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Review and Concept Development for Electricity Generation from Municipal Solid Waste Using MFCs

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ABSTRACT

The aim of this manuscript is to review and conceptualization of electricity generation from solid waste using Microbial Fuel Cells (MFCs) technology. MFCs technology has an ample future for both waste remediation and renewable energy generation due to an aerobic microbe produces less sludge in MFCs compared with conventional methods. Electricity can be generated from different organic matters such as fatty acids, proteins, wastewater, and carbohydrates etc. Elegant energy can be generated which helps for compensating the costs. The performance of MFCs depends on the system architecture, internal resistance, species and amount of bacteria on the anode, type of organic matter, chemical characteristics of the medium (pH, solution conductivity and chemical concentration) and the electrode surface characteristics. One set of practical experiment was performed using single chamber MFCs and the power generation along with COD removal was measured. The results show significant power generation and effective COD removal parallel in MFC cell. This study will help in design and research for renewable energy production and waste management.

Keywords: Waste Management, Electricity Generation, MFCs Technology.

INTRODUCTION

Both, the demand of energy, and the amount of waste dissipated are ever increasing with the increase in population. The annual estimates from various studies suggest that MSW generation in India ranges between 40 MT and 55 MT[1]. Along with the increase in waste generation there is also change in the composition of waste generation[2]. Recently IPCC 2007 reports show the maximum methane (25 times greater GHP) generated from South Asia due to rice food waste. Microbial fuel cell (MFCs) technology has an ample future for both waste remediation and renewable energy generation due to an aerobic microbe produces less sludge in MFCs compared with conventional methods. Electricity can be generated from different organic matters such as fatty acids, proteins, wastewater, and carbohydrates etc., and Omission of gas treatment. Elegant energy can be generated which helps for compensating the costs[3].

Objectives

To concept development for electricity generation from solid waste using construct single chambered and multiple chambered MFCs which can be run in parallel under different set of conditions/substrates.

Microbial fuel cells

The Microbial fuel cells (MFCs) is emerging technology to support the generation of renewable energy from waste. The performance of MFCs depends on the system architecture, internal resistance, species and amount of bacteria on the anode, type of organic matter, chemical characteristics of the medium (pH, solution conductivity and chemical concentration) and the electrode surface characteristics. With the consideration of above parameters, the single MFC generates a maximum working voltage of 0.3-0.7 V (theoretically 1.23V in case of air as catholyte) due to redox potential between the respiratory enzymes of anodophilic bacteria and cathodic reactant, suggesting the electricity production is limited[4].

A typical MFCs has two chambers, which contains an anode in one chamber and a cathode electrode in another[5]. An electron donor on the anode side, often hydrogen or methanol, is oxidized on the anode surface, leads to the accumulation of electrons and cations. The electrons captured by the anode create current in the circuit. A potential difference across the circuit is the active force for the reaction. The anodic cations then traverse through selective membrane to the cell cathode side, in order to level the charge transported by the electrons[6]. In some cells, an anionic shift from the cathode to the anode occurs during process. When the cathode oxidized by the electrons, power is created due to redox reactions during second step on the anode, and require oxidized electron acceptor.

Mechanisms of MFCs

In anaerobic process, the rate of oxidation for a fuel increases with catalysts. As the growth rate of organisms increases the rate of oxidation increases hence the time taken to treat the waste water also decreases. Whatever the quantity of electrons generated at anode will be transferred through an external load circuit, which has resistance to the cathode. Whereas proton diffuses across a proton exchange membrane or proton permeable membrane (PEM) to cathode side where reduced oxygen is converted into water through a catalyzed reaction as shown in equation1[7].

$(CH_2O)\,n + nH_2O \rightarrow nCO_2 + 4ne- + 4nH^+$
(Anode Oxidation reaction)
$4e^- + 4H^+ + O_2 \rightarrow 2H_2O$
(Cathode Reduction reaction)

Equation 1: Reduced oxygen is converted into water through a catalyzed reaction.

By means of microbiological fermentation, a whole range of bio fuels and related bio products can be obtained from organic biomass present in solid waste and wastewater [8, 9]. Considering glucose as the primary building mass of material of biomass, one can compare the stoichiometry reactions for the generation of bio-ethanol, biogas (CO_2 and CH_4) and hydrogen gas with the overall reaction taking place in a microbial fuel cell (as shown in equation2):

Table 1: Comparison of power density with different type of microorganisms, substrates and anodes

Microorganism	Substrate	Anode	Current (mA)	Power (mW/m²)	Reference
Shewanella putrefaciens	lactate	woven graphite	0.031	0.19	[8]
Geobacter sulfurreducens	acetate	graphite	0.4	13	[14]
Rhodoferax ferrireducens	glucose	woven graphite	0.2	8	[15]
Rhodoferax ferrireducens	glucose	porous graphite	0.57	17.4	[15]
Rhodoferax ferrireducens	glucose	graphite	74	33	[15]
Mixed seawater culture	acetate	graphite	0.23	10	[16]
Mixed seawater culture	sulphide/acetate	graphite	60	32	[17]
Mixed active sludge culture	acetate	graphite	5	-	[18]
Mixed active sludgeculture	glucose	graphite	30	3600	[19]

Bio-ethanol

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

Biogas

$$C_6H_{12}O_6 \longrightarrow 3CH_4 + 3CO_2$$

Hydrogen gas

$$C_6H_{12}O_6 + 6\,H_2O \longrightarrow H_2 + 6\,CO_2$$

Microbial fuel cell

$$C_6H_{12}O_6 + 6\,O_2 \longrightarrow 6\,H_2O + 6\,CO_2$$

Equation 2: comparison of Stoichiometry reactions for the production of bio-ethanol, biogas (CO_2 and CH_4) and hydrogen gas with MFC.

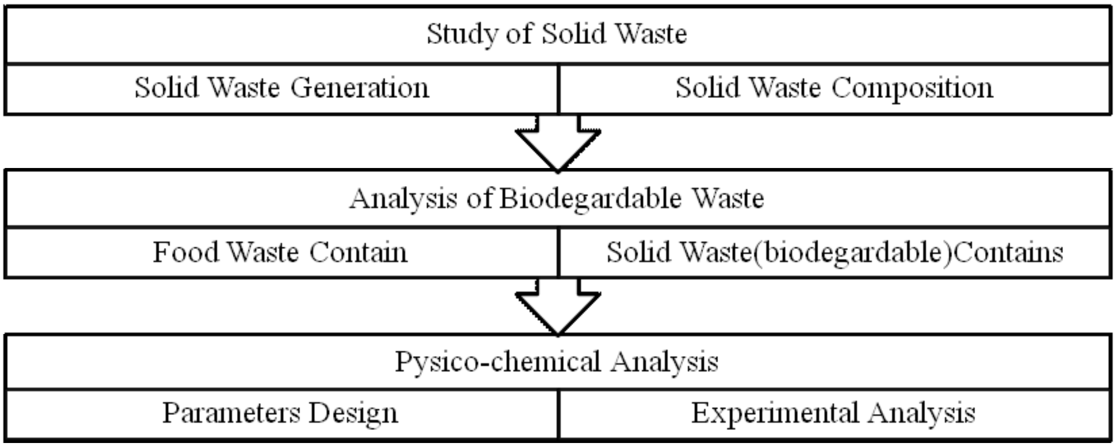
The study shows, in the membrane-less system, the maximum power density obtained is 494 mW/m^2whereas in a cell with PEM, it is 262 mW/m^2[10]. Fan et al (2007) shows that the separation of anode and cathode by two layers of j-cloth instead of PEM; causes little more additional ionic resistance, decreasing the diffusion of oxygen in to the MFC which in turn causes a drastic increase of power production[11,12,13].

Power Densities of MFC's

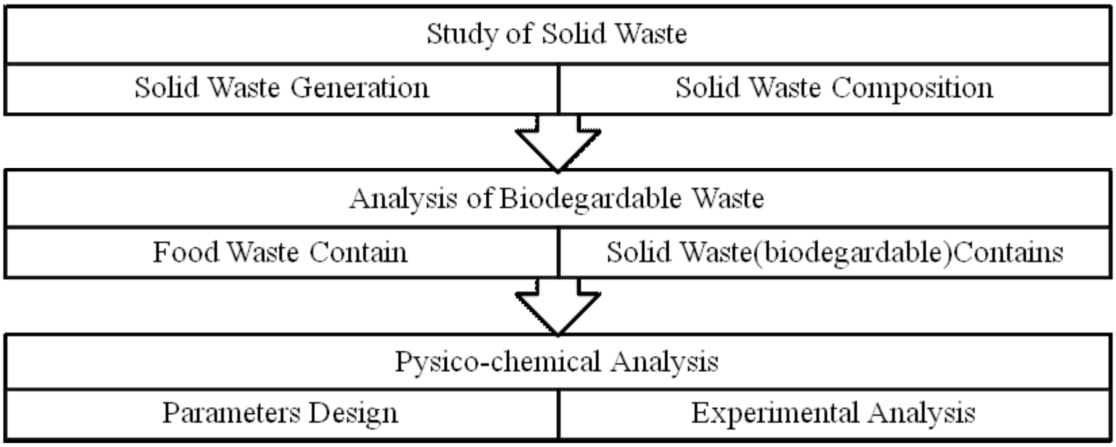
The literature on power densities of MFC's mostly depend on the type of fuel used, type of reactors used and its configuration as shown in Table 1.

Framework

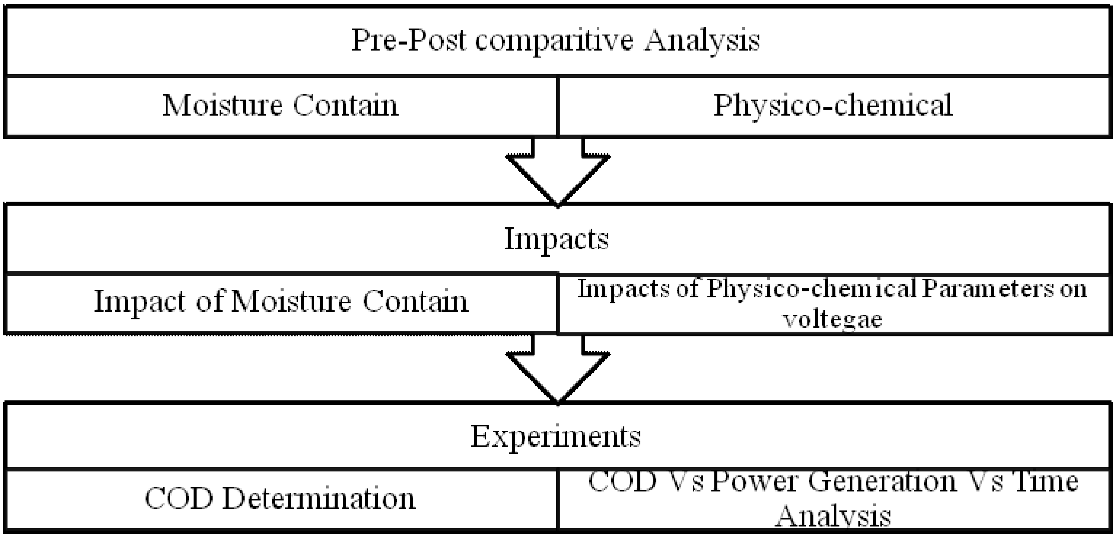
Solid Waste: Characterizations



MFCs Implementations



Remediation Determination



Performance Analysis of Single chamber MFCs for Power generation and COD removal: Case Study

A single chamber MFCs was developed having the 120 cm by length and 60 cm wide and 60 cm by height using glass frame. The anode and cathode were installed inside the chamber and packed with air tight materials. The 10kg collected municipal waste was initially taken in chamber along with one-liter water. The single chamber MFC was fed with approximately 7.8 kg of biodegradable waste

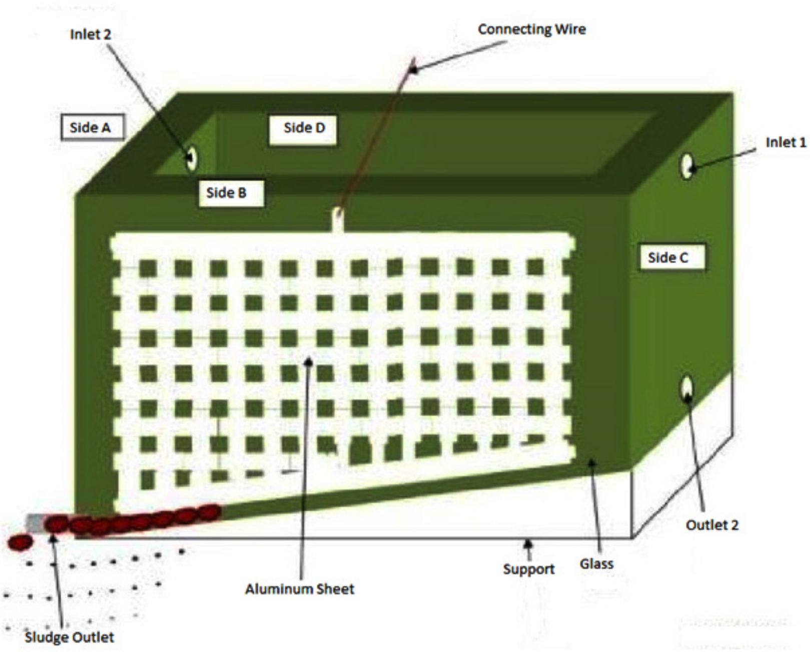
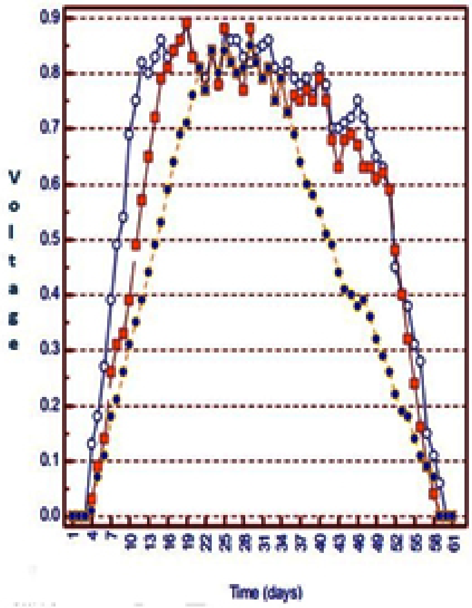


Fig. 1: Overview of single chamber MFC used in power generation from municipal solid waste and COD removal performance

Table 2: Different mediators used in MFC's

MFC Feed	Anode	Cathode	Mediators	Peak V	Peak I	Powerdensity
Wastewater	Graphite	Graphite	Mediator less	423	1.6	
Acetate with geobacter sulfurrenducens	Carbonpaper	Mixture ofPt./C	Mediated		0.20 -0.24	430 mW
Leachate	Graphiteplate & rod	Platinum	Mediator less	438		742 mW
Dairy waste (yogurt) with microbes fromgarden compost	Graphite	Platinum	Mediator less	1450mAm^{-2}		
Domestic waste water	granulargraphite	Plain granulargraphite	Mediator less	223	15.36	19.53mWm^{-3}
MFC with microbialcatalyzed cathode	Graphitefibers	Graphite fiberbrushes	Mediator less	0.324	117.2mAm-3	24.7mWm^{-3}

with initial COD 1660mg/G. From the graph1, it was observed that, the voltage readings were low initially but improved as the experiment continued. This was because of oxidation of organic matter by the biofilm formed on the electrode. After day 10, increase in the voltage generation was noted 0.82V. Voltage in MFC



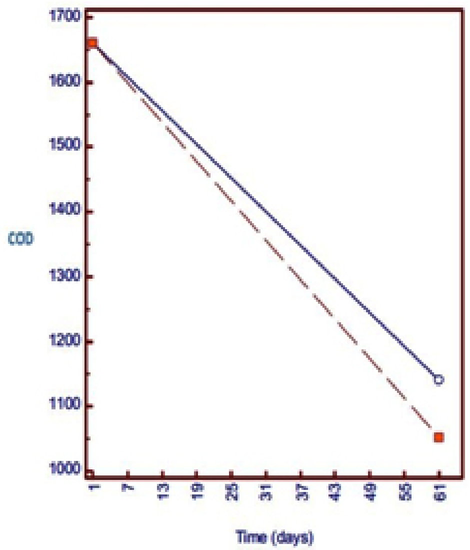


Fig. 2: Power Generation and COD removal in single chamber MFC

was almost stable for next 20 days. The increase in the voltage suggests that the bacteria settled into a structured bio-film. After day 30, a slight decrease in voltage was noticed till day 65. Voltage remained constant at 0.6V till day 95.

In the last few days voltage reduced significantly and dropped to 0V. MFC sustained for 109 days, with peak voltage of 0.86V and an average of 0.6V. MFC showed stable performance for about 66 days. The average power 6 cm below the top cell was obtained as 1.071×10^{-7} W and the 6 cm above the bottom of cell average power obtained in the MFC was 1.87373×10^{-7} W. i.e. the energy produced by the anode, placed at the top of the cell was higher than the anode placed at the bottom of the cell which indicates that the placing of anode plays a key role in production of electrical energy. The power generation and COD was measured per day in upcoming 60 days. The results show the power generation increases with time and reached to peak after 16 days and was continue to 40 days. Parallel to generation, COD was observed decreasing continuously.

CONCLUSION

MFC designs need improvements before a marketable product will be possible. Issues of the scale up of the process remain critical issues. While full-scale, highly effective MFCs are not yet within our grasp, the technology holds considerable promise, and major hurdles will undoubtedly be overcome by engineers and scientists. The growing pressure on our environmental issues and the call for renewable energy sources will fulfill the future needs. Furthermore, development of this technology, leading soon to its successful implementation in practical purposes for the wastewater treatment and energy production.

Therefore, the aim of this study was to investigate the power generation and COD removal preformation analysis using single chamber MFC in laboratory. A small scale MFC was fabricated having anode and cathode. The municipal waste was used to cell along with optimal amount of water. The electricity generation and COD removal was measured on daily basis. The results shows the effective power generation along with COD removal. It is observed that having good network of anode electrodes i.e. anode in good contact with substrate, will reduce the losses to some extent. Maintaining suitable environmental conditions like DO, temperature and pH can help optimize the yield from such cells. This study will help in future renewable energy generation as well as sustainable waste management.

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