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Generation of Bioelectricity Using Salt Bridged Two Chambered Mediator-less Microbial Fuel Cell

[1]Hardik Shah, [2]Heena Patel, [1]Kirankumar Patel

[1]*Department of Microbiology, Mehsana Urban Institute of Sciences, Ganpat University, India.*
[2]*Department of Microbiology, Shri A. N. Patel PG Institute, India.*

Address For Correspondence:
Hardik Shah, Department of Microbiology, Mehsana Urban Institute of Sciences, Ganpat University, Mehsana-Gozaria Highway, Ganpat Vidyanagar, Pin Code – 384012, Gujarat, India.
E-mail: hsshah.2001@gmail.com

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ABSTRACT

BACKGROUND: A microbial fuel cell (MFC) works on principle of conversion of chemical energy to electrical energy by the catalytic reactions of microorganisms. Typically, microbial fuel cell comprises of anode and cathode compartments separated by a cation exchange membrane. In the anode compartment, fuel in form of nutrients is oxidized by microorganisms, generating electrons and protons. Through an external electric circuit electrons are transferred to the cathode compartment while protons are transferred to the cathode compartment through membrane. Electrons and protons are consumed in the cathode compartment, where they get combined with oxygen to form water. Microbial fuel cells can be an attractive solution to the pressing issues of energy production and wastewater treatment. In this study, electricity generation by microorganisms was investigated in a salt bridged microbial fuel cell with two chambers. The MFC was using mixture of domestic waste water and industrial byproduct like molasses and distillery spent wash. OBJECTIVE: The objective of this work was to build low-cost double-chambered MFCs that can harvest electricity using waste water as inoculant supplemented with industrial byproducts as source of nutrient without using mediators. RESULTS: Microorganisms were able to utilize the nutritional substrates existing in molasses and distillery spent wash for generation of bioelectricity. The open circuit potential was determined and the maximum voltage generated by microorganisms was measured. The MFCs produced maximum 65.92 mW/m^2 and 35.42 mW/m^2 bioelectricity using distillery spent wash and molasses respectively as source of nutrient. CONCLUSION: MFC demonstrated excellent stability in power generation using industrial byproducts as source of nutrient and sustainably good yield of bioelectricity was obtained.

KEYWORDS: Microbial fuel cell, domestic waste water, bioelectricity, Molasses, Distillery spent wash, MFC

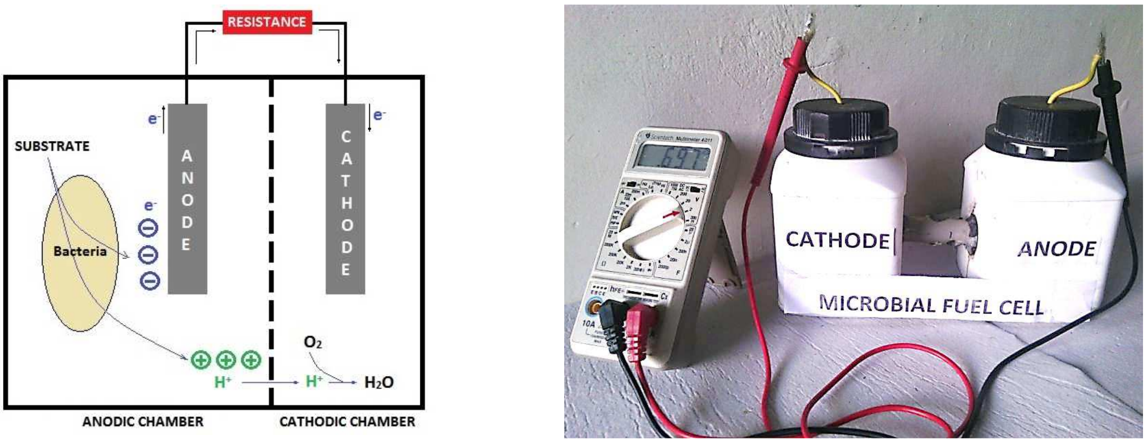
INTRODUCTION

Microbial fuel cells (MFCs) can be considered as a kind of bioreactor that can convert chemical energy present in organic compounds into electricity. Production of electricity occurs through catalytic reactions of microorganisms in which electrons are generated. These electrons are transferred to anode in anodic chamber followed by passing through circuit to the cathode. In case of MFCs where direct transfer of electrons from bacteria to anode is not possible, mediators can be used which can accelerate the transfer [1]. Since, the cost of mediator is eliminated in mediator-less MFCs, they can be more advantageous [2]. At small scale, they can serve as an alternative to conventional methods of generating electricity [3]. There are three generations of MFCs based on their historical development and mechanisms of electron transfer. All these had been studied and reviewed very well [2].

MFCs offer great opportunities for harvesting electricity from a wide range of carbon sources such as organic wastes and biomass. Both fossil fuel depletion and environmental concerns have fostered significant interest in MFCs as novel technologies for the simultaneous treatment of waste water, electricity generation and powering devices/sensors for long term monitoring in remote areas [4, 5]. MFCs may also find potential in application as biosensors and in production of secondary fuel. Research on domestic wastewater for its application in MFC has been extended to a large variety of industrial wastewaters, e.g. from starch [6], wastewaters coming from the meat packing industry [7], swine farms [8] and cereal [9] and potato-processing units [10]. Microbial fuel cell had successfully been used for reduction of COD from industrial wastewaters [11, 12]. Treatment of effluents like Palm oil mill effluent has also been reported [13]. As a novel approach for utilization of MFC, it can also be used for low or non-alcoholic beer too [14].

Research exploiting the ability of living microorganisms for generation of electric power has history of 100 years [15]. It is evident that humankind is increasingly becoming dependent on energy with the advancement of science and technology. The current energy situation in Asian nation and round the globe is precarious, thus driving to the search of alternatives to fossil fuels. Increasing energy consumption could result in unbalanced energy management and critically requires power sources that are able to sustain for longer periods. Recently, considerable interest is noticed in the fraternity on green energy production utilizing renewable energy resource by sustainable means. In this direction, production of ethanol, biodiesel, biohydrogen and bioelectricity from waste materials are finding prominence. Due to its clean, efficient and renewable nature, generation of bioelectricity using microbial fuel cell (MFC) is one of the areas gaining importance [16].

Objective of the study was to utilize wastewater as source of microbes. The wastewater was supplemented with various industrial byproducts like Molasses (MOL) and Distillery spent wash (DSW) for providing nutritional substrates for generation of bioelectricity. The simple diagram of double chambered MFC is shown in Figure 1a.



(a) (b)

Fig. 1: - Double chambered MFC (a) Representation of MFC (b) One of the MFC used for experiment

MATERIALS AND METHODS

Collection of samples:

Domestic waste water was sampled from Goya Pond, Anand, Gujarat (India). Domestic waste water contains broad diversity of microbes that could be rich source of different bacteria. So wastewater was considered as source of microorganisms while industrial byproducts like Molasses and Distillery Spent Wash were considered to provide source of nutrient as fuel for MFC. All of these byproducts belong to different Industries e.g. byproduct of sugar Industry is molasses while DSW is byproduct remaining after distillation of ethanol. Molasses is frequently used as source of different nutrients in various fermentation processes while DSW has very limited applications. Here, all these were used for study of MFC for generation of bioelectricity.

Construction of MFC:

This study included construction of double chambered MFC where salt bridge was used for the electrolytic contact of solutions contained within both compartments. Cathodic and anodic compartments were constructed using non-reactive plastic chambers of 500ml capacity. The salt bridge connecting both the compartments was made using saturated KCl solution solidified using 3% agar in polyvinylchloride pipe with internal diameter 1 inch. An agar solution was prepared by heating 3% agar with saturated KCl [17]. Joints were sealed using regular epoxy compound. For assembly of electric circuit single stranded insulated copper wire with 1 mm internal core diameter was used. Both the chambers were containing two graphite electrodes with the surface area of 7.18 cm^2 each and connected to the copper wire. Electricity generated was measured using Scientech Multimeter 4011. Diagrammatic representation and assembly of MFC are shown in Figure 1.

Operation of MFC:

The anodic chamber was inoculated using domestic waste water supplemented with 10% of nutrient source. Separate units of MFCs were constructed for purpose of both of the substrates (i.e. Molasses and Distillery Spent Wash). Initially, 10% substrate was mixed with the domestic wastewater and kept on rotary shaker at room temperature for 24 hours to allow initial growth of microbes. After 24 hours of incubation the content was transferred to anodic chamber of respective MFCs. The cathodic compartment was filled with 1M solution of potassium dichromate [17]. As an alternative to potassium dichromate, use of sodium bromate as cathodic electron acceptor had also been reported [18]. Cathodic and anodic ends of multimeter were connected to respective chambers and the electricity generated was measured in terms of millivolt and milliampere. Optical density (OD_{600nm}) was continuously monitored after every 24 hours to observe the correlation of electricity production with the biomass. The turbidity of the medium was considered as indicator of amount of biomass i.e. higher the optical density observed, higher the amount of biomass produced. pH of anodic chamber was also regularly measured using pH meter at the interval of 24 hours.

Calculation of power density (PD):

The electric power was measured according to the Ohm's low P = IV

Where, P = Electric power in milliwatts (mW)
I = Current in milliamperes (mA)
V = Potential in millivolts (mV)

Correlation analysis:

Correlation between different parameters relevant to power generation was determined using PAST software (PAleontological STatistics, version 1.89).

RESULT AND DISCUSSION

Potential of MFC can be defined as the capacity of MFC to generate flow of electrons through the circuit, while the capacity of cathode to allow electron flow is called cathode potential. The initial potential observed for all the MFCs was low. After loading anodic chamber in all fuel cells with respective sources of nutrients and waste water, the turbidity of the medium was found to be increasing continuously with time (Table-1) that indicates raise in the number of microbes within the chamber. In case of molasses, the increase in number of microbes is due to utilization of molasses as it is rich source of carbohydrate [19]. Value of current was also found to be increasing with the concomitant increase in the number of microbes (Figure-2a and b). Notable amount of current was observed at 192 hours incubation. Hence, the increase in the number of microbes results in simultaneous increase in current within the circuit and was concluded to be responsible for increased potential of MFC during the operation. Increase in generation of current was also reported by using waste water as source of microbes and molasses as source of nutrient [19, 20]. Each of the substrates was able to yield substantial rise in the biomass. The observed rise of biomass in the anodic chamber was 725.9% and 665.5% for molasses and DSW respectively within 172 hours by considering values of initial optical density and final optical density.

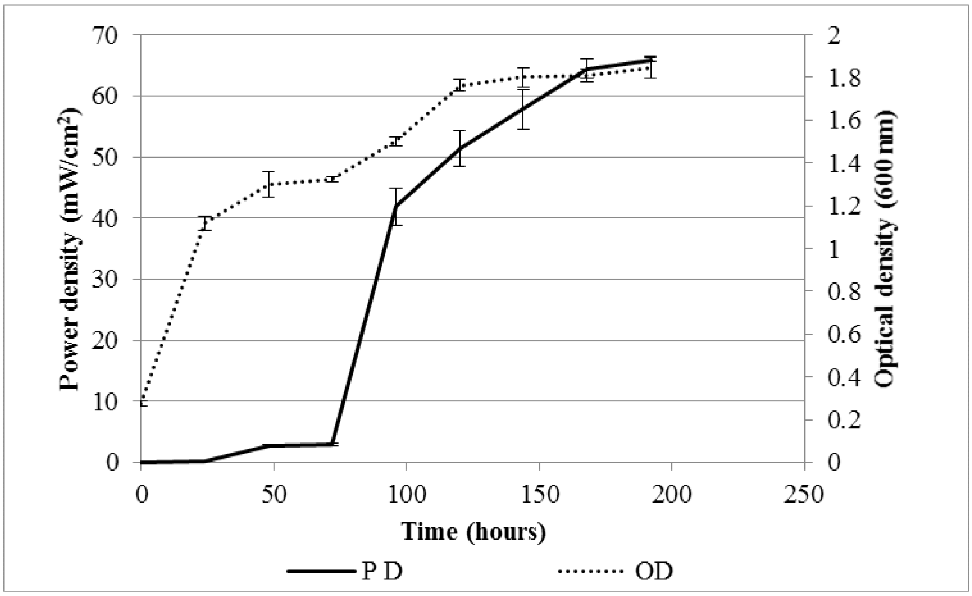


Fig. 2a: Power densities achieved by MFCs containing Distillery Spent Wash and growth of bacteria.

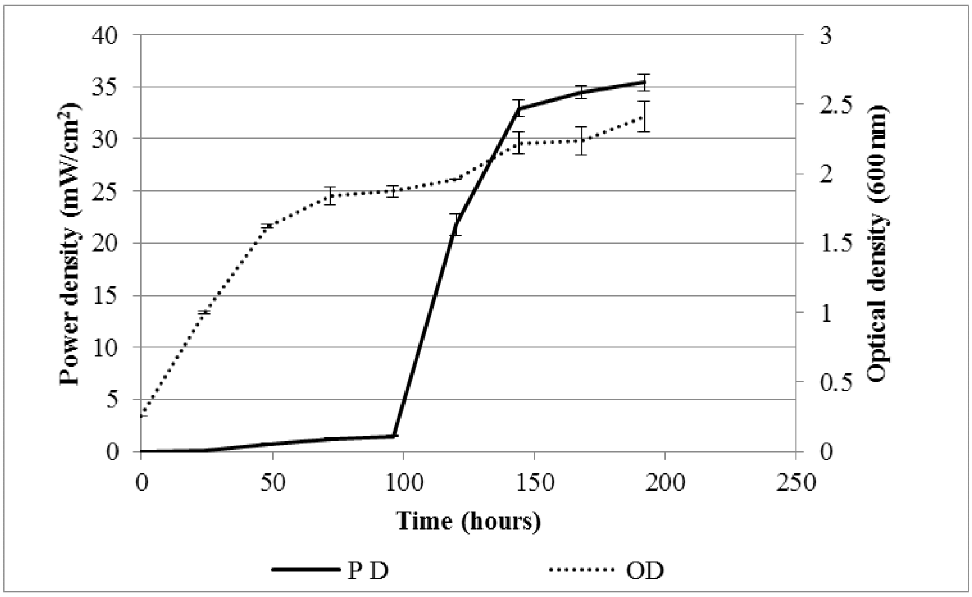


Fig. 2b: Power densities achieved by MFCs containing molasses and growth of bacteria.

Table 1: Anodic pH, optical density and power densities produced by MFCs using MOL and DSW. The table represents Mean±SE (n=3)

	Time (hours)	pH	OD at 600 nm	Current (mA)	Voltage (mV)	Power Density (mW/m²)
MOL	0	3.25±0.01	0.332±0.08	0.01±0.001	6±0.6	0.008±0.00
	24	3.25±0.01	1.00±0.01	0.020±0.001	16±1.2	0.04±0.01
	48	3.25±0.01	1.62±0.01	0.023±0.002	220±6.9	0.70±0.08
	72	3.30±0.01	1.84±0.06	0.031±0.002	273±8.3	1.18±0.12
	96	3.31±0.02	1.87±0.04	0.035±0.002	300±17.0	1.46±0.08
	120	3.36±0.01	1.96±0.01	0.400±0.023	391±10.1	21.77±1.02
	144	3.35±0.01	2.22±0.08	0.472±0.012	501±10.3	32.93±0.77
	168	3.36±0.01	2.24±0.10	0.480±0.009	516±8.7	34.49±0.61
	192	3.36±0.01	2.41±0.11	0.491±0.014	518±3.5	35.42±0.83

	Time (hours)	pH	OD at 600 nm	Current (mA)	Voltage (mV)	Power Density (mW/m²)
DSW	0	3.40±0.01	0.278±0.012	0.007±0.000	30±2.6	0.03±0.01
	24	3.41±0.00	1.12±0.033	0.019±0.002	60±1.6	0.16±0.03
	48	3.42±0.01	1.30±0.057	0.314±0.006	62±2.2	2.71±0.14
	72	3.44±0.01	1.32±0.012	0.340±0.018	63±0.6	2.97±0.17
	96	3.44±0.00	1.50±0.019	0.426±0.026	705±14.4	41.84±3.01
	120	3.45±0.01	1.76±0.027	0.518±0.007	711±8.7	51.30±2.96
	144	3.46±0.01	1.80±0.042	0.580±0.023	715±16.0	57.77±3.18
	168	3.46±0.01	1.81±0.03	0.621±0.005	745±13.9	64.44±1.50
	192	3.47±0.01	1.85±0.049	0.634±0.009	747±8.3	65.92±0.29

Initially, in MFCs containing molasses and DSW the increase in power density was slow. Splendid amplification in power generation was observed after 72 hours in case of MFC with DSW (Figure 2a). In case of MFC with molasses such rise was found to be arising after 96 hours (Figure-2b). Maximum electricity generation was reported by the MFC that had utilized DSW as substrate (Table 1). The MFC with molasses as substrate also displayed considerable amount of power density as displayed in Table 1. The values of final power density produced by MFC with DSW and molasses were recorded to be 65.92 and 35.42 mW/m^2 respectively. Using MFC, generation of power density up to 3.6mW/m^2 was reported by Rebaey *et al.* [10] using glucose solution as substrate while Borole *et al.* [21] reported power density up to 12.7 mW/m^2 using media containing tryptic soy broth. Anupama *et al.* [22] achieved power density 18.35 mW/m^2 using distillery waste water in MFC. Using cow dung, Prakash [23] succeeded to generate power density up to $9.47x10^{-4}$ mW/m^2.

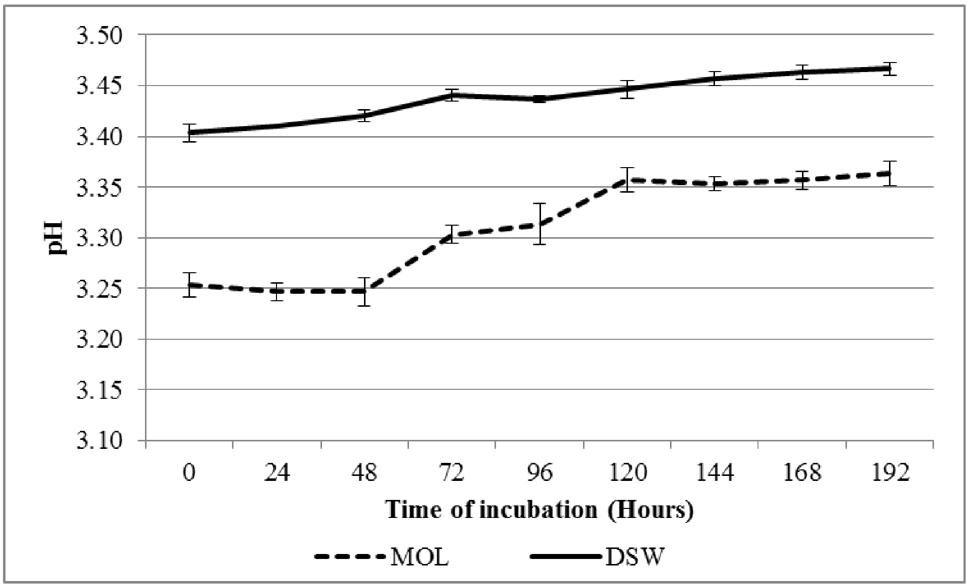


Fig. 3: pH of MFC's anodic chamber during incubation

Very low levels of wavering was found in pH of anodic chambers in MFCs containing molasses and DSW. The observed pH was 3.25 to 3.36 in MFC containing molasses and 3.40 to 3.47 for MFC containing DSW (Figure 3). Nimje *et al.* [24] also reported that relatively higher current generation can be achieved at acidic pH. The significance of pH on current generation is also reported by Gil *et al.* [6] and Jadhav *et al.* [25]. The results obtained here are in accordance with Raghavulu *et al.* [26] where better efficiency was reported by acidophilic MFC. Here, the results obtained indicate that the oxidation of substrates by microbes in anodic chamber results in very minute alterations in pH or no alteration.

Table 2: Correlation analysis among various parameters like cell density (OD_{600}), current (mA), voltage (mV) and power density (mW/m^2). Asterisks represent significant correlation at *P≤0.05, and **P≤0.01. For each parameter, three replications were used.

		OD	Current	Voltage	PD
MOL	OD	1			
	Current	0.72284*	1		
	Voltage	0.94256**	0.87065**	1	
	PD	0.72555*	0.99158**	0.87643**	1
		OD	Current	Voltage	PD
DSW	OD	1			
	Current	0.90839**	1		
	Voltage	0.79539*	0.86424**	1	
	PD	0.80812	0.89879**	0.97868**	1

We also tried to establish correlation between number of bacteria and the power density achieved as shown in Table 2. Linear correlation analysis was performed to find the relationship between key parameters like cell density (OD_{600}), current (mA), voltage (mV) and power density (mW/m^2) for MOL and DSW. Current, Voltage and PD have shown significant positive correlation in-between. In Case of MOL, Voltage and power density has recorded strong positive correlation with OD (r = 0.94) and current (r = 0.99) respectively. While in case of DSW, Current and PD has shown strong positive correlation with OD (r = 0.91) and Voltage (r = 0.98) respectively (Table 2). Similar positive correlation between turbidity and voltage was reported for MFC utilizing different industrial wastewater by Abbasi *et al.* [27]. This suggests that, MOL and DSW can serve as batter source to increase turbidity which leads to increase in the generation of electricity as turbidity shows strong correlation with major determinants of electricity such as current and voltage.

Contribution to Knowledge:

In the present era where the demand of electricity is continuously increasing day by day, the MFCs can be one of the solutions for generation of energy from renewable resources. Utilization and study of various organic substrates for the generation of electricity instead of fossil fuels may generate interest in researchers regarding the subject. On using industrial byproducts instead of costlier organic substrates, the operational cost of MFCs can be reduced to provide cheaper source of bioelectricity. In future, it could be possible that the application of techniques that don't involve combustion of fossil fuels may give rise to new era of energy generation which would be free from greenhouse gases promising clean environment.

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Conclusion and future work:

This study demonstrated the feasibility of bioelectricity production using salt bridged two chambered microbial fuel cell. As it was fabricated with low-cost anode materials (non-coated plain graphite electrodes), without any toxic mediators (mediator less anode), the procedure can be remarked as cost-effective, environmentally sound and sustainable due to utilization of wastewater as substrate as well as due to utilization of different industrial byproducts as source of nutrient. Based on the successful operation of MFC using waste water and treating molasses and distillery spent wash, this current work and process can be adapted to other industrial wastewaters with high organic content. The development of MFC is still in initial phase and studies are continued. The MFC fabricated here has produced plentiful amount of voltage. There is broad scope for optimization of various parts of MFCs and process parameters that can result in increased production of electricity. In addition, the bacteria responsible for generation of electricity can be isolated, identified and genetically modified to provide more efficient electron transfer to electrodes.

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