Bioconversion of Food Waste with Cosubstrate to Electricity using Microbial Fuel Cell

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Abstract. Bioelectricity generation from canteen based food waste in microbial fuel cell (MFC) is an interesting alternative energy producing technology. In this research work, an equal proportion of confectionery wastewater and hostel food waste was homogenised and used as substrate. Agar salt bridge was used as proton exchange membrane (PEM). At the end of 212th h of the experiment, the COD concentration decreased to 2800 mg COD/L with the COD removal efficiency of 85.86 %. A maximum potential of 2250 mV and current of 22.50 mA with external resistance of 100Ω at the end of 65th hour was generated.

1. Introduction
In recent decades, world energy consumption has a progressive trend [1-3]. At present, global energy requirements are mostly dependent on fossil fuels, which eventually lead to foreseeable depletion of limited fossil energy sources. Traditional source of energy is indeed unsustainable [4]. Combustion of fossil fuels also has serious negative effect on environment due to carbon dioxide emission. Climate changes, increased global demand for the limited oil and natural gas reserves and energy security have intensified search for alternative fuels to reduce dependence on fossil fuels [5]. Alternative fuels are becoming more and more attractive and important due to the decreasing storage of fossil fuels and the environmental concerns [6,7]. The new resources of energy should be renewable and also environmental-friendly [3-7]. Among the new sources of energy, fuel cells (FCs) have gained lots of attractions in recent years. The first fuel cell came almost 180 years ago, but its viability for the generation of electricity happened after many companies invested in this type of technology. They represent an excellent alternative for combustion engines, small (up to 1kW), medium (100kW) and large (1MW) electric power generation. [8-10]. There are several types of fuel cells, depending the composition of its electrolyte, the operating temperature and the type of fuel used. Considering these characteristics, six main types of fuel cells are the most studied: proton exchange membrane fuel cells, alkaline fuel cells, phosphoric acid fuel cells, solid oxide fuel cells, molten carbonate fuel cells and microbial fuel cell [8-11]. Microbial fuel cells are rapidly growing sustainable technology for energy production. Microbial fuel cells (MFCs) are special kinds of FCs which use microorganism as a biocatalyst, instead of high value metal catalysts used in traditional fuel cells, to generate energy. They have characteristics similar to traditional power sources and act as to anaerobic reactors. MFCs can be described by electrochemical parameters such as current density, power density and cell voltage and also through biological parameters such as substrate loading rate in continuous systems [12]. MFCs provide new opportunities for direct electricity generation from renewable and biodegradable materials by active microorganism [13]. MFC has a number of attractive characteristics such as direct electricity generation, high efficiency, and
operation in ambient temperatures [14]. The electrical power output of MFCs are basically dependent on the factors such as nature of fuel used, fuel cell configuration, working dimensions [13,14].

The urban population of India is expected to grow to 45% of total from the prevailing 28%. Hence, the magnitude of municipal solid waste (MSW) problem is likely to grow to even larger proportions [15-18]. Food waste (FW) (both precooked and leftover) is a biodegradable waste discharged from various sources including food processing industries, households, and hospitality sector. It has been reported that the annual amount of urban FW in Asian countries could rise from 278 to 416 million tonnes from 2005 to 2025 [19-21]. Approximately 1.4 billion hectares of fertile land (28% of the world’s agricultural area) is used annually to produce food that is lost or wasted. About 500 million tons (MT) of crop residues are generated out of total agriculture produce per year, which are either used as animal feed, livestock bedding, packaging material, cooking in households, papermaking, etc. or burned in the farms and create the environment pollution along with deterioration of the farm fertility. Apart from food and land resource wastage, the carbon footprint of food waste is estimated to contribute to the greenhouse gas (GHG) emissions by accumulating approximately 3.3 billion tonnes of CO₂ into the atmosphere per year.

In this research work, an attempt was made to generate bioelectricity from homogenised food waste with cosubstrate using microbial fuel cells (MFC) connected in series. As such, this will facilitate to meet the energy demands and also help in the effective management of the environment.

2. MATERIALS AND METHODS

Anodic Inoculum
The sediment sample was collected from the mangrove rhizosphere of Pichavaram in Cuddalore district of Tamil Nadu State (Figure 1) and used as inoculum.

Substrate - Homogenised Food Waste
The wastewater was collected from confectionery industry in Tamil Nadu State, India and used as cosubstrate. Food waste was collected from the hostel of Maharishi International Residential School, Sunguvachathiram, Tamil Nadu State. An equal proportion (v/v) of confectionery wastewater and hostel food waste was homogenised and used as substrate.

Agar Salt Bridge
An agar solution was prepared by heating 3% (3 grams in 100 mL) of agar powder in 1 Molar NaCl solution. This solution was poured into a glass tube with a measure of 12 cm length. The prepared agar salt bridge was used as proton exchange membrane (PEM).

3. CONSTRUCTION OF EXPERIMENTAL SETUP
A two chambered MFC was constructed using two plexi jars of 1500 mL capacity with a working volume of 1200 mL. (Figure 2). The two jars were, through the two perforations made on its side at one point close to 2/3 of its height from top were connected with each other by an agar salt bridge and sealed tightly to avoid leakage of the substrate and cathodic solution. The substrate was inoculated with 50 g of pre-treated mangrove sediment under aseptic conditions. The initial pH of the substrate was maintained at 5.5. The experiments were carried out in duplicate at room temperature of 30 – 35°C. The salt bridge was used for the electrolytic contact of the solutions in the two jars, where the two electrodes of the MFC were immersed. The electrodes made of graphite plates were used as anode and cathode. Copper wires were used to connect the electrodes to the external circuit. Three such units were made and connected in series (Figure 2).
4. **SAMPLING AND ANALYSIS**

The substrate sample was collected and analyzed at once for pH and COD concentration at 24 hours intervals following standard methods of APHA 1995 [22]. The potential measurements were recorded between anode and cathode of the MFC using a multimeter after stabilization of the readings. Performance of the MFC was evaluated by substrate (COD) removal efficiency during the operation.

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\text{COD removal efficiency (\%)} = \frac{C_{SO} - C_S}{C_{SO}} \times 100
\]

**Figure 1** Sediment sample used as inoculum

**Figure 2** LED bulb is lighted with the electricity generated using MFC

5. **RESULTS AND DISCUSSION**

**COD removal Efficiency**

The initial COD concentration of the homogenised food waste used was 19800 mg COD/L. At the end of 212\textsuperscript{th} h of the experiment, the COD concentration decreased to 2800 mg COD/L with the COD removal efficiency of 85.86 %.

**Bioelectricity Generation**

In this batch experiment three units of MFC with the initial substrate concentration of 19800 mg COD/L each were connected in series and it was experimented. The potential measured was found to increase gradually and reached a maximum potential of 2250 mV at the end of 65\textsuperscript{th} hour (Figure 3). The highest potential generation recorded could be attributed to the availability of favourable nature of carbon sources for the microbes from the substrates to transfer electrons at higher rate between microbial film and solid electrode [12,13]. Moreover, the strong oxidation ability of cathodic solution might also have influenced the maximum potential generation [12,13]. Above all the record of maximum potential generation could be ascribed to connection made in series with all the three
sets of MFC. During the experimental period the potential produced by the MFC was highly unstable and it varied between 120 and 2250 mV during the study period (Figure 3, 4).

A variation in power density and current density was obtained and it ranged from 0.7762 to 272.882 mA/cm$^2$ and from 0.0065 to 0.1213 mA/cm$^2$, respectively (Figure 5). Such fluctuations might be due to the irregular rate of electron transfer to the anode and it was one of the major limiting factors. The reason for such fluctuations could also be traced to occurrence of different microbial groups in the anaerobic system [23, 24]. A maximum power density and current density obtained was 272.882 mW/cm$^2$ and 0.1213 mA/cm$^2$, respectively.

![Figure 3](image3.png)
**Figure 3.** Voltage variations at 100Ω resistance during MFC operation with series connection

![Figure 4](image4.png)
**Figure 4.** Voltage and current profile during MFC operation with series connection
6. CONCLUSIONS

The homogenized food waste used as substrate in the three units of MFC connected in series with the initial substrate concentration of 19800 mg/L, generated a maximum potential of 2250 mV and current of 22.50 mA with external resistance of 100 Ω at the end of 65th hour.

The up-gradation of the design of MFC in various aspects will help in scaling up of the electricity generation so as make the school hostel self-reliant in electricity generation in the near future. With the generation of electricity LED lamp was lighted and the COD removal efficiency has also been achieved to a great extent.

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