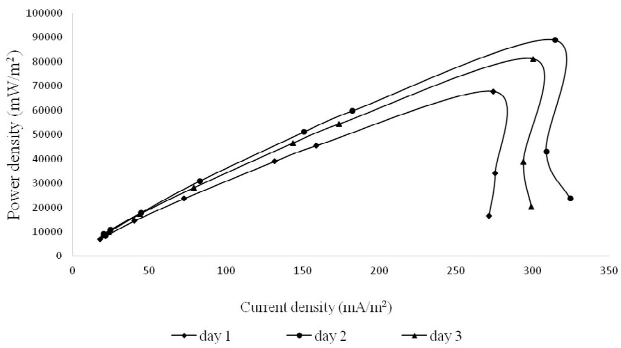

Fig. 4. Polarization curve.

It has been found that U-shaped MFC is advantageous when compared to the power production by commonly used H-shaped dual chambered microbial fuel cell. This U-shaped was the modification in term of the membrane joint which was bring at the bottom instead of the center by keeping the view of taking advantage from the anaerobic microbial community which tends to grow at bottom.

The minimum internal resistance was 123.23Ω on day-2 which was the reason of higher power density. Negligible change in internal resistance was observed for day-1 and day-3 as: 125.88Ω and 125.80Ω, respectively (Fig. 5).

In present study, difference in the internal resistance wasn't high because of relation of increase in current generation and higher microbial density with time period. But slight increase in the internal resistance was calculated for third day of the process evidencing the increase in microbial density and lower current as compare to the second day due to which the volumetric resistance increased. This result is in accordance to Clauwaert et al. (2008). Operation of MFC at anodic pH of 4.5 to support the higher power output by making the pH difference between the anodic and cathodic chamber results for increase the ionic strength in present studies which is in accordance with Jadhav and Ghangrekar (2009) and Zhuang et al. (2010).

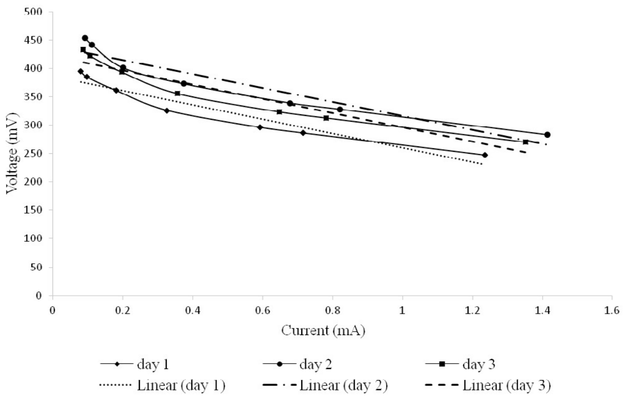

Fig. 5. Identification of internal resistance from the linear zone of plot.

Electrode also has some effects on the performance of MFCs. The electrode material should be cost effective, a good conductor and chemically stable. The electrodes in dual chambered MFC are bio-electrode which also serves as the carrier for the biofilm. Metal electrodes if used should be non-corrosive and chemically resistance. Stainless steel mesh is one of the alternatives for the usage of metals. The electrode material should also be non-toxic to the biofilm, as we can see that the copper can cause toxicity to many of bacteria so it would be good to avoid copper (Zhang *et al*., 2009; Deng *et al*., 2010). Most of the time graphite or carbon material is used because it gives good results as compare to the aluminum, stainless steel and iron electrode (Sangeetha and Muthukumar, 2013).

Sludge derived microbial inocula remain prominent microbial source for enhanced production of bioelectricity in MFCs. Recent studies utilized sewage waste water as source of mixed microbial inocula for bioelectricity production and reported considerably efficient power densities of 432mW/m^2 (Li *et al*., 2013) and 230mW/m^2 (Mansoorian *et al*., 2013). These results are in accordance with power density output of present study. Besides sludge inocula, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Escherichia coli*, *Enterobacter cloacae* has been used in various studies and reportedly produced power densities of 15.29, 2.86, 590 and 5.5mW/m^2, respectively (Shen *et al*., 2014; Kalleary *et al*., 2014; Makinen *et al*., 2013; Rezaei *et al*., 2009). In comparison of these bacterial cultures, enriched mixed microbial inocula from activated sludge proves better source because it contains a variety population of microorganisms which comparatively generates more powerful electron impulse rather than a single bacterium.

Present studies showed continuous increasing trend, for each day, in the power density that evidences for the optimum microbial activity and increased microbial growth with the substrate used in microbial fuel cell. Maximum power density production in present work was 88990 mW/m^2 which was higher than most of the reports so far to our knowledge (Ren *et al*., 2008; Wang *et al*., 2014; Yong *et al*., 2014; Cao *et al*., 2015). However, higher power densities: 119310mW/m^2 (Mohan *et al*., 2008), 7,205,000mW/m^2 (Cirik, 2014) and 642000mW/m^2 (Akman *et al*., 2013) have been reported. Higher power output in these studies was due to minimum ohmic losses because of higher contact between the electrodes and microorganisms at the bottom of the MFC and optimized ionic strength due to Phosphate buffer and proper salt concentration (Clauwaert *et al*., 2008; Li *et al*., 2013). The application of MFC technology is not desirable in the larger scale yet because of the higher cost material that would be used in the larger scale. But its application at household level seems prominent as its future aspect especially in countries like Pakistan where power is such a big issue. MFC can be utilized here to overcome power shortage.

Statement of conflict of interest

Authors have declared no conflict of interest.

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