

Power Generation by Algal Microbial Fuel Cell Along with Simultaneous Treatment of Sugar Industry Wastewater

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Abstract

Algal biotechnology has gained interest world over as it is a better resource in comparison to land biomass. One interesting emerging application is its utilization in microbial fuel cells (MFCs) for the production of electricity while utilizing these algae for the treatment of industrial wastewater besides hydrocarbons and lipid production later. Presently, the potential of two strains of an oil-rich green alga *Botryococcus braunii* has been studied for its utilization in microbial fuel cells. Photosynthetic algal strains in various media in the cathodic half of the MFCs provided a continuous source of oxygen from their photosynthesis to serve as electron acceptor. This helped in reducing the cost of energy needed for mechanical aeration to enrich the catholyte with oxygen as electron acceptor. These cathodic half cells were combined separately with three different anolytes, firstly *Saccharomyces cerevisiae* culture alone, secondly, *Saccharomyces cerevisiae* culture supplemented with the mediator methylene blue (350 mg/L) and thirdly, sugar industry wastewater mixed with activated sludge. Amongst MFCs consisting of various combinations of these catholytes and anolytes, highest values of power density (7.27 $\mu\text{W}/\text{cm}^2$) and current density (20.87 $\mu\text{A}/\text{cm}^2$) were observed with *Saccharomyces cerevisiae* culture supplemented with methylene blue as the anolyte and *B. braunii* in soap industry wastewater as the catholyte. Present study demonstrates the potential of the coupling of cultivation of photosynthetic *B. braunii* for biodiesel production with the wastewater treatment plant as a sustainable source of electricity in microbial fuel cells.

Keywords: Microbial fuel cell; *Botryococcus braunii*; *Saccharomyces cerevisiae*; Mediator; Wastewater treatment; Photosynthetic oxygen

Introduction

Microbial fuel cell is the promising technology for clean power generation and has gained lot of attention in recent years. The algae obtained after MFC utilization can be further used for the production of biodiesel, green diesel or bioethanol [1,2]. Complete utilization of biomass is important for the transition to biofuels and bioeconomy [3]. Microbial fuel cell (MFC) consists of an anodic and a cathodic chamber, separated by a proton exchange membrane (PEM). At anode, organic compounds are oxidized by the microorganisms and electrons move towards cathode through an external circuit and combine with an electron acceptor (mainly oxygen) to generate electricity. At cathode, oxygen is supplied continuously by aeration which is an energy consuming process. In MFCs, mediators can accelerate the process of electron transfer [4]. Recently, the concepts of MFCs have been extended into different technologies such as Bio-Electrochemical Systems (BESs) which produce numerous useful products such as formate, [5] methane [6] and acetate [7]. The microbial desalination cell is the most attractive option as this can be successfully implemented for power generation, treatment of wastewater with the simultaneous desalination of water [8]. MFCs can be used for the production of hydrogen gas [9], powering environmental sensors and digital wrist watch, charging a mobile phone, smartphone and LEDs [10-13]. MFCs are also coupled with solar cells for power production

[14] which provides opportunities for utilizing solar energy in this field. Future applications of MFCs may include their use in human systems as well.

Utilization of microalgae in MFCs has gained interest as phototrophic microalgae act as biocatholytes as the oxygen produced by them serves as final electron acceptor, minimizing the energy needed for the aeration at the cathode. Earlier work from author's laboratory was reported on the H₂ production from algae and its utilization in carbon fuel cells for power generation [15]. Later work involved the studies of the potential of power generation from algal MFCs [2]. In the present study, potential of two strains of a green colonial hydrocarbon (petroleum oil) rich microalga, *Botryococcus braunii*, has been analyzed for its application in MFCs while generating biomass for oil production. In these MFCs, green algal strains have been used at the cathode as the source of photosynthetic oxygen as electron acceptor, whereas sugar industry wastewater with activated sludge, *S. cerevisiae* culture alone and *S. cerevisiae* with supplementation of methylene blue (350 mg/L) was used at the anode. This technology has great potential to couple the algal and yeast biomass cultivation for the oil and bioethanol production, respectively, along with wastewater treatment and power generation. Algal biomass obtained from MFCs may be used for the production of biodiesel and for bioethanol production through hydroliquefaction.

Materials and Methods

Experimental organisms

Two strains of *B. braunii*, Udaisagar strain from Udaisagar lake, Udaipur Rajasthan, India and Loktak strain from Loktak lake, Manipur, India, were isolated by serial dilution method and plating on the solidified Chu-13 medium [16] which were grown and maintained under controlled conditions in an incubator. *Saccharomyces cerevisiae* (Bakers's yeast), obtained from Indian Institute of Technology, Delhi, New Delhi, India was revived by adding 1.3 gm yeast powder in 1 L Sayed et al. medium [17] for 16 h at 27°C temperature in dark.

MFC design and operation

The MFC contained two chambers, an anode and a cathode, each of 250 ml capacity with 6.5 cm diameter and 12 cm length and with electrode area of approximately 30 cm². Both the electrodes were made up of carbon and separated by a proton exchange membrane (Nafion). A digital multimeter (Haqyue) was connected to the system for continuous measurement of voltage (V) and current (I) at the external load of 100 Ω. Peak values of current density (μA/cm²) and power density (μW/cm²) were calculated from the values of V, I and A (area of electrode). In MFCs under study, five sets of catholytes examined separately with the two strains of *B. braunii* were

- Algal strains in Chu-13 medium;
- Algal strains in Chu-13 medium supplemented with 0.5 M NaCl;
- Algal strains in simulated sugar industry wastewater;
- Algal strains in simulated soap industry wastewater;
- Algal strains in simulated treated sewage water.

Whereas the three anolytes used were, *S. cerevisiae* culture in Sayed et al. medium [17]. *S. cerevisiae* with 350 mg/L methylene blue (MB) as mediator and sugar industry wastewater (198 ml) (obtained from Saraswati Sugar Mills, Yamunanagar-135001, Haryana, India) with activated sludge (22 ml) (obtained from the sewage treatment plant Vasant Kunj, New Delhi, Delhi-110070, India). The experiment was conducted in an incubator under controlled conditions of 27 ± 1°C temperature, 1.2 ± 0.2 klux light intensity and 16L:8D light:dark cycle to support microalgal growth and photosynthesis for 21 days which is the best harvesting time for *B. braunii* strains.

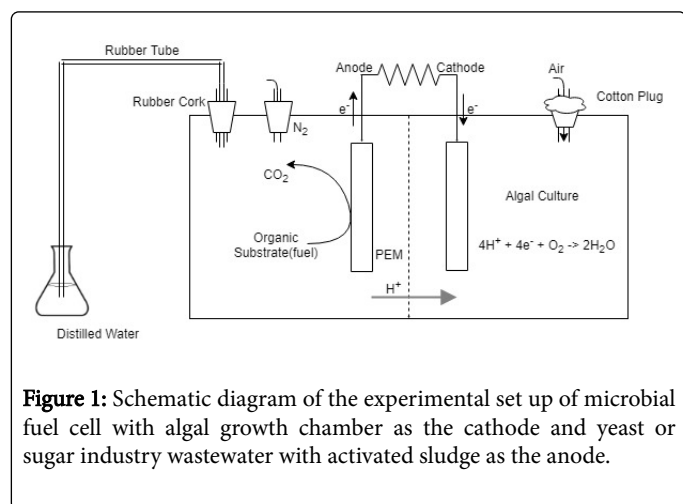


Figure 1: Schematic diagram of the experimental set up of microbial fuel cell with algal growth chamber as the cathode and yeast or sugar industry wastewater with activated sludge as the anode.

The working volume of microbial cultures in both the chambers of MFCs was 220 ml. During operation, the anodic chamber was covered with a black paper to avoid any exposure of light to check the growth of algae [18]. It was made anaerobic by sparging nitrogen gas before the operation and connected to a conical flask filled with distilled water through a rubber tube for the exhaustion of gases formed by the microbial metabolic activities. The mouth of the cathodic chamber was covered with a cotton plug to facilitate aeration. For both *B. braunii* and *S. cerevisiae* cultures, pH was adjusted to around 7 using 1 N KOH and 1 N HCl, respectively. The schematic diagram of the experimental set up has been shown in Figure 1.

Chemical Oxygen Demand (COD) Measurement

COD of the sugar industry wastewater sample in the anodic compartment of MFC was measured on 1st and 21st days of the experiment by APHA (American Public Health Association) standard methods [19].

Simulated wastewater

Simulated treated sewage water and simulated sugar industry wastewater were prepared in the laboratory as per the composition devised by Poddar and Sahu; Yoshioka et al., Yadav et al., Yetis et al. [20-23]. Simulated soap industry wastewater was prepared after analyzing the wastewater obtained from soap industry. Calcium, magnesium and nitrogen were analyzed by EDTA titrimetric method and semi-micro-kjeldahl method, respectively [19]. Phosphorus was analyzed by Olsen's method [24]. Amount of glycerol was added on the basis of the composition given by Israel et al. [25].

Results and Discussion

Earlier work in the author's laboratory was performed on the successful utilization of urine for the generation of power through microbial fuel cell [26]. However, presently it was decided to utilize algae along with sugar and soap industry wastewater in MFCs. Driving aim was to study the use of *B. braunii* in algal MFCs, boost the growth of algae by utilizing industrial wastewater, to treat the sugar industry wastewater in MFCs, utilize the algae for production of biofuels after its growth in MFCs and above all avoiding the use of costly hydrogen in the fuel cells. Two strains of *B. braunii* biomass in the cathodic compartment of the microbial fuel cells in five different media (Figure 2) were coupled with the three types of anolytes.

Significant results of voltage, power and current densities were obtained with all the combinations of catholytes and anolytes (Tables 1 and 2) in MFCs and the best results were obtained with *S. cerevisiae* supplemented with the mediator methylene blue as the anolyte in combination with the five catholytes, respectively under study.

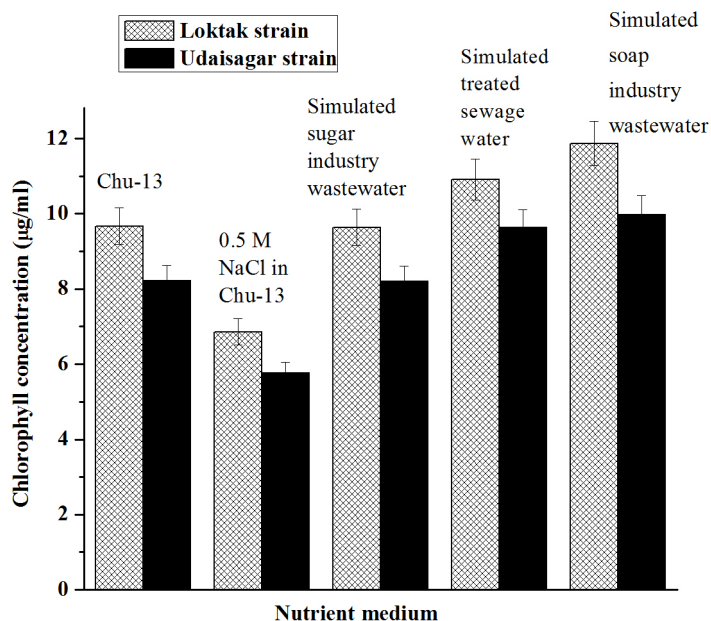


Figure 2: Growth of the two strains of *Botryococcus braunii* in different media on 21st day.

Concentration (g/L)				
S. No	Component	Simulated sugar industry wastewater	Simulated soap industry waste water	Simulated treated sewage water
1	K ₂ HPO ₄	0.2	3.421	2.8
2	Copper (CuSO ₄ ·7H ₂ O)	0.0333	-	-
3	Calcium (CaCl ₂ ·2H ₂ O)	1.324	1.785	0.4
4	Magnesium (MgSO ₄ ·7H ₂ O)	2.717	0.32	0.2
5	Zinc (ZnSO ₄ ·4H ₂ O)	0.00092	-	-
6	C ₁₂ H ₂₂ O ₁₁ (Sucrose)	1.4372	-	-
7	C ₃ H ₉ O ₃ (Glycerol)	-	4	-
8	Iron (FeSO ₄ ·7H ₂ O)	0.06372	-	-
9	Oil	0.012	-	-
10	KNO ₃	-	0.64	0.4
11	NaCl	-	-	0.7
12	NH ₄ Cl	0.5	-	-
13	Vegetable extract	-	-	11
14	Peptone	-	-	16

Table 1: Composition of various simulated wastewaters used for the cultivation of *B. braunii* strains.

Anode	Parameter	<i>B. braunii</i> in Chu-13 medium	<i>B. braunii</i> in Chu-13 with 0.5 M NaCl	<i>B. braunii</i> in simulated sugar industry wastewater	<i>B. braunii</i> in simulated treated sewage water	<i>B. braunii</i> in simulated soap industry wastewater
		Udaisagar/Loktak strains				
<i>S. cerevisiae</i> in Sayed et al. medium with methylene blue (350 mg/L) as mediator	Voltage (mV)	334/339	302/307	334/340	342/348	349/356
	Power density ($\mu\text{W}/\text{cm}^2$)	6.47/6.53	6.18/6.21	6.5/6.59	6.72/6.8	7.21/7.27
	Current density ($\mu\text{A}/\text{cm}^2$)	16.72/16.83	14.54/14.72	16.78/17.15	18.95/19.13	19.84/20.87
<i>S. cerevisiae</i> in Sayed et al. medium	Voltage (mV)	256/260	223/232	259/263	264/267	269/274
	Power density ($\mu\text{W}/\text{cm}^2$)	2.12/2.24	1.93/1.96	2.15/2.26	2.66/2.71	2.91/3.02
	Current density ($\mu\text{A}/\text{cm}^2$)	10.23/10.45	9.17/9.39	10.25/10.48	10.78/10.85	10.91/10.93
Sugar industry wastewater with activated sludge	Voltage (mV)	261/263	224/230	264/267	268/270	273/278
	Power density ($\mu\text{W}/\text{cm}^2$)	4.57/4.6	3.23/3.34	4.59/4.64	4.92/4.98	5.24/5.32
	Current density ($\mu\text{A}/\text{cm}^2$)	13.37/13.78	11.31/11.52	13.39/13.81	14.45/14.68	15.74/15.94

Table 2: Peak values of voltage, current and power densities obtained with various anolytes and catholytes in the microbial fuel cells.

Maximum values of power density ($7.27 \mu\text{W}/\text{cm}^2$ with Loktak strain and $7.21 \mu\text{W}/\text{cm}^2$ with Udaisagar strain) and current density ($20.87 \mu\text{A}/\text{cm}^2$ with Loktak strain and $19.84 \mu\text{A}/\text{cm}^2$ with Udaisagar strain) were obtained with *B. braunii* in soap industry wastewater as the catholyte and *S. cerevisiae* with methylene blue as the anolyte. This might be possibly due to the best growth of algal strains in soap industry wastewater of the five catholytes used (Figure 2) and fastening of the transfer of electrons from *S. cerevisiae* to the anode by the mediator methylene blue in the anodic chamber. Higher values of power density ($5.32 \mu\text{W}/\text{cm}^2$ with Loktak strain and $5.24 \mu\text{A}/\text{cm}^2$ with Udaisagar strain) and current density ($15.94 \mu\text{A}/\text{cm}^2$ with Loktak strain and $15.74 \mu\text{A}/\text{cm}^2$ with Udaisagar strain) obtained with the anolyte sugar industry wastewater with activated sludge may be due to the presence of electrochemically active bacteria in activated sludge possessing the ability to transfer the electrons to the anode [27]. The power density may be further enhanced by using food industry waste or paper industry waste in anodic compartment of microbial fuel cell.

Substantial removal of COD of the anolyte, sugar industry wastewater was also observed (COD value of 2.56 g/L was observed on 1st day whereas significant reduced values obtained on 21st day were 1.21 g/L with *B. braunii* in Chu-13 medium, 1.04 g/L with *B. braunii* in Chu-13 medium supplemented with 0.5 M NaCl, 1.42 g/L with *B. braunii* in simulated sugar industry wastewater, 1.3 g/L with *B. braunii* in simulated treated sewage water and 1.6 g/L with *B. braunii* in simulated soap industry wastewater, respectively). Researchers have successfully integrated various green and blue-green algae at the cathode in microbial fuel cells with significant values of current and power densities. Yadav et al. [22] have reported the peak values of current density ($149.5 \text{ mA}/\text{m}^2$) and power density ($34.32 \text{ mW}/\text{m}^2$) at the external load of 220 Ω using blue-green algae assisted cathode with 89.23% COD removal. Powell et al. [28] have reported maximum power density of $0.95 \text{ mW}/\text{m}^2$. Jia et al. [29] used microbial fuel cell for

the removal of organics and bio-electrochemical denitrification and $1.7 \text{ mW}/\text{m}^2$ was the maximum power density obtained at a current density of $15 \text{ mA}/\text{m}^2$. Zhang et al. [30] used photomicrobial fuel cell and produced a stable power density of $68.5 \text{ mW}/\text{m}^2$. Authors feel that there is a great potential of using *Botryococcus braunii* in MFCs and for treating sugar industry wastewater.

Conclusions

The present study demonstrates the potential of the two strains of *Botryococcus braunii* as catholytes in MFCs. The MFCs were coupled with the sugar industry wastewater as anolyte which led to its successful treatment during power generation by algal MFCs. There is a future scope of utilizing urine and other industrial wastewater along with different algal species in MFCs. There is also a future scope of increasing power generation in MFCs by optimizing the relevant parameters. Maximum power from the algal MFC was however obtained by using soap industry wastewater along with the algae in the present studies.

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