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# Impact of Electrode Configurations on Hydraulic Retention Time (HRT) in Treatment of Sugar Mill Wastewater Using Microbial Fuel Cell

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**ABSTRACT** Brisk industrialization and urbanization in developing countries like India propound major problems in collection, disposal and treatment of effluents, this leads to public health problems and other environmental problems. For constructing a sustainable world we require to minimize the use of fossil fuels which leads to less generation of pollutions, MFCs are the alternative technology for wastewater treatment and generation of electricity. In this study sugar mill wastewater is used as substrate and is inoculated with sludge from UASB and Cow dung for the production of bioelectricity. This study explores application of single chambered MFC in generation of bioelectricity. The maximum average voltage, average current and average power produced in MFC using 220 $\Omega$  external resistor were 177.66mV, 0.807mA and 143.171 $\mu$ W respectively at 20h HRT and The maximum coulombic efficiency in MFC is 5.295% at 20h HRT. At maximum average power generation, 1000 mg COD/L of feed concentration, the COD removal efficiency was 86.75% at 20h HRT and Average maximum power density in MFC was 6507.7 $\mu$ W/m<sup>2</sup>. Single chambered MFC with double cathodes might be more advantageous on the bases of electrical power production but would have higher capital costs due to the use of more cathodes and greater surface area of electrodes and Single chambered MFC with single cathode might be more useful on the basis of capital costs due to the use of less cathode surface area and less surface area of electrodes.

**KEYWORDS**: Microbial fuel cell (MFC), Single chambered MFC with single cathode (MFC-A), Single chambered MFC with double cathode (MFC-B), Hydraulic retention time (HRT), continuous flow mode, Electricity generation.

### I. INTRODUCTION

Water pollution, disposal of wastes and their management is the most important environmental problem faced by the world today. Agricultural waste, household waste and industrial waste are best substrates for energy production as they are rich in organic contents [1]. India is one of the leading producers of sugar in the world and has nearly 650 sugar mills that produce about 13 million tons of molasses and 15 million tons of sugar. These sugar mills discharge a bulk amount of wastewater per day without proper treatment during working seasons, for every one tone of sugarcane crushed the sugar industries generates about thousand liters of wastewater from different units, sugar industry wastewater has high COD and BOD, which is hazardous for aquatic life and human use [2]. MFC have gained importance in the last few decades due to their ability to produce bioelectricity from renewable sources, MFCs have been used to treat various kinds of wastewater such as Sugar, brewery, domestic sewage, distillery, rice mill, paper and pulp, swine wastewater etc. Sugar mill wastewater is an important source of organic material thus microorganisms degrade the organic matter there by releasing electrons and protons. Electron flow leads to the generation of electricity



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in Microbial Fuel Cell. In this study, generation of electricity from sugar mill wastewater is carried out using single chambered with single and double cathodes MFC

"MFCs are Bio-reactors that can utilize microorganisms for converting chemical energy into electrical energy under anaerobic condition".

Basic MFC design consists of two compartments one is anode and the other is cathode. These two compartments are separated by proton exchange membrane. Substrate is oxidized in anode chamber by using microorganisms, producing electrons, protons and carbon dioxide ( $CO_2$ ). The electrons are transferred from anode compartment to cathode compartment through an external circuit and protons are transferred from anode to cathode compartment through PEM (as salt bridge). In cathode compartment, protons, electrons are consumed and combining with oxygen ( $O_2$ ) to form water. Prof. M C Potter in 1911 gave the idea of obtaining energy from bacteria, he discovered how microorganisms degrade the organic matters and produces electrical energy, he was trying to stock this source of energy for human use. In recent years many researchers are working to improve the types, electrode materials, combination of bacteria and their types, mechanism of electron transfer in MFC [3].

### II. RELATED WORK

**Kyoung-Yeol Kim et al., 2015 [4]** Studied that MFCs requires hydraulic retention times for the treatment of wastewater (Domestic wastewater) under continuous flow mode. Using two different brush electrode MFC configurations, two MFCs in series were compared at 8.8h, 4.4h and 2.2h theoretical HRTs. MFC with full brush having two cathodes ( $S_2C$ ) produces more power(mW) than the MFC with trimmed brush having single cathode ( $N_1C$ ), power generation in  $N_1C$  reactor is 1.12mW at 4.4h HRT and  $S_2C$  reactor is 1.72mW at 4.4h HRT and COD removal efficiency of  $N_1C$  reactor is more than  $S_2C$  reactor, COD removal efficiency of  $N_1C$  reactor, the CE of  $N_1C$  reactor is 48.3±1.0%. The coulombic efficiency (CE) of  $N_1C$  reactor is also higher than  $S_2C$  reactor, the CE of  $N_1C$  reactor is less than or equal to 37% and  $S_2C$  reactor is less than or equal to 29%.  $N_1C$  reactor is more efficient on the basis of COD removal, costs and use of less cathode area.

**Sang-Eun Oh et al., 2005 [5]** says that power production in MFC is a function of surface areas of the anode relative to that of the cathode and Proton Exchange Membrane (PEM). The sizes of the cathode and anode were varied in twochambered MFCs having PEMs with different surface areas (APEM=  $30.6 \text{ cm}^2$ ,  $6.2 \text{ cm}^2$  and  $3.5 \text{ cm}^2$ ), for a fixed cathode and anode surface area (ACathode=AAnode= $22.5 \text{ cm}^2$ ), the power density increased with the PEM size in the order 190 mW/m<sup>2</sup> (APEM= $30.6 \text{ cm}^2$ ).  $68\text{mW/m^2}$  (APEM= $6.2 \text{ cm}^2$ ) and  $45\text{mW/m^2}$  (APEM= $3.5 \text{ cm}^2$ ). Due to an increase in internal resistance, surface area of the PEM was shown limited power production when surface area of the PEM is less than that of electrodes. Cathode and anode surface areas are equal to the PEM surface area, a condition (2ACat=APEM=2AAn), the power density of the MFCs with the three different PEM sizes ( $30.6 \text{ cm}^2$ ,  $3.5 \text{ cm}^2$  and  $6.2 \text{ cm}^2$ ) was essentially the same or  $168\pm5\text{mW/m}^2$ . Using ferricyanide at the cathode compartment increased power generation in MFC.

**Vinicius Fabiano Passos et al., 2016 [6]** studied that electricity generation in Microbial Fuel Cell by using anaerobic sludge from wastewater treatment plant, maximum power density in MFC is  $13.5\mu$ W/cm<sup>2</sup> at 24 days of operation. The coulombic efficiency (CE) of the MFC is only 5% by using 1000 $\Omega$  resistor, hence 95% of the wastewater was not used to generate the bioelectricity, this is because of improper selection of eletrogenic microorganisms, in general low COD increases the Coulombic Efficiency in MFC.

**Kavyashree R Dodddamani et al., 2014 [8]** Studied that using sugar mill wastewater, electricity generation by single chambered MFC give the maximum Voltage, Current, and Power generation of 0.9mV, 1.28mA, and 0.304W/m<sup>2</sup> and showed BOD, COD and TDS removal efficiency 69.3%, 68.1%, and 56.35% respectively. 2mm diameter pencil leads are used as both anode and cathode electrodes



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**Hampannavar U S et al., 2011 [9]** Studied that the comparison of single chambered MFC and double chambered MFC for the treatment of distillery wastewater and generation of electricity, single chambered MFC proves more efficient and produces the more power than double chambered MFC and double chambered MFC proves more efficient in the removal of COD than the single chambered MFC, Sewage is used as inoculum. Maximum current density and power density of single chambered MFC is 0.84mA and 28.15mW/m<sup>2</sup>. The maximum power density and current density of double chambered MFC is 17.76mW/m<sup>2</sup> and 0.36mA. COD removal efficiency of Double chambered MFC is 61% and single chambered air cathode MFC is 48%. 2mm diameter and 90mm length graphite rods are used as anode and cathode electrodes. Single chambered air cathode MFC is more reliable because of higher electricity generation, low maintenance and reduced cost of construction.

# **III. MATERIALS AND METHODOLOGY**

#### COLLECTION OF WASTEWATER

Wastewater was collected from nearby Sugar mill Industry and wastewater was stored in a deep freezer.

#### MFC

For the treatment of sugar mill wastewater, Single chambered MFC with Single cathode and Single chambered MFC with double cathodes have been fabricated, which are connected in series.

### MATERIALS AND THEIR USES FOR THE CONSTRUCTION OF MFC

1. PVC Pipes

PVC pipes are used to build the anode chamber and cathode, anode chamber holds the sugar wastewater and cathode holds agar and salt solution. Length and diameter of the anode pipes are 400mm and 127mm, cathode pipes are 220mm and 32mm.

- 2. Agar-agar and Common salt Common salt and agar-agar are used to construct agar-salt bridge.
- Graphite rods from pencil (Pencil leads)
   Pencil leads are used as both anode electrode material and cathode electrode material.
   MFC-A Length and diameter of the anode and cathode materials are 60mm, 0.7mm, MFC-B Length and diameter of the anode materials are 90mm, 2.0mm.
- Wires (Copper wires) Copper wires are used to connect the electrodes and to a recording devices.
   Rubber pipes
- J. Rubbel pipes
- Pipes are used to make sampling ports and to transfer the wastewater from MFC-A to MFC-B.
- 6. Sealant
- To prevent the leakages M-seal is used.
  7. Multi-meter and Fixed resistor DT-830D Digital multi-meters are used to measure the voltage and current and 220Ω external fixed resistor is used to calculate the current.
- Peristaltic Pump (Miclins:PP 20 EX-2C) It is used to pump the wastewater from the storage tank to MFC Reactors and to maintain continuous flow of wastewater.

#### MFC CONSTRUCTION

#### a] Selection of anode chamber

Anode chamber is having 5 liters capacity with working volume of 4.434 liters. Length and radius of anode chamber is 40cm and 6.35cm respectively. Figure 1 shows length and radius of anode chamber for both MFC-A & MFC-B.



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Figure 1.Anode chamber of both MFC-A and MFC-B

### b] Construction of agar-salt bridge [1]

Materials required for the construction of agar-salt bridge are water, agar and common salt.650 ml of water is boiled in a clean beaker, 65 gm of agar and 75 gm of common salt are slowly added to the boiling water, the whole mixture is further boiled for 4-5 minutes then Mixture was poured into open end of PVC pipe, other end of pipe is kept closed by using plastic wrap. After pouring the mixture into PVC pipes, pencil leads are placed in mixture; whole set up is allowed to solidify and is kept 24 hours in refrigerator. Length and diameter of the salt-bridge are 220mm and 32mm [1]. Figure 2 shows agar-salt bridge preparation.



Figure 2.Preparation of agar salt bridge

### c] Arrangements of Electrode materials

Pencil leads are selected as both anode and cathode electrode materials, For MFC-A, length and diameter of the electrode materials are 60mm, 0.7mm. For MFC-B, length and diameter of the electrode materials are 90mm and 2mm. In MFC-A & MFC-B, 32 No of electrodes are used in anode chamber and 12 No of electrodes are used in cathode chamber, Figure 3 shows arrangements of electrode materials.



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Figure 3.A-MFC-A anode chamber electrode arrangements B-MFC-B anode chamber electrode arrangements

### d] Fabrication of MFC

Two different electrode configurations of MFC reactors were constructed, The electrodes were placed into the anode chambers and cathodes, copper wires were used to connect anode electrodes and cathode electrodes including a  $220\Omega$  fixed resistor between them, at the canter of both reactors a circular groove was made for fitting the agar-salt bridges, In both reactors sampling ports are provided at top and bottom, then the whole set up is sealed and made air tight.

#### **OPERATION OF MFC**

Anode chamber of MFC-A and MFC-B were filled with inoculums (80% of the volume of the reactor) as the mixture of sludge from UASB and cow dung. Both sludge and cow dung slurry is mixed in equal proportion. The different HRTs of 24h, 20h, 16h, 12h, 10h, 8h, 6h, 4h and 2h were maintained by using sugar mill wastewater for the above stated two electrode configurations.

Sodium Bicarbonate (NaHCO<sub>3</sub>) was used to maintain the optimum pH and for stabilization the entire reactor set up was left for a week (7 days), initial reading were noted down.

i] Hydraulic residence time (HRT)

"HRT is the measure of average length of time that liquid remains in a reactor".

HRT=  $V_1 / Q$ Where HRT in (h)  $V_1$ =Volume of the reactor in m<sup>3</sup> Flow rate (O) in m<sup>3</sup>/h.

ii] Volume of the reactor (V<sub>1</sub>)  $V_1 = \pi/4 \times d^2 \times h$ Where d=Diameter of the reactor in (cm) h=Height of the reactor in (cm)

The wastewater characteristics were analysed at different HRTs, each HRTs were changed at every 2 ½ days [4]. Voltage, Current readings were monitored at every 4h intervals using digital multi-meter. Figure 4 shows cross section of MFC.



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### CALCULATION OF POWER AND COULOMBIC EFFICIENCY

#### i] Calculation of Power

According to ohms law, I=V/RWhere R=fixed resistor (220 $\Omega$ ) Power (P)= I<sup>2</sup>R or I×V Where I=Current in (Amp) V=Voltage in (Volts)

#### ii] Calculation of Coulombic efficiency(CE) [7,4]

"It is the ratio of total coulombs actually transferred to the anode from the substrate to maximum possible coulombs if all the substrate removal produced current".

 $CE = Ct/Cp \times 100$ 

Ct=Average current (A) ×Time (s)

 $Cp = f \times b \times \Delta s(g) \times \overline{v}(L)/32$ 

where f=96485 (C/mol electron) is the faradays constant.

b=Number of electrons exchanged per mole of oxygen (4 Nos)

- 32= Molecular weight of oxygen,  $\Delta s$ =Change in COD over time (COD<sub>in</sub>-COD<sub>out</sub>)
- $\overline{v}$  =Volume of liquid in anode chamber (L)



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#### **IV. EXPERIMENTAL RESULTS**

#### CHARACTERISTICS OF SUGAR MILL WASTEWATER

Table 1.Characteristics of sugar mill effluent

| Sl.no | characteristics                                    | unit | Sugar wastewater values |
|-------|--|------|-------------------------|
| 1     | рН   | -    | 7.5                     |
| 2     | Chemical Oxygen Demand (COD)                       | mg/L | 4400                    |
| 3     | Biological Oxygen Demand (BOD <sub>5</sub> @20 °C) | mg/L | 1320                    |
| 4     | Chloride   | mg/L | 516                     |
| 5     | Total Solids                                       | mg/L | 3730                    |
| 6     | Total Dissolved Solids (TDS)                       | mg/L | 3000                    |
| 7     | Suspended Solids                                   | mg/L | 730                     |
| 8     | Total Volatile Solid (TVS)                         | mg/L | 2000                    |
| 9     | Fixed Solids                                       | mg/L | 1730                    |
| 10    | Phosphate  | mg/L | 5.85                    |

#### POWER GENERATION IN MFC

Power generation in MFC-A & MFC-B and power generation in MFC are shown in Figures 5 and 6, when MFC were started up at longer HRT of 24h with  $220\Omega$  external resistor there was an inconsistent power generation in MFC, when MFC operation was switched to shorter HRTs of 8h, 6h, 4h, 2h there was consistent power production. MFC with double cathode produced more power than the MFC with single cathode this is because of greater PEM surface area can results in the higher power production [5]



Figure 5.Power generation in MFC-A & MFC-B



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Figure 6.Power generation in MFC

### AVERAGE POWER IN MFC

Maximum power generation is observed at 20h (143.171 $\mu$ W). There is an inconsistence power production at longer HRTs (24h, 20h, 16h, 12h and 10h) and consistence power generation is observed at shorter HRTs (8h, 6h, 4h and 2h). Higher will be the voltage generation, higher will be the current generation thus results in higher power production, using ohms law, current and power will be determined. The power generation with respect to time (d) as shown in Figure 7



Figure 7. Average power generation in MFC

### pH IN MFC-A AND pH IN MFC-B

In MFC-A the pH increased from 7.3 to 7.63 and in MFC-B the pH increased from 7.39 to 7.81. The pH was neutralized for every different HRTs and is varied from neutral to alkaline slightly during the process of oxidation in anode chamber of both MFC. Results of this study and other study done by other researchers showed that slower microbial activity is in less pH than the optimum pH, low pH deactivates microorganisms and MFC efficiency. Variation of pH in MFC-A and MFC-B with respect to different HRTs are shown in Figure 8.



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# COD Removal efficiency (%) in MFC

The maximum COD removal efficiency in MFC is 92% at 24h HRT and maximum power generation in MFC is 143.171 $\mu$ W, at this point MFC reaches COD removal efficiency of 86.75% at 20h HRT, MFC with double cathodes results lower COD removal efficiency than the MFC with single cathode, this is because of using the greater cathode surface area per volume of the reactor (two cathodes) which would allow more leakage of oxygen into MFC[4]. COD removal efficiency in MFC reactors slightly decreasing at shorter HRTs, as shown in Figure 9





# COULOMBIC EFFICIENCY (%) IN MFC

Maximum coulombic efficiency in MFC is 5.295% and low coulombic efficiency could be due to improper selection of culture medium or environmental conditions, in general low COD content increase the coulombic efficiency, this low coulombic efficiency is not only to improper selection of non electrogenic microorganisms but also the reactor design [6] and MFC with double cathodes (PEM) results higher coulombic efficiency than the MFC with single cathode. At shorter HRTs, MFC shows a consistent coulombic efficiency, which is shown in Figure 10.



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Figure 10.Coulombic efficiency (%) in MFC

# AVERAGE CURRENT (mA), AVERAGE VOLTAGE (mV) AND AVERAGE POWER (µW)

Increasing in voltage and current generation using fixed resistor, increases the power generation in MFC and at maximum average current in MFC, showed the maximum average voltage and maximum average power generation of 177.66mV and 143.171 $\mu$ W respectively at 20h HRT, higher voltage and current generation in MFC results higher power production, abundant acceptor such as oxygen availability in the air is the prime reason for generation of higher current and higher the voltage. The variation of average voltage and average power with respect to average current generation is show in Figure 11.



Figure 11.Average current (mA), average voltage (mV) and average power ( $\mu$ W)

### V. CONCLUSIONS

The conclusions are as follows

i. The maximum average voltage, average current and average power generation in MFC was 177.66mV, 0.807mA and 143.171 $\mu$ W respectively at 20h HRT, measured across 220 $\Omega$  resistor. The maximum coulombic efficiency in MFC is 5.295% at 20h HRT and at maximum power generation, COD removal efficiency is 86.75% at 20h HRT.



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- ii. MFC with double cathodes produced more power than the MFC with single cathode this because of MFC with double cathodes has greater PEM surface area  $(1.608 \times 10^{-3} \text{m}^2)$  and the MFC with single cathode has smaller PEM surface area  $(8.042 \times 10^{-4} \text{m}^2)$  than the MFC with double cathodes.
- iii. Average maximum power density of the MFC is  $6507.7 \mu$ W/m<sup>2</sup>
- iv. Single chambered MFC with double cathodes is more advantageous on the bases of electrical power production but would have higher capital costs due to the use of more cathodes and greater surface area of electrodes and Single chambered MFC with single cathode is more useful on the basis of capital costs due to the use of less cathode surface area and less surface area of electrodes.

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