JOURNAL OF MARINE SCIENCES & ENVIRONMENTAL TECHNOLOGIES
Vol. 1, Issue No. 2 (December-2015)

ISSN: 2413-5267

Applications of Microbial Fuel Cell on Sewage Treatment by Using Electrogens

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تطبيقات خلايا الوقود الميكروبية على معالجة مياه الصرف الصحي باستخدام الإلكترونات

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Abstract

Renewable and clean forms of energy are one of the major needs at present. Microbial Fuel Cells (MFC's) offers unambiguous advantages over other renewable energy conversion methods. Production of energy resources while minimizing waste is one of the best ways for sustainable energy resource management practices. The application of Microbial Fuel Cells (MFCs) may represent a completely new approach to wastewater treatment with the production of sustainable clean energy. The increase in energy demand can be fulfilled by Microbial Fuel Cell (MFC) in the future. In recent years, researchers have shown that MFCs can be used to produce electricity from water containing glucose, acetate, or lactate. Studies on electricity generation using organic matter from wastewater as substrate are in progress. Waste biomass is a cheap and relatively abundant source of electrons for microbes capable of producing electrical current outside the cell. Rapidly developing microbial electrochemical technologies, such as microbial fuel cells, are part of a diverse platform of future sustainable energy and chemical production technologies. In the present investigation to study the two wastewater samples, municipal wastewater from nearby areas of Guntur (A.P.) and Dairy waste from Guntur (A.P.) were used as substrates in Microbial Fuel Cells (MFCs) to generate electricity. Along with electricity generation, the MFCs can successfully help in treating the same sewage samples. The parameters like pH, TS, TSS, TDS, BOD, and COD were analyzed for all two samples. The COD removal efficiency of the MFCs was analyzed using the standard reflux method. All the MFCs were efficient in COD removal. 50%, 75%, and 85% COD removal was observed after 10, 15, and 30 days respectively of operation of MFCs with municipal waste as substrate.

Keywords: *Microbial fuel cell, COD, Municipal wastes, Dairy industry, Bioelectricity production***.**

الملخص

إن أشكال الطاقة المتجددة والنظيفة هي واحدة من الاحتياجات الرئيسية في الوقت الحاضر حيث أن الخلايا الوقود الميكروبية تقدم مزايا لا لبس فيها على أساليب تحويل الطاقة المتجددة الأخرى و إنتاج موارد الطاقة مع التقليل من النفايات، وهي واحدة من أفضل الطرق لممارسات إدارة الموارد الطاقة المستدامة، ويعتبر تطبيق خلايا الوقود الميكروبية (MFC) الذي يمثل نهجاً جديداً تماماً لمعالجة مياه الصرف الصحي مع إنتاج الطاقة النظيفة المستدامة، يمكن أن تتحقق الزيادة في الطلب على الطاقة من قبل خلايا الوقود الميكروبية في المستقبل. في السنوات الأخيرة أظهر الباحثون أن خلايا الوقود الميكروبية يمكن استخدامها لإنتاج الكهرباء من المياه التي تحتوي على الجلوكوز، خلات رصاص الثنائية أو محلول رنغر المركز. كما أن الدراسات على

توليد الكهرباء باستخدام المواد العضوية من مياه الصرف الصحي لا زالت جارية إلى حد الآن. إن الكتلة الحيوية للنفايات هي مصدر رخيص ووفير نسبيا حيث توفر الإلكترونات للميكروبات التي تصبح قادرة على إنتاج التيار الكهربائي إلي خارج الخلية بسرعة تطوير التقنيات الكهرو كيميائية الميكروبية مثل خلايا الوقود الميكروبية حيث أنها جزء من منصة متنوعة من تقنيات الطاقة وإنتاج المواد الكيميائية المستدامة في المستقبل. في هذه الدراسة تم أخذ اثنين من عينات مياه الصرف الصحي، ومياه النفايات البلدية من منطقة قريبة من كنتور ولاية أندرا براديش بالهند (.A.P) وعينات من نفايات الألبان ببلدية كنتور (.A.P) وقد استخدمت في مكعبات (MFCs) خلايا الوقود الميكروبية لتوليد الكهرباء، حيث أنه إلى جانب توليد الكهرباء في الخلايا الوقود الميكروبية بنجاح يساعد في معالجة نفس مياه النفايات من العينات. وقد تم تحليل بعض المعاملات مثل (الأس الهيدروجيني، العسر الكلي ومجموع الأملاح الذائبة والأوكسجين المستهلك كيميائياً والأوكسجين المستهلك حيوياً لكلتا العينتين). كما تم تحليل كفاءة إزالة خلايا الوقود الميكروبية باستخدام طريقة ارتداد القياسية. وكانت جميع خلايا الوقود الميكروبية فعالة في إزالة الأوكسجين المستهلك كيميائياً 50٪، 75٪، 85 % بعد فترة زمنية قدرها 10، 15، 30 يوم علي التوالي لتشغيل خلايا الوقود الميكروبية مع النفايات البلدية.

الكلمات الدلالية: خلايا الوقود الميكروبية، الأوكسجين المستهلك كيميائياً، النفايات البلدية، صناعة الألبان، إنتاج الطاقة الكهربائية البيولوجية.

1. Introduction

The need for energy in world increases every year, as there is continuous step up in the cost of fuels and also the depletion of fossil fuels to a higher extent. Microbial Fuel cells are categorized into two different types: biofoul cells that generate electricity from the surcharge of artificial electron shuttles (mediators)and microbial fuel cells that do not require the add-on of mediator. These fuel cells convert energy from one form to another and will continue to operate as long as fuel is fed to it. But a fuel cell does not store energy like a battery. Fuel cells convert chemical energy directly into electricity without a transitional conversion into mechanical power. The benefits of using fuel cells include: clean, safe, noiseless, high energy efficiency, low emissions, and ease in operating. Biofuel cells use biocatalysts for the translation of chemical energy to electrical energy (Allen *et al.*, 1993). The fuel cell is a device which uses traditional electrochemical technology to convert the energy produced either from a microbial metabolism or enzyme catalysis into electricity. The biological catalysts, say the microorganisms or redox-enzymes acids in the transfer of electrons between the inorganic or organic fuel-substrate and the surface of the electrodes, thereby enhancing the cell current.

Environmental pollution is high risk problem today. To meet growing population demand there is industrialization urbanization which is major contributor of the pollution. Untreated industrial waste is hazardous to population at site of disposal whether it is human, animal, plant or microbial population every one suffers pollution hazards. It disturbs food web which leads to imbalance of environment creating pollution problem (Hampannava, 2010). Every country having its own legal criteria for waste water treatment and disposal. Industrial waste treatment before disposal of it is necessary as it is hazardous to environment. Waste treatment in the view of industries is economic task with respect to both money and electricity Current research provides novel microbial solution to this problem (Mali *et al.*, 2012; Chonde, 2014; and Yifeng, 2012). Recirculation of the waste to minimize pollution hazards along with

ISSN: 2413-5267

electricity generation can be the great resolution. It is the innovative research area for production of energy source from waste water. Microbial fuel cells (MFCs) represent a completely new long term, affordable, accessible and eco-friendly approach to waste water treatment with production of sustainable energy.

Microbial Fuel Cell that involves waste recirculation for the purpose of electricity generation. Microbial fuel cells are devices that generate electricity by live microorganism that is electrogens which utilize organic waste as substrate. The electricity generation is achieved by utilization of substrate by anaerobic digestion phenomenon during which there is removal of COD of waste samples with same organism that are involved in electricity generation (Mathuriya and Sharma, 2009). Thus by using MFCs reactor two aims that is electricity generation and waste water treatment can be achieved at a time by minimizing pollution hazards with power generation by eco-friendly mean. The MFC usage in waste water treatment leads to two main benefits. Firstly, the contaminants present in the wastewater serves as an eternal source for carbon. Secondly, the diminution in energy consumption; as the energy obtained from the removal of contaminants could be used to power up the wastewater treatment processes. With high prospective application of MFC's in wastewater treatment processes, remarkable work has been put in to increase the power output of MFC's. MFC's which has catalyst coated with specific substances such as platinum (Moon *et al.*, 2005) *Mn(IV)* and *Fe(III)* (Park and Zeikus, 2003) are being developed and used for higher power output. The bacterial strains such as *Geobacter sulfurreducens* (Bond and Lovely, 2003), *Shewanella putrefaciens* (Kim *et al.*, 1999), *Rhodoferax ferrireducens* (Chaudhuri *et al.*, 2003), have been found to directly transfer electrons to anode surfaces without adding artificial mediators.

The microbial cells are inactive electrochemically. In this case, they require the aid of mediators to facilitate electron transfer from microbial cells to electrode. Therefore, any organic or inorganic or a mixture can serve as a fuel given that they are oxidized by the appropriate organism (Jang *et al.*, 2004). The general reaction can be put forth as follows;

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24e^- + 24\,H^+ \quad \text{……………………. (1)}$$

It has been shown that specific metal-reducing bacteria, belonging primarily to the family *Geobacteraceae* and *Shewanella* species can directly transfer electrons to electrodes using electrochemically active redox enzymes, such as cytochromes on their outer membrane. These microbial fuel cells do not need mediator for electron transfer to electrodes and are called as mediator less MFC's. Mediator less MFC's are considered to have more mercantile application potential, because mediators used in biofuel cells are costly and can be lethal to the microorganisms. In a MFC, two electrodes (anode and cathode) are placed in two compartments separated by a salt bridge. Most studies have used electrodes of solid graphite (Bond and Lovely, 2003), graphite-felt (Chaudhuri *et al.*, 2003), carbon cloth (Liu *et al.*, 2004) and platinum coated graphite cathode electrode (Jang *et al.*, 2004). Microbes in the anode compartment oxidize fuel (electron donor) generating electrons and protons. Electrons

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are transferred to the cathode compartment through the external circuit, and the protons through the salt bridge. Electrons and protons are consumed in the cathode compartment reducing oxygen to water.

2. Materials and Methods

2.1. Collection of Waste Samples

The Municipal waste and Dairy waste sample from nearby area of Guntur city were collected aseptically and kept into the refrigerator for further research purpose.

2.2. Construction and Operation of MFCs

Double chambered MFCs were constructed with salt bridge as mean for proton transfer and operated using two different waste water as substrate to generate electricity as shown in Figures (1 and 2), Pethkar *et al.* (2012).

2.2.1. Working

In normal microbial catabolism, a substrate such as a carbohydrate is initially oxidized anaerobically, when its electrons are released by enzymatic reactions as shown in Figure (1a). The electrons are stored as intermediates (e.g., Nicotinamide adenine dinucleotide – *NADH*, quinines) which become reduced and are then used to provide the living cell with energy. The ending location for the electrons is molecular oxygen or dioxygen at the end of the respiratory chain. A MFC uses bacteria to catalyze the conversion of organic matter into electricity by transferring electrons to a developed circuit. Microorganism can transfer electrons to the anode electrode in three ways first using exogenous mediators (ones external to the cell) such as potassium ferricyanide, thionine, or neutral red secondly using mediators produced by the bacteria and lastly by direct transfer of electrons from the respiratory enzymes (i.e. cytochrome) to the electrodes. These mediators can divert electrons from the respiratory chain to outer cell membrane, becoming reduced and then leaving in a reduced state to shuttle the electron to the electrode (Logan and Regan, 2006; Cheng *et al.*, 2006; and Berk and Canfield, 1964).

2.2.2. Two-Chambered MFC

The simplest type of MFC consists of two chambers separated by material that conducts protons between the chambers (Figure 1b). This widely used and inexpensive design consists of two chambered MFC built in a traditional “H” shape, consisting of usually two bottles connected by a tube containing a separator which is usually a cation exchange membrane (CEM) such as Nafion or Ultrex or a simple salt bridge. The key to this design is the choice of a membrane that allows protons to pass between chambers (CEM is also called a proton exchange membrane, PEM) but optimally not the substrate or electron acceptor in cathode chamber typically oxygen. The electrodes can be made of any conducting, non-corrosive, depending on the system plain carbon paper, carbon cloth, or graphite is used for the anode.

ISSN: 2413-5267

The cathode must contain a catalyst for generating water from the protons, electrons and oxygen and typically *Pt* is used and held on carbon surface using a binder. The electrodes are connected by copper wire with all surfaces coated with a non-conductive epoxy. To avoid wires inside the chambers the carbon electrodes are extended outside the chamber and then a regular wire and clip can be used on electrode. The anode chamber contains the biodegradable substrate and nutrients (nitrogen, phosphorous, oxygen and trace mineral). The oxygen should not diffuse into the anode chamber and it is found that the rate of oxygen diffusion into the anode without a PEM is 2.7% higher than a double chamber design using a Nafion membrane (Logan and Regan, 2006; and Kim and Premier Lee, 2010).

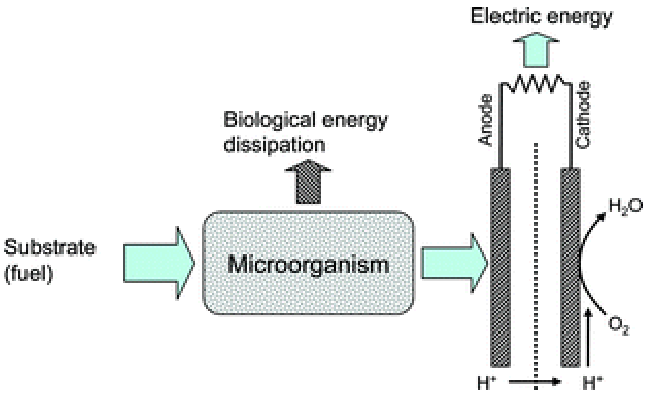

Figure 1a. Working of Microbial Fuel Cell

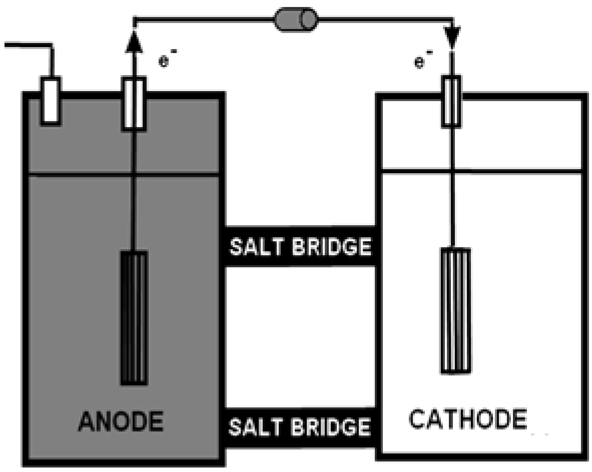

Figure1b. Double chambered Microbial Fuel Cell

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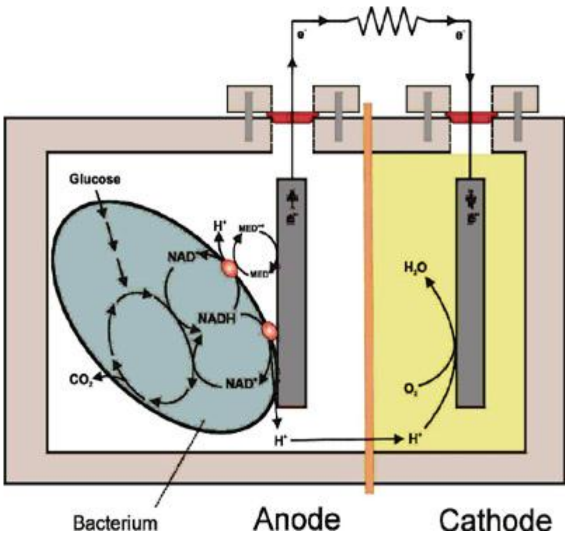

Figure 2. Diagramatic representation of whole enzymatic process.

2.3. Physical Analysis of Waste Samples

All the waste samples collected were analyzed physically with the parameters, pH, TS, TSS, TDS, BOD (Byung *et al.*, 2006), and COD.

2.3.1. COD Removal of Waste Samples During the Electricity Generation Experiment by MFCs

Municipal waste samples mentioned above were fed batch wise for electricity generation in two separate MFCs constructed during research work. Power generation measured in terms of voltage after every 24 *hrs*. All the samples were analyzed for COD removal efficiency by standard reflux method. COD measurement were carried out after 15 and 30 *days*. COD removal efficiency can be calculated using formula is*;*

$$ECOD = [COD_{in} - COD_{out}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

4. Results and Discussion

Physical analysis of sewage is carried analyzing various parameters pH, TS, TSS, TDS, BOD and COD (Table 1). Minor change in pH of waste was observed during operation of MFCs with waste. There is slight reduction in pH of Municipal wastewater while there is increase in pH of Dairy waste. About TSS there is great reduction in TSS after treatment the appearance and color also changed during treatment. TDS values are observed to be increased it may be due to increase in number of microorganism during treatment. BOD values are monitored by conventional method by samples after 5 days of incubation in MFCs proving the fact that MFCs can be good BOD sensor (Kim and Premier Lee, 2006). The COD removal efficiency of the MFCs was analyzed using standard reflux method (Table 2).

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Table 1. Characterization of water before and after incubation of 15 *days* in MFC

S. No	Waste water samples	PH		TSS (*mg/l*)		TDS (*mg/l*)		TS	
		Before	After	B	A	B	A	B	A
1	Dairy Waste	8.0	7.2	7,500	3,200	75,000	10,000	95,000	1,045,000
2	Municipal Waste	7.8	7.1	12,500	9,500	1,50,000	30,4000	143,000	322,800

Table 2. COD removal ability of MFCs for different wastes

S. No	Waste water samples	COD (%) Removal efficiency			Maximum Power generation after 15 *days*
		10 *days*	15 *days*	30 *days*	
1	Dairy Waste	60	80	90	750 *mv*
2	Municipal Waste	65%	75%	95%	680 *mv*

All the MFCs were efficient in COD removal 65%, 75%, and 95%. COD removal was observed after 10, 15, and 30 *days* respectively of operation of MFCs with municipal waste as substrate. Also, about 60%, 80%, and 90% COD removal was observed after 10, 15, and 30 *days* respectively of operation of MFCs with dairy waste as substrate. During current research goal of recirculation of waste to minimize pollution hazards can be achieved along with power generation by novel microorganism in MFCs. Figures (1 and 2) show the MFCs set up constructed during current research successful COD removal (Table 2) of all the two waste samples were observed while operating MFCs for electricity generation. Maximum 90% COD removal and maximum electricity generation of 750 *mv* (Table 2) were observed during operation of MFCs as compare to other waste recirculation. Local area waste samples were applied for isolating electrogenic bacteria and the most occurring strains are traced out for COD removal as well as electricity generation efficiencies of isolates. During the operation of double chambered MFCs the current research successful in generation of electricity as well as COD removal similar type goal can be achieved by various researchers using single chambered MFCs (Pandey *et al.*, 2011) Domestic wastewater treatment using single chambered MFCs were carrying out by the results are 65% to 95% COD removal efficiency. Current research successfully progressing toward goal of achieving good electricity generation using mediator less MFCs which confirms the fact that the bacteria did not require soluble mediators, but can donate electrons directly by adhesion to the electrode surface perform the work operating the MFCs with a proton exchange membrane. The changes in the amount of BOD removed and COD removed would give the data about the concentration and biodegradability of organic matter fed into the MFC (Logan and Regan, 2006; and

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Ramnarayan *et al.*, 2004). BOD and COD removal were the function of detention time of waste water in the chambers (Kim and Premier Lee, 2010). While full-scale, highly effective MFCs are not yet economically feasible this technology holds considerable promise and major hurdles will be undoubtedly overcome by scientists and engineers. The going pressures on our environment and the need for long term renewable energy sources will further speed up development of Microbial fuel cells.

5. Conclusion

During the current research one Dairy wastes and a municipal waste water sample from nearby area of Guntur district were analyzed for electricity generation and COD removal efficiency successfully. 90% maximum COD removal was achieved after 15 *days* by utilizing Dairy waste as substrate for MFCs constructed during current research. So it is concluded that the electrogens isolated from MFCs reactors are successful mean for waste water treatment along with generation of electricity.

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