Electricity Production by Membrane-less Microbial Fuel Cells

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Abstract: The performance of single chambered microbial fuel cells (mediator and membrane-less) under anaerobic condition utilizing different substrates glucose, cyanobacterial hydrolysate and potato peel hydrolysate were evaluated. The biofilm of microbe Bacillus firmus –NMBL-03 over plain graphite electrodes was used as biocatalyst under current investigation. The design of the MFC (50 ml) used in the current investigation was simple and cost effective. The maximum current density 37.9 mA/m^2 and power density 8.7 mW/m^2 were observed with cyanobacterial hydrolysate. However, maximum power density observed in the case of potato peel hydrolysate and glucose was 2.5 mW/m^2 and 2.9 mW/m^2 respectively. It was observed that the performance of the microbial fuel cell depend upon the substrate used.

***IndexTerms* - Microbial fuel cell; Single chamber; Membrane-less; Bacillus firmus –NMBL-03; Glucose; Cyanobacterial hydrolysate; Potato peel hydrolysate.**

I. INTRODUCTION

Fuel cells are one of the renewable and environment friendly sources of energy [1]. These are electrochemical devices that continuously convert the chemical energy into electricity by electrochemical reactions along with biochemical pathways [2]. Biological fuel cells have two categories namely microbial fuel cells and enzymatic fuel cells [3, 4]. Microbial fuel cells (MFCs) use living cells as biocatalyst, whereas enzymatic fuel cells use active enzymes [5, 6].

The electrical power generation of MFCs are basically dependent on the factors; such as (a) nature of carbon source used, (b) fuel-cell configuration (single/multiple chamber), (c) working dimensions and volume of MFC, (d) nature and type of electrode, (e) electron acceptors (mediators) present in the cathode chamber, (f) electrolytes used, (g) operating temperature, (h) nature of inoculum (biocatalyst) used in the anode chamber, and (i) nature of the proton exchange membrane [7]. The electricity generation from pure culture of microbial consortium by microbial fuel cells has been reported [8, 9]. It has been observed that microbial biofilm provides greater potential for cell-to-cell contact which helps to stimulate the electron transfer mechanism in the electrochemical process [10].

Since proton exchange membranes give high internal resistance and biofouling, which limits the power generation and practical use of MFCs. Therefore single chambered membrane-less MFCs with different construction have been demonstrated [12-18]. The proposed MFC configurations are based on the single chamber, mediator and membrane-less using pure culture of Bacillus firmus –NMBL-03 as biocatalyst in anaerobic condition. The pre-colonized anodes are used for three MFC's configuration. The basic aim of the present study is to design MFCs with low-cost materials..

II. MATERIALS AND METHODS

A. Anaerobic single consortia

Anaerobic single culture of Bacillus firmus –NMBL-03 was used from our laboratory. The inoculum was grown on all three anodes by suspending the electrodes in log phase grown culture broth filled with designed synthetic wastewater with yeast, vitamin and 10% of inoculum. The bottle was sealed with parafilm and placed on a magnetic stirrer (speed 100 rpm; at room temperature i.e. 32 ± 2 oC) for 30 min for biofilm formation. Upon growth of inoculum the electrodes were placed vertically in MFC.

B. Chemical wastewater

Glucose/cyanobacterial hydrolysate/potato peel hydrolysate as substrate with macro solution (NH_4Cl, 8.1 g; KH_2PO_4, 9.4 g; K_2HPO_4, 19.3g; NaCl, 0.4 g; $CaCl_2.2H_2O$, 0.5g; $MgCl_2.6H_2O$, 0.93g; $FeSO_4.2H_2O$, 13.9 µg; $NiCl_2.6H_2O$, 60.0 µg; $NaMoO_4$, 90.0 µg; $CoCl_2$. $6H_2O$, 200.0 µg; $MnCl_2.4H_2O$, 300.0 µg; H_3BO_3, 90.0 µg; $ZnSO_4.7H_2O$, 300.0 µg) were used separately. The COD content of glucose, cyanobacterial and potato peel substrate were 8 g/l, 8 g/l and 12 g/l respectively with initial pH of 7.0 pH.

C. MFC configuration

Falcon tubes were used to construct the MFCs. The wire input point (at top), inlet port, outlet port and cathode fixing port were designed on falcon tube. The design of all three MFCs (inner diameter 3 cm and working volume 50 ml) was same as shown in Fig 1. A rectangular anode of surface area 62 cm^2 inserted vertically and a cylindrical cathode of surface area 24 cm^2 was placed horizontally at the bottom port of the MFC (Fig 2). Both, anode and cathode was made of graphite without catalyst coating treatment. The overall surface area was increased by creating holes of 0.1cm diameter on the surface of the anode. The electrodes were soaked in deionized water for 24 h and then placed at the distance of 1.6 cm inside MFC [10].

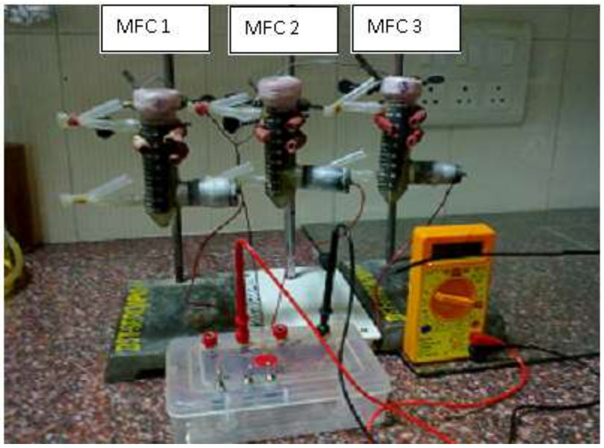

Fig 1. Photograph of single chambered membrane-less MFCs (MFC 1 with cyanobacterial hydrolysate; MFC 2 with glucose and MFC 3 with potato peel hydrolysate).

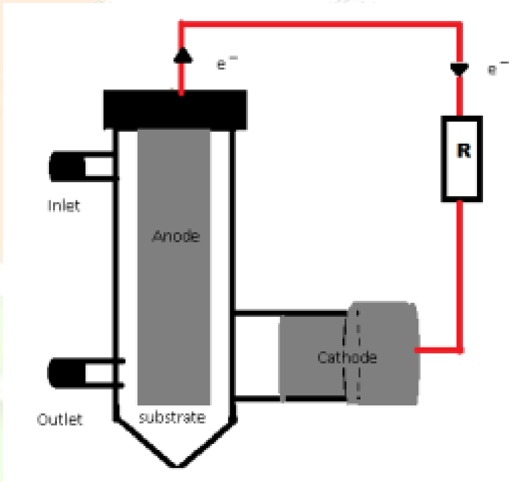

Fig 2. Schematic of single chambered membrane-less MFC.

D. MFC operation

All three MFCs were allowed to work simultaneously under same conditions. The MFCs were operated in open circuit mode firstly for 14 days. MFCs were washed with 70 % (v/v) ethanol followed by distilled water and put in UV chamber for 20 min before installing next set-up. MFCs were operated with fresh setup in closed circuit mode by connecting external resistance of 1000 Ω. MFCs were operated in fed batch mode at room temperature. MFCs were refilled with the substrates after every 6-7 days. Each time the spent media from the MFCs were removed and filled with fresh medium.

E. Analysis

Voltage (V) was recorded after every 3 h for open and closed circuit (1000 Ω resistance). For polarization, current production during stabilized operation of MFC was monitored by connecting to various resistances (100-40,000 Ω) in parallel. Current (I, in amperes) and power was calculated as I=V/R and P=IV respectively. Power density (mW/m^2) and current density (mA/m^2) were calculated by dividing the obtained power and current with the surface area (m2) of anode [11].

III. RESULTS AND DISCUSSION

The open circuit voltage in membrane-less MFCs was measured for first 14 days (Fig 3). The maximum open circuit voltage of 830 mV with the MFC containing cyanobacterial hydrolysate was recorded. Initial voltage of 467 mV was developed with cyanobacterial hydrolysate, which gradually increased with time and remained constant nearly after 140 h. The maximum open circuit voltage of 586 mV with the MFC containing glucose after 10 h; and with potato peel hydrolysate 548 mV after 20 h was observed. The outputs from glucose and potato peel decreased with time.

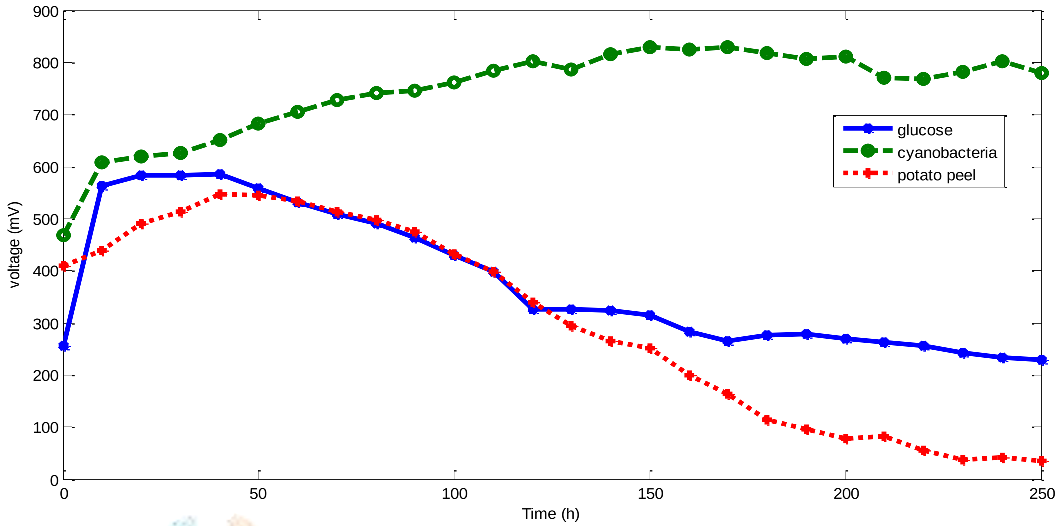

Fig 3. Open circuit voltage produced by the MFCs with glucose, cyanobacterial hydrolysate and potato peel as substrate using Bacillus firmus –NMBL-03 as biocatalyst.

The same set-ups were made for closed circuit by connecting external resistance of 1000 Ω (Fig 4). The maximum closed circuit voltages of 161 mV, 74 mV and 40 mV were observed with cyanobacterial hydrolysate, glucose and potato peel hydrolysate respectively. The current density profile with time was shown in Fig. 5. No improvement in closed circuit voltage (1000 Ω) with every feed of potato peel hydrolysate was observed.

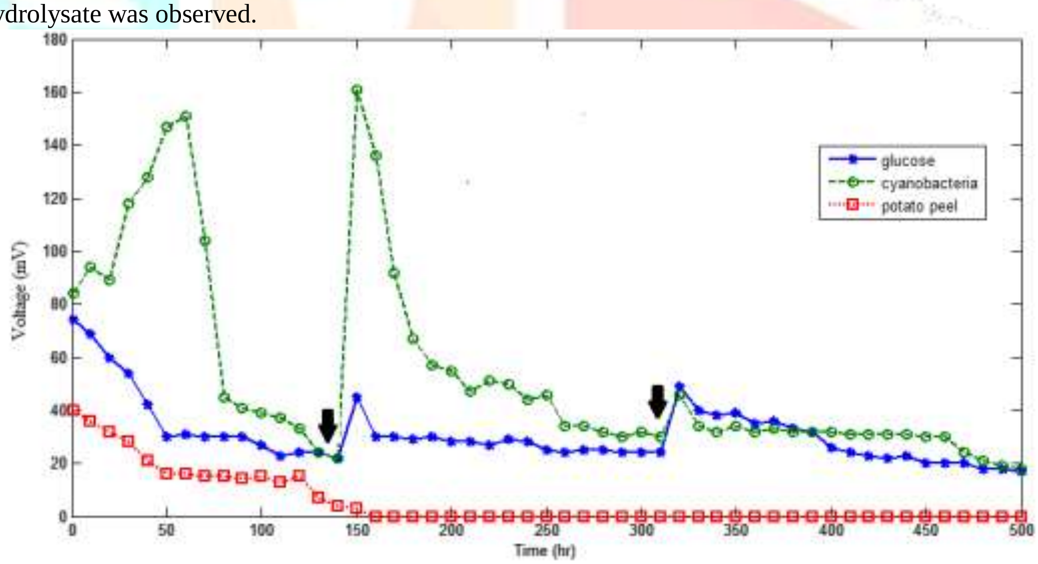

Fig. 4. The output voltage measured at 1000 Ω for all three MFCs (‘ ↓ ’ indicates the change of feed).

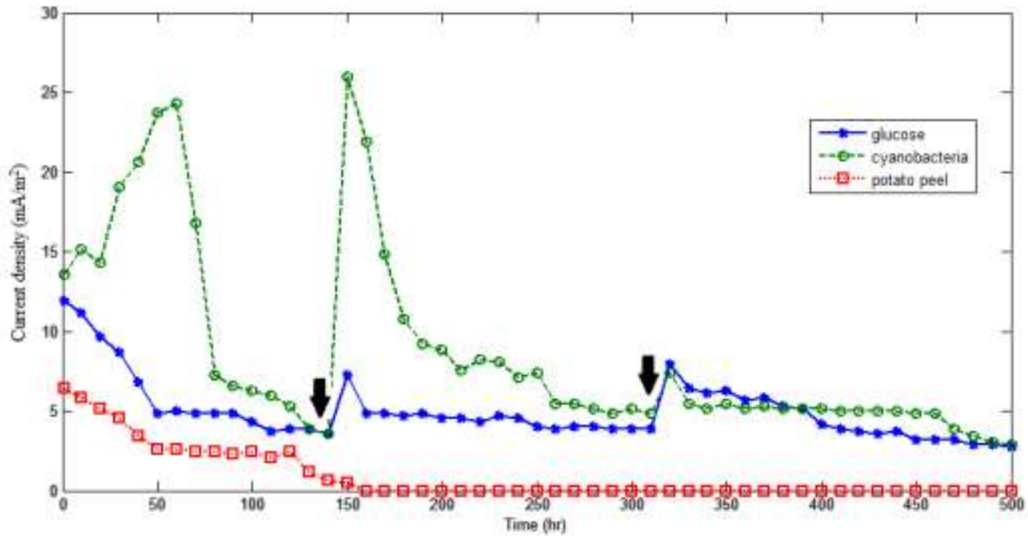

Fig. 5. The current density with time measured at 1000 Ω for all three MFCs ('↓' indicates the change of feed).

The polarization curve was plotted with current density against, potential and power density separately at different resistance (100 Ω to 40 k Ω) (Fig 6). The current density was calculated in different resistance when the maximum voltage obtained. The curve of current density and voltage (Fig 6) of all three MFCs showed the lesser drop in voltage at lower resistance. The voltage stabilization was comparatively rapid at higher resistances. The plot of current density against power density (Fig 6) depicted a maximum power density of 2.9 mW/m^2 (17.7 mA/m^2; at 1.5k Ω) for glucose, 8.7 mW/m^2 (37.6 mA/m^2; at 1 kΩ) for cyanobacterial hydrolysate and 2.5 mW/m^2 (14.1 mA/m^2; at 2 kΩ) for potato peel hydrolysate. It was observed that the performance of MFC for electricity generation depends on the substrate used (Table 1). The highest power density 8.7 mW/m^2 was found with cyanobacterial hydrolysate. It was found that in membrane-less MFCs electricity generation performance also depends on the MFC design (Table 2). The maximum power density of 887 mW/m^2 was recorded with graphite-granule anode, tubular air-cathode MFC (GTMFC). In GTMFC design the flexible carbon cloth with 20% platinum coating onto the inside surface was used as cathode. The two separate peristaltic pump were used to circulate the anodic medium [13]. Continuous flow membrane-less air cathode MFC (MLAC-MFC) with conductive microfiber cleaning cloth as separator was demonstrated by Tugtas et al. [14]. The maximum power density of 750 mW/m^2 was obtained with MLAC-MFC. The anode and cathode were made of carbon cloth. The cathode was coated with 1 mg/cm2 platinum catalyst. The anode chamber was continuously fed and mixed with synthetic wastewater by using peristaltic pump and magnetic stirrer. In baffle-chamber membrane-less MFC, the maximum power density of 161mW/m^2 was recorded [15]. A plastic (plexiglass) baffle was used in baffle-chamber membrane-less MFC to mix the fluid in anode so that oxygen diffusion can be minimized to cathode surface. The gas diffusion electrode, made of standard carbon cloth was used as cathode. The micromagnatic stirrer was used to mix the fluid in chamber adjacent to anode. The maximum power density of 67 mW/m^2 was obtained with twin compartment brush type anode electrodes (TBE) design [16]. In TBE, the central compartment was filled with cattle manure with two compartments on both side fitted with brush anode and air cathode (30% wet-proofed carbon cloth coated with 10% platinum as a catalyst, and ionomer). In cylindrical down-flow single-chamber MFC, the maximum power density of 30 mW/m^2 was recorded [17].). In down-flow single-chamber MFC, both rectangular anode and circular cathode were made from graphite plates without catalyst coating treatment. The anode was vertically inserted into the bottom of the MFC and about half cathode was kept above the liquid level at the upper part of the MFC. Synthetic glucose wastewater was used, which continuously flowed out from bottom of the MFC using a peristaltic pump. In up-flow single-chamber MFC reactor, the highest power density of 1.3 mW/m^2 was achieved [18]. Anode was made from graphite felt as roll form and cathode of same material in a disk form. Glass wool and glass bead was place on the upper of the anode. The artificial wastewater containing glucose and glutamate was fed continuously to the up-flow single-chamber MFC reactor. Air pump was used in cathode compartment.

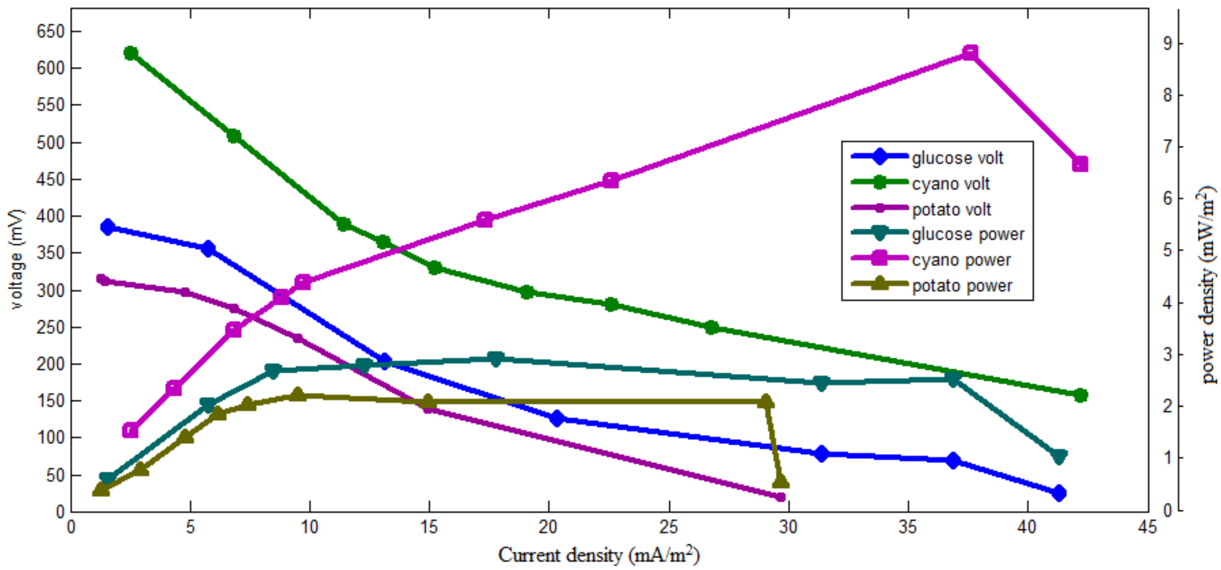

Fig. 6. Polarization curve measured at different resistance (100 Ω to 40 kΩ) for all three MFCs.

Table1. Comparison of voltage, current density and power density of MFCs containing substrates glucose/cyanobacterial hydrolysate/potato peel hydrolysate.

substrate	Maximum open voltage (mV)	Maximum closed voltage (mV)	Maximum current density (mA/m^2)	Maximum power density (mW/m^2)
Glucose	586	74	17.7	2.9
Cyanobacterial hydrolysate	830	161	37.6	8.7
Potato peel hydrolysate	548	40	14.1	2.5

Table 2. Consolidated experimental data of present study in comparison to work reported with membrane-less MFC of different designs.

MFC design	Anode specification	Cathode specification	Substr-ate	Maximum open voltage (mV)	Maximum closed circuit voltage	Maximum current density (mA/m^2)	Maximum power density (mW/m^2)	References
Graphite-granule membrane-less tubular air cathode MFC	Carbon granules	Carbon cloth with 20% platinum coating	Synthetic glucose wastewater	710	384 mV with 50 Ω	—	887	[13]
Continuous flow membrane-less air cathode with spunbon-ded olefin diffusion layer	Carbon cloth	Carbon cloth with 1mg/cm^2 platinum coating	Synthetic waste water with 180mg/L acetate	–	525 mV with 150 Ω	2.0	750	[14]
Baffle-chambered mem-braneless	Carbon paper	Carbon cloth (gas diffusion)	Synthetic glucose wastewater	600	360 mV with 1400 Ω	—	161	[15]

MFC								
Twin compartment brush-type electrode	Carbon fibers brush	30% wet-proof carbon cloth with 10% platinum as catalyst	Cattle manure	550	0.37 mV with 470 Ω	490	67	[16]
Membrane-less single-chamber down- flow feeding onto the cathode	Graphite plate	Graphite plate	Synthetic glucose wastewater	425	—	196	30	[17]
Novel Membrane-less with glass wool and glass bead as separator	Graphite felt in disk form	Graphite felt in disk form	Glucose and glutamate artificial wastewater	800	20 mV with 10 Ω	16	1.3	[18]
single chambered membrane-less M FC	Graphite	Graphite	cyanobacterial hydrolysate containing synthetic wastewater	830	161 mV with 1000 Ω	37.6	8.7	This study

IV. Conclusion

The bioelectricity generation from three single chambered, mediator- and membrane-less MFCs of same design were observed with different substrates containing glucose, cyanobacterial hydrolyslate and potato peel hydrolysate simultaneously. The overall cost of a single MFC was very less due to simple design and use of inexpensive materials. The performance of MFC containing cyanobactreial hydrolysate was better in comparisons with the substrates containing glucose and potato peel hydrolysate. The maximum power density of 8.7 mW/m^2 was observed with the substrate containing cyanobacterial hydrolysate. It was also observed that the substrate containing potato peel was less effective for the growth and metabolism of the microbes. In the absence of proper electron acceptors (oxygen), the less power generation was obtained. This caused increase in the number of protons in substrate with simultaneous production of hydrogen.

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