Evaluation of Photosynthetic Microbial Fuel Cell for Bioelectricity Production

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Abstract

Photosynthetic Microbial Fuel Cell captures solar energy by photosynthetic organisms and plants for the production of green energy - as bioelectricity. This study reviews the potentials of algal and higher living plants as microbial fuel cells towards production of electricity. A critical analysis is undertaken of various microbial fuel cell and photosynthetic fuel systems on their usefulness for production of bioelectricity. The economic feasibility and potentials applications of this energy production system, depending on the design and power output, are assessed in the context of demand for alternative renewable energy system.

Keywords: Fuel cell, Bioelectricity, Geobacter sulfurreductans, Photobioreactor, Rhizideposit, Sediment MFC, Anaerobic bacteria, Biofuels.

1. Introduction

Solar energy conversion by plants due to photosynthetic process may be a significant in renewable energy production such as hydrogen, bioelectricity and other biofuels [1]. Photosynthetic microbial fuel cell (PMFC) is a promising device in biotechnology strategy for the production of electricity in sustainable manner. Since the demand for energy is rapidly increasing, all non-renewable resources being depleted fast, renewable energy gains significance in overcoming future energy crisis. Although, utilization of various renewable energy like solar energy, wind, hydro and wind energy are in the pipeline [2, 3 and 4], utilization of renewable resources like solar energy are indispensible to meet the energy demand both in developed and developing countries. Several milestone achievements have been made to generate various forms of energy including bioelectricity. In this context, novel approaches like utilization of microbial fuel cells and photosynthetic microbial fuel cell have potential to generate bioelectricity**.**

2. Microbial Fuel cell

Lately microbiological fuel cells (MFC), recycled from carbohydrates and complex organic waste water, have recognised increased potential as an effective means for production of electrical energy. MFC devised to utilize as catalyst micro organisms and treated waste water for converting this chemical energy into electricity, in most of the experimental work [5, 6, 7, 8 and 9]. MFC consists of two component *i.e.* anode and cathode, which are often separated by proton exchange membrane (PEM). The anode chamber containing micro organism oxidizes the available substrate. The anaerobic oxidation is coupled with liberation of electrons, transferred through the cellular respiration chain ultimately to the anode. The flow of electron and the potential difference among the electrodes generates electric power.

In MFC, electron donors are oxidized at the anode, generated electrons flow through an energy consumer towards the cathode where oxygen is reduced to water. Tubular single chambered MFC have also been developed [10]. A set of unique microorganisms like *Geobactor, Rhodoferox,*[11], *Shewanelle* [12.13,14,15 and 16], are able to oxidize organic matter by generating electron, obtaining energy for their own growth, giving rise to electricity generation.. The efficient use of bacteria at anode as an electron acceptor and the extent they generate electrical output depends on operational parameters of MFC have been discussed [17,18 and 19}. Several research reports have analysed the merits and demerits of different electron acceptors at anodes. For optimizing the performance of cathode, hexacyanoferrate or acetic permanganate has been used to accept electrons [20]. However, liquid state electrons acceptors are impractical and unsustainable because they need to be regenerated. In comparison to liquid state oxidants, the use of O_2 as final electron acceptors in the cathode greatly improves the sustainability of MFC. According to the current reports, MFC with O_2 or air as the cathode electron acceptor, need expensive platinum as catalyst to accelerate the O_2 reduction reaction. Cheaper metal catalyst such as pyrrolysed iron (II) pthalacyanine are suggested to replace platinum [21]. The cost effective & unsustainable method to increase the efficiency of cathode limited their potential. A novel anaerobic microorganism as cathode catalyst, has also been developed.

Although microbial fuel cell was explored for domestic waste water treatment, optimization and further development in 1991 had been effected. MFC with an enhanced power output have been developed for opportunistic practical applications [8, and 10].

The possibility of exploiting mediators, sans mediator and membrane, in waste water treatment and electricity generation was accomplished in MFC [22, 23]. Utility of cellulose for electricity production in a MFC using *Clostridium celluolytic* and *Geobacter sulfurreducens* as binary culture was demonstrated [24]. This co-cultured system achieved maximum power density of 143mv/ m^2 at anode area. In MFC, the performance of the cathode is an important limitation due to usage of sustainable catholyte. The sans mediator MFC using anaerobic microorganism with cathodic catalyst was designed and tested..

Biowaste as a key feeder component in MFC is used for current generation. A mixture of biowaste can result in higher extractable current than any single component. Several biomass wastes such as cow dung, rice washing water and vermicompost were used for power generation up to 150 millivolts [25].

3. Photosynthetic Algal Microbial Fuel cell (PAMFC)

Photosynthetic MFC (PMFC) converts sunlight into electricity within the metabolic reaction of Microbial fuel cell (MFC). Several photosynthetic organisms such as blue green algae, green algae and few higher algae have been used directly or along with MFC to generate bioelectricity. In research, mainly photosynthetic cyanobacterial species like *Anabaena* [26]. *Synochocystis* [27] and some other microalgae have been used in outdoor bioreactors. [28,29]. The photosynthetic chlorella algae have been used with heterotrophic bacteria in a synergistic reaction in electricity generation [30, 31]. A photosynthetic biofilm was utilized in MFC for the production of energy [32]. Microalgae have also been investigated as biocatalyst for power generation in microbial fuel cell with mediators like HNQ (hydroxy, 1, 4 napthaquinone) as artificial redox mediator to shuttle the electron from microorganism to the anode. Several species of marine algae have also been similarly investigated. [33,34]. Similarly, power generation has been achieved by growing *Saccharomyses* for glucose oxidation and blue green algae for electron generation in micromachined microbial fuel cell and photosynthetic electrochemical cells respectively [35]. Most of these studies observed increasing power generation during dark phases. The oxygen production by algae, however, limited power production during light phases.

Utilization of solar energy by photosynthetic algae for providing feed stock to microbial fuel cell for bioelectricity production is a remarkable step in sustainable current production. Recently, principle of photosynthetic algal microbial fuel cell (PAMFC) is based on naturally selected algae and electrochemically active micro organism in an open system without the addition of toxic mediators is an important step [36]. The externally generated biomass formed through photosynthetic growth can be fed to MFC as feeder to generate electricity. Algae have been used as the anode fuel in MFC for electron production. These *exsitu* photo MFC systems require separated photobioreactor for optimal algae growth and less complicated dark MFC system for optimal electricity generation. However, there are limitations of feeding a complex organic matter to a mixed heterotrophic bacterial community in MFC due to low columbic efficiency. Therefore, improvised strategies like development of photobioreactor with immobilized cyanobacteria to generate and degrade metabolic products in series, with a dark MFC to increase the columbic efficiency. The development and performance of photosynthetic microbial fuel cell (PAMFC) for power generation have been demonstrated [37]. The continuous current output of 539 mA/m^2 for 150 days was established by developing solar powered PAMFC by designing photobioreactor coupled to MFC [38, 39].

The performance of photosynthetic MFC using two different types of algae such as *chlorella vulgaris* (microalgae) and *Vulva lactuca* (macroalgae) having two different organic composition was evaluated and obtained difference in energy recovery at anode of MFC. *Chlorella vulgaris* produced more power generation of power densities ($277w/m^3$) than *C, lactuca* ($215w/m^3$) [40]. Several researchers have made prominent endeavor in improvising the performance of cathode system by increasing oxygen level by growing blue green algal immobilized in beads [41] or without immobilization [42] and directly growing Chlorella at cathode [43]. This enhances the power output due to increased concentration of oxygen as electron acceptor liberated during photosynthesis.

4. Plant Microbial Fuel Cell (PMFC)

Electricity production capturing solar energy by living higher plants and in combination with microbial fuel cell is attractive because these systems promise to generate useful renewable energy in sustained manner. Several attempts have been made to apply MFC systems to generate electric power from marine or river beds- termed sediment MFC (SMFC) [44, 45 and 46]. These two systems are based on natural potential gradient between bottom sediment and upper oxygenic water. Electrons are released by microbial oxidation of organic matter and anaerobic environment of sediment and flow from anode to the cathode through an external circuit. Some of the earlier reports on marine sediment MFC show the production of stable output of 10-20mW/m^2. Plants are known to release organics in to soil or aquatic sediments as rhizodeposits, which comprises of carbohydrate, fatty acids, aminoacids, hormones, and organic compounds [47]. This material, rhizodeposits, were then in situ oxidized in the bio anode of the MFC and transformed into electrical power. Rhizodeposits account up to 40 % of plants photosynthetic productivity. The proof of living photosynthesizing plants in microbial fuel cell producing organic materials and releasing rhizodeposits into the surrounding via their roots, producing electricity was shown by David et.al, [48, 49]. The utility of one of the well investigated photosynthetic plants *Glyceria maxima, as* a model, in photo MFC achieved a maximum power production of 67mw/m^2. Among several PMFC investigated power production maximum of average power density 50 mw/ m^2 was accomplished by *Spartina anglica* for 33 days [50]. Plant-Microbial fuel cell can currently generate 0.4 watt per square meter of plant growth. This is more than is generated by fermenting biomass. In future, bio-electricity from plants could produce as much as 3.2 watt per square meter of plant growth. This would mean that a roof measuring 100 m^2 would generate enough electricity to supply a household (with an average consumption of 2,800kw/year).

4.1 Bioelectricity from Rice Paddy Field

The relationship between photosynthetic microorganism and heterotrophic bacteria SMFC for electricity production was examined by several workers [35, 43, 47, 48,49 and 50]. Two independent research groups have studied rice plants in photosynthetic MFC. The idea was to extract energy from ubiquitous rice paddy fields and operated for thousands of hours and showed a direct correlation between photosynthetic activity and power output [35 and 47]. The idea of using rice paddy fields MFC was the rich organic residue of paddy rice plant bodies and root exudation as rhizodeposit, when oxidized by set of bacteria, produce electricity. The initial output of 50mV is jumped up to 200 mV after 7 days of experiment in paddy open field. Performance indices i.e., the maximum power density (mW/m2), normalized to the anode projection area, internal resistance (Ω), and open-circuit voltage (V), were estimated to be 5.75, 156 and 0.701 respectively, for the month of June, while for August were 0.85, 58.2 and 0.428 respectively [50]. On viewing this progress, paddy fields could be effectively utilized for sustainable production of bioelectricity.

5. Conclusion

For combating future energy crisis, alternative energy production strategies are gaining importance. Microbial fuel cells and photosynthetic microbial fuel cells could be an effective means to enhance bioelectricity production. Although photo MFC using higher plants is promising to generate sustainable energy, several challenges are to be overcome to enhance the performance of anodic and cathodic system. At present microbial fuel cells and photosynthetic microbial fuel cells are employed in waste water treatment for simultaneous production of small amount of electricity to supply remote areas. The continuous and sustainable production of electricity is challenging. Particularly; rice plants could meet the challenges of bioelectricity production for commercial use. Better understanding and utilization of rhizodeposit for sustainable growth of electrochemical bacteria in MFC, selection of higher plants capable of growing in semi anaerobic conditions are some of the aspects that need to be studied.

6. References

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