Treatment of Domestic Wastewater & Generation of Electricity Using Microbial Fuel Cells

Dr. Babitha Rani.H[1], Dr. N Krishna Murthy[2], Swathi D L[3], Shivom S Revankar[4], Praveen Sawant[5]
[1,2,3,4,5] *School of Engineering and Technology, Jain Global Campus*

Abstract- **India is rapidly shifting from agricultural-based nation to industrial and services-oriented country. About 31.2% population is now living in urban areas. There are four mega cities-Greater Mumbai, Delhi, and Kolkata, Bengaluru. Bengaluru having population of 10 million or more (2015). Management of solid waste has become option to the biggest problems that are facing today in cities. In the present study, urban kitchen waste was converted into compost in two methods one is conventional composting and vermicomposting. As kitchen waste is rich in organic material while deficient in nitrogen, cow dung was mixed with organic waste to make suitable for earth worms. The compost was prepared by both conventional composting and vermicomposting separately. Comparative quality of compost and duration taken for compost process were examined after 60 days and 45 days. Biochemical parameters were analyzed during the compost period. Comparative to the conventional compost (without worms), vermicomposting indicates there was increase in all the parameters like total nitrogen (N), phosphorus (P) and potassium (K). More than 30% of the urban solid waste consists of kitchen waste and if backyard (utility) composting practices are adopted in the city, 30% load can be reduced on the overall solid waste management. The results of the studies demonstrate that MFC (MICROBIAL FUEL CELL) processes were able to treat waste successfully. MFC-2 proves to be better for power generation when compared with MFC-1 due to the fact that cathode in single chambered MFC (MFC-1) is exposed to air**

Index Terms- Domestic waste, FOGs, High rate anaerobic processes, Double chambered MFC.

INTRODUCTION

Domestic wastewater is made up of solids, biological pollutants as well as fats, oils and greases (FOGs). Removal of these materials is accomplished by a combined effort between the septic tank and percolation system. The purpose of a septic tank is to remove FOGs and solids from the wastewater, while the purpose of the percolation area is to biologically treat the wastewater, removing biological pollutants and to distribute treated wastewater into the groundwater network. It is vital that both components are installed and maintained properly to ensure a trouble free on-site wastewater treatment system. The high energy requirement of conventional sewage treatment systems are demanding for the alternative treatment technology which will be cost effective and require less energy for its efficient operation. In past two decades, high rate anaerobic processes are finding increasing application for the treatment of domestic as well as industrial wastewaters. The major advantages these systems offer over conventional aerobic treatment are no energy requirement for oxygen supply, less sludge production, and recovery of methane gas. While treating sewage, particularly in small capacity treatment plant recovery of methane may not be attractive, because most of the methane produced in the reactor is lost through effluent of the reactor. The methane concentration of about 16 mg/L (equivalent COD 64 mg/L) is expected in the effluent of the reactor due to high partial pressure of methane gas inside the reactor. Hence, while treating low strength wastewater major fraction of the methane gas may be lost through effluents, reducing the energy recovery.

WASTEWATER TREATMENT TECHNOLOGIES

Physical, chemical and biological methods are used to remove contaminants from waste-water. In order to achieve different levels of contaminant removal, individual waste-water treatment procedures are combined into a variety of systems, classified as primary, secondary, and tertiary wastewater.

OBJECTIVE OF STUDY

The treatment of Domestic waste water using various treatment technologies has been widely explored and this has been revised and discussed in the literature survey. The study has been undertaken to assess the efficiency of the treatment of domestic wastewater using MFC. The specific objectives of the research work are as under:

- Fabrication of microbial fuel cell
- Analysis of waste water characteristics of domestic sewage before treatment
- Analysis of waste water characteristics of a Domestic sewage after treatment in microbial fuel cell
- Analysis of Current and Voltage generation in MFC

REVIEW OF LITERATURE

Fossil fuels have supported the industrialization and economic growth of countries during the past century, but it is clear that they cannot indefinitely sustain a global economy. Oil will not appreciably run out for at least 100 years or more, but demand for oil is expected to exceed production from known and anticipated oil reserves ten or twenty years from now, or within the 2015 to 2025 time frame. The infrastructure changes needed to address our global energy needs will be far more extensive and will likely require changes not only to our infrastructure but also to our lifestyle. Changes will affect everything from home heating and lighting, to where we prefer to live and work and how we get there. The costs of energy and how much energy we use will come to dominate our economy and our lifestyle in the coming decades [1]. It is evident that mankind is increasingly dependent on energy with the advancement of science and technology. The present day energy scenario in India and around the globe is precarious, thus driving to the search of alternative to fossil fuels. Increasing energy consumption creates unbalanced energy management and requires power sources that are able to sustain for longer periods. Trapping renewable energy from waste organic sources is the present trend of active research. In this direction, bioelectricity generation through microbial fuel cells (MFCs) using a variety of substrates, including wastewater is being studied extensively [2]. Microbial fuel cells (MFC) are electrochemical devices that convert the chemical energy contained in organic matter into electricity by means of the metabolic activity of living microorganisms [3].

Process of Electro genesis: In an MFC, microorganisms degrade (oxidize) organic matter, producing electrons that travel through a series of respiratory enzymes in the cell and make energy for the cell in the form of ATP (Adinosine Tri Phosphate). The electrons are then released to a terminal electron acceptor (TEA) which accepts the electrons and becomes reduced. Oxygen in the anode chamber will inhibit electricity generation, so the system must be designed to keep the bacteria separated from oxygen. Separation of the bacterial community from oxygen can be achieved by placing a membrane that allows charge transfer between the electrodes, forming two separate chambers: the anode chamber, where the sample has to be fed and the bacterial growth takes place due to the high content of biodegradable organic compounds; and the cathode chamber is completely filled with the saturated salt solution [1].

COMPONENTS OF MFC

The main three components of the MFC are the anode, cathode, and if present, the separator or agar salt bridge.

Anode:The requirements of an anode material are: highly conductive, non-corrosive, high surface area, high porosity, inexpensive, and easily made and scaled to larger sizes. Graphite rods, carbon paper, cloth, carbon plates and sheets are used as anode. The use of carbon-based electrodes in paper and cloth forms for the MFC anode is very common. These materials have high conductivity and appear to be well suited for bacterial growth. There are a large variety of graphite materials to choose from for MFC electrodes which vary greatly in price, composition, surface area and are highly conductive. The biofilm grows on the anode surface [1].

Cathode: The design of the cathode is the single greatest challenge for making an MFC a useful and scalable technology. The chemical reaction that occurs at the cathode is difficult to engineer as the electrons, protons and oxygen must all meet at a catalyst in a tri-phase reaction (solid catalyst, air, and water) [1].

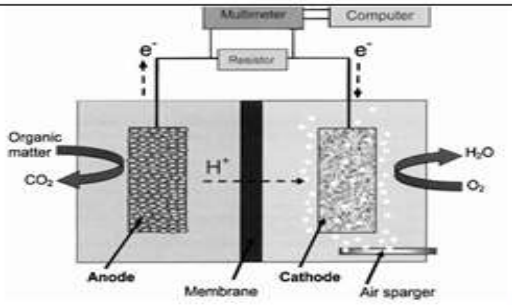


Fig 2.1: Schematic representation of the basic components of a microbial fuel cell [1].

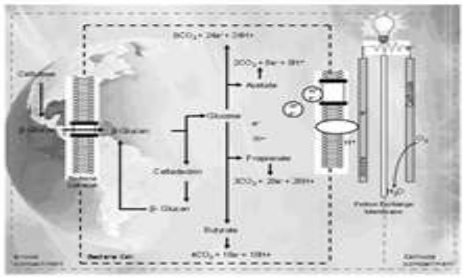


Fig 2.2: Biological Mechanism [4].

Glucose Conversion Reaction:

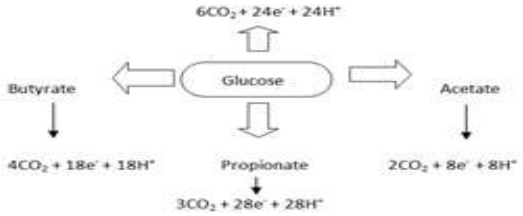


Fig 2.3: Flowchart showing the glucose metabolism.

Components	Materials
Anode	Graphite, carbon paper, carbon cloth, Platinum
Cathode	Graphite, carbon paper, carbon cloth, Platinum
Anodic chamber	Glass, polycarbonate, plexiglass
Cathodic chamber	Glass, polycarbonate, plexiglass
Proton Exchange System	Proton exchange membrane: Nafion, Ultrex, salt bridge, porcelain septum
Electrode Catalyst	Pt, MnO_2, Fe^{++}, polyaniline

Table 2.1: Basic Components of MFC [5].

Microbes	Substrate	References
Actinobacillus succinogens	Glucose	Park and Zeikus (2000) [10]
Aeromonas hydrophila, Alcaligenes faecalis, Enterococcus gallinarum, Pseudomonas aeruginosa	Glucose	Rabaey *et al.*, (2004) [11]
Clostridium beijerinckii	Starch, glucose, lactate, molasses	Niessen *et al.*, (2004) [12]
Clostridium butyricum	Starch, glucose, lactate, molasses	Niessen *et al.*, (2004) [12]
Geobacter metallireducens	Acetate	Min *et al.*, (2005) [13]
Geobacter sulfurreducens	Acetate	Bond and Lovley (2003) [14]
Klebsiella pneumonia	Glucose	Rhoads *et al.*, (2005) [15]
Pseudomonas aeruginosa	Glucose	Rabaey *et al.*, (2004) [11]
Rhodoferax ferrireducens	Glucose, xylose, sucrose, maltose	Chaudhuri and Lovley (2003) [16]
Shewanella putrefaciens	Lactate, pyruvate, acetate, glucose	Kim *et al.*, (1999) [17]

Logan et al., (2007), used random bundles of ammonia-treated graphite fibers as cathode material. It is not essential to place the cathode in water or in a separate chamber when using oxygen at the cathode. The cathode can be placed in direct contact with air either in the presence or absence of a membrane. Much larger power densities have been achieved using oxygen as the electron acceptor when aqueous-cathodes are replaced with air-cathodes [9].

Sukkasem et al., (2008), had used single chamber air cathode MFC to analyse the effect of nitrate on the performance of MFC.

Applications: Few of the important applications of Microbial Fuel Cell have been given below:

Renewable Electricity Production: Renewable energy production from waste biomass is likely to be a more viable route for near-term energy recovery. MFC technologies appear to be technically feasible for energy recovery from waste biomass materials [8].

Wastewater Treatment: A treatment system based on an MFC provides a great opportunity to develop the technology, because the substrate is "free" and wastewater must be treated. At a modern treatment

plant, the wastewater may contain 9.3 times energy required to treat it. Energy recovery at a wastewater treatment plant could lead not only to a sustainable system based on energy requirements but also to production of a net excess of energy.

Production of Hydrogen: MFCs can also be modified to produce hydrogen gas (H2) by removing oxygen at the cathode and adding in a small voltage via the bio electrochemically assisted microbial reactor (BEAMR) process or the bio catalyzed electrolysis process. The reactor used for the production of hydrogen has been given the name "microbial electrolysis cell" (MEC). The production of H2 in a MEC process, rather than electricity generation in an MFC, is still an endothermic process overall, and thus energy needs to be added to the reactor in order to make hydrogen evolution possible [1].

Environmental Sensors: Data on the natural environment can be helpful in understanding and modeling ecosystem responses, but sensors distributed in the natural environment require power for operation. MFCs can possibly be used to power such devices, particularly in river and deep water environments where it is difficult to routinely access the system to replace batteries. Sediment fuel cells are being developed to monitor environmental systems such as creeks, rivers, and the ocean. Power for these devices can be provided by organic matter in the sediments. The high salinity of the seawater provides good ion conductivity between the electrodes, and the organic matter needed by bacteria to produce electricity is already in the sediments. Power densities are low in sediment fuel cells because of both the low organic matter concentrations [8].

MATERIALS AND METHODOLOGY

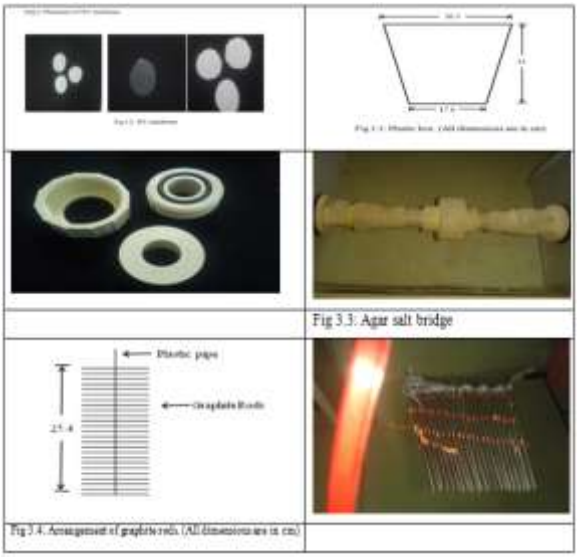
Double Chambered (MFC) Microbial Fuel Cell have been fabricated for the treatment of domestic wastewater.

Microbial Fuel Cell (MFC): Materials used For the fabrication of MFC

Various materials used for the construction of MFCs were as follows: Two Non-Reactive Plastic Boxes of Two liter capacity, TFC Membrane, Potassium chloride, Pencil Leads, Copper Wire, PVC Pipe-3.81 cm diameter, Nipple- 3.81 cm diameter, Adaptor-

3.81 cm diameter, Sealants.

Construction of Microbial Fuel Cells: Step 1: Selection of anode and cathode chamber material: Non-reactive, non-conductive and non-biodegradable plastic boxes were selected as anode and cathode chambers and are as shown in Fig 3.1. The dimensions of plastic boxes are 17.8 x 20.3 x 33 cm.



In MFC-1, there was no cathode chamber. Instead, the graphite rods from pencils have been placed on the agar salt bridge and the copper wire was wound on it. This acted as cathode for MFC-1. The oxygen in air would help in accepting the electrons from anode chamber. Hole was drilled on top of anode chamber so that plastic pipe containing the graphite rods can pierce through the hole. In MFC-2, holes were drilled on top of anode and cathode chambers so that the plastic pipe containing the graphite rods can pierce through the hole. For anode chamber care was taken to avoid entry of air from atmosphere by air tight seal.

Step 4: Assembling of Microbial Fuel Cell: The assembled electrodes were placed into the anode and cathode chambers. A circular groove was made at the center of plastic boxes. Nipple had been placed tightly in the already made circular groove in such a way that there were no leakages. For MFC-2, one end of the PVC pipe containing agar salt had been fitted into the nipple of anode chamber and the other end of the PVC pipe was fitted into the nipple of cathode chamber as shown in the figure 3.4.

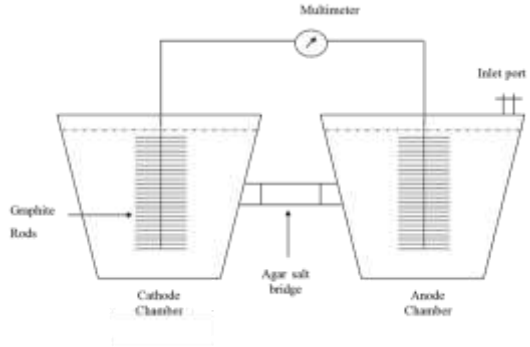


Fig 3.5: Double chambered MFC (MFC-2)

Fig 3.6: Generation of current using MFC 2

ANALYSIS OF WASTWATER AND CURRENT GENERATION

Biological Oxygen Demand: Microorganisms such as bacteria are responsible for decomposing organic matter. Organic matter such as dead plants, leaves, grass clippings, manure, sewage, food waste is present in wastewater, the aerobic bacteria will start the oxidation of these wastes

$$DO = \frac{\text{Burette Reading} \times \text{Normality of titrant} \times \text{Equivalent weight of } O_2\ (8) \times 1000}{200} \quad \text{--- (3.1)}$$

Biological Oxygen Demand was calculated using the formula given below

Initial DO of diluted wastewater sample = So

DO at the end of 3 days for diluted wastewater sample = S3

Initial DO of distilled water (blank) = Do

DO at the end of 3 days of distilled water (blank)= D3

BOD3 of the sample (mg/L) = (Initial DO – Final DO) x Dilution ratio --- (3.2)

$$BOD = (S_o - S_3) - (D_o - D_3) \times \frac{\text{Volume of BOD bottle 300 ml}}{\text{ml of sample taken in BOD bottle}} \quad \text{--- (3.3)}$$

Chemical Oxygen Demand: Chemical oxygen demand (COD) is the oxygen required for chemical oxidation of biodegradable organics (BO), non-biodegradable organics (NBO) & inorganic impurities by strong oxidizing agents like Potassium Dichromate (K2Cr2O7), Potassium Permanganate (KMnO4) or Potassium Chromate (K2CrO4) under acidic conditions.

COD was calculated using the formula given below

$$\text{COD in mg/L} = \frac{(A - B) \times \text{Normality of Titrant} \times \text{Eq.wt. of } O_2\ (8) \times 1000}{\text{Quantity of sample taken (20 ml)}} \quad \text{--- (3.5)}$$

Total solids (TS)

An evaporating dish/gooch crucible (oven dried) was taken and the initial weight was noted as W1 grams. 100 ml of sample from the reactor was taken after every 24 hrs in a crucible and was placed on a burner. The wastewater was allowed to evaporate completely and was cooled in a dessicator. The final weight was noted as W2 grams.

The amount of total solids was estimated using the formula:

$$\text{Total solids in (mg/L)} = \frac{(W_2 - W_1) \times 10^6}{\text{ml of sample taken}} \quad \text{--- (3.6)}$$

Dissolved Solids (DS)

An evaporating dish/gooch crucible (oven dried) was taken and the initial weight was noted as W1 grams. The dish was filled with 100 ml of wastewater sample after filtering it through the filter paper and was placed on a burner. The wastewater was allowed to evaporate completely and was cooled it in desiccator. The final weight was noted as W2 grams.

The amount of dissolved solids was estimated using the formula:

$$\text{Dissolved solids (mg/L)} = \frac{(W_2 - W_1) \times 10^6}{\text{ml of sample taken}} \quad \text{--- (3.7)}$$

Suspended Solids (SS)

Suspended solids was calculated using the formula given below

Suspended Solids (mg/L) = Total Solids (TS) – Dissolved Solids (TDS) --- (3.8)

pH

The pH value of water is defined as the log of reciprocal of hydrogen ion concentration in water. Sorensen gave the expression for pH in the year 1909.

$$pH = \log_{10} (1/ H^+) \quad \text{--- (3.9)}$$

Conductivity

Electrical or specific conductivity is the measure of capacity of a solution to carry an electric current, therefore a measure of the water's ionic activity and content.

Conductance (mho) = 1/ Resistance (ohm) The unit for Conductance is mho or Siemen (S).

Chlorides

Small amounts of chlorides are required for normal cell functions in plant and animal life. Chlorides are found in all natural waters at greatly varying concentration depending on the geochemical conditions.

Chloride (mg/L) = (A - B) x N of titrant ($AgNO_3$) x 35.46 (Eq. wt of Cl^-) x1000x D.F

Analyses of Current and Voltage

The voltage (V) and Current (I) in the MFC circuit was monitored at 24 hour intervals using a multi meter (UNI-T ®, Model Number- DT830D) (Kim *et al.*, 2005).

Power Density were calculated using the formula

Power Density = (Current x Voltage) / (Surface area of anode) --- (3.11)

RESULTS AND DISCUSSION

Sl. No.	Constituents	Typical ranges
1	pH	5.8
2	Chloride	453.884 mg/lt
3	Total Solids	1750 mg/lt
4	Dissolved Solids	1240 mg/lt
5	Suspended Solids	510 mg/lt
6	Conductivity	0.64 mho
7	COD	1930 mg/lt
8	BOD @ 23 □	500 mg/lt

Table 4.2: For the 15th day after collecting from the MFC chamber

Sl. No.	Constituent	Typical ranges
1	pH	7.4
2	Chloride	250.9 mg/lt
3	Total Solids	1095 mg/lt
4	Dissolved Solids	930 mg/lt
5	Suspended Solids	165 mg/lt
6	Conductivity	0.42 mho
7	COD	1600 mg/lt
8	BOD @ 23 □	285 mg/lt

Table 4.1: For the first day before adding the wastewater for MFC snchamber

Table 4.3: Generation of electricity in MFC method

Dates	Days	Current in µA
20-04-2017	1	19
21-04-2017	2	22
22-04-2017	3	30
23-04-2017	4	37
24-04-2017	5	47
25-04-2017	6	55
26-04-2017	7	64
27-04-2017	8	78
28-04-2017	9	85
29-04-2017	10	144
30-04-2017	11	158
01-05-2017	12	167
02-05-2017	13	198
03-05-2017	14	202
04-05-2017	15	195

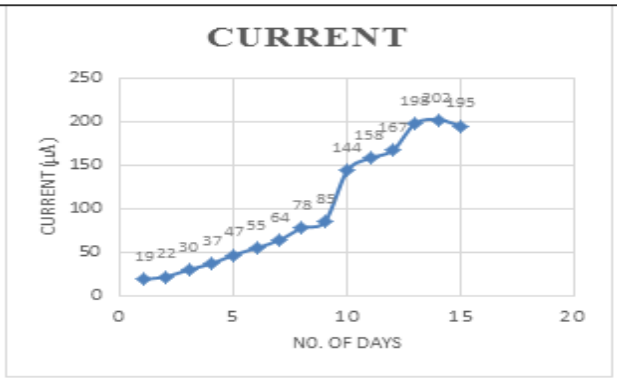


Fig 4.1: Graph of Current (µA) generated in MF

Dates	Days	COD removal (mg/lt)
20-04-2017	1	1930
21-04-2017	2	1899
22-04-2017	3	1885
23-04-2017	4	1869
24-04-2017	5	1864
25-04-2017	6	1786
26-04-2017	7	1742
27-04-2017	8	1702
28-04-2017	9	1698
29-04-2017	10	1659
30-04-2017	11	1650
01-05-2017	12	1646
02-05-2017	13	1628
03-05-2017	14	1600
04-05-2017	15	1597

Table 4.4: Removal of COD in wastewater treatment for 24 hrs

Dates	Days	BOD removal (mg/lt)
20-04-2017	1	
21-04-2017	2	
22-04-2017	3	
23-04-2017	4	
24-04-2017	5	500
25-04-2017	6	
26-04-2017	7	
27-04-2017	8	
28-04-2017	9	
29-04-2017	10	395
30-04-2017	11	
01-05-2017	12	
02-05-2017	13	
03-05-2017	14	
04-05-2017	15	285

Table 4.5: Removal of BOD level in wastewater treatment @23°C

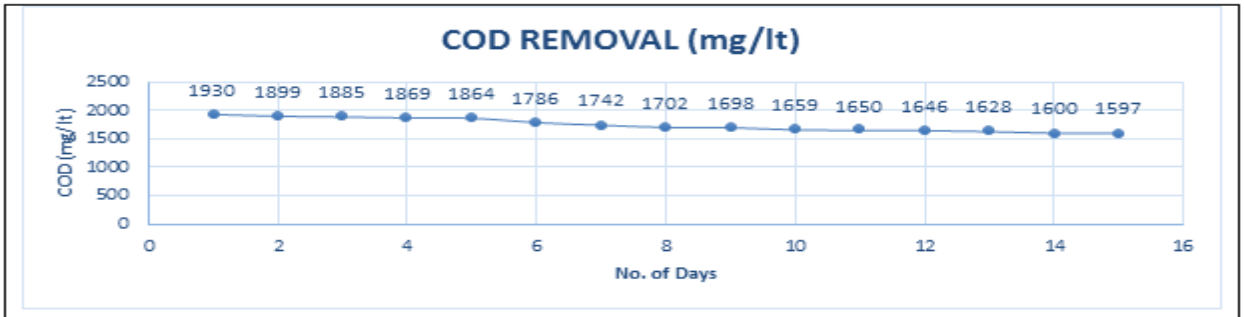


Fig 4.2: Graph of COD removal for 24 hrs

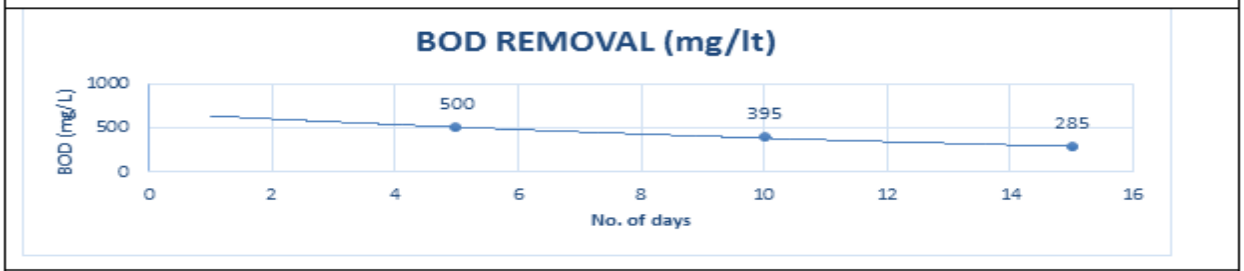


Fig 4.3: Graph of BOD removal @ 23□

CONCLUSIONS

The results of the studies demonstrate that MFC processes were able to treat spent wast successfully. The conclusions drawn from the studies are as follows:

1. MFC-1 and MFC-2 showed more or less similar behavior having maximum removal of COD-64%, TS- 45% and DS-48% at the feed concentration of 1600 mg COD/L during spent wash treatment.
2. MFC-1 produced maximum current of 145 µA , at the feed concentration of 1600 mg COD/L.
3. MFC-2 produced maximum current of 202 µA, at the feed concentration of 1600 mg COD/L.
4. Average power density of 100.51 mW/m2 was observed in MFC-2 and 72.15 mW/m2 MFC-1 at the feed concentration of 1600 mg COD/L.
5. MFC-2 proves to be better for power generation when compared with MFC-1 due to the fact that cathode in single chambered MFC (MFC-1) is exposed to air.
6. The optimal feed concentration for MFC-1 and MFC-2 were 1600 mg COD/L.
7. The performance of MFC-2 deteriorated at the feed concentration of 1600 mg/L COD and 9100 mg/L for MFC-1.
8. The optimal effluent from MFC-1 and MFC-2 were obtained 70% and 85% COD removal respectively as against 64% for usual MFC-1 as noted in (1) above.

Discussion: Further research is essential in order to gain more knowledge, especially with respect to micro-organisms involved in the treatment of spent wash.

1. Study on micro-organisms capable of utilizing high organic content has to be carried out.
2. Genetic studies will provide more insight to the gene structure and function responsible for the treatment of spent wash.
3. Experiments using various electrode materials, electrode arrangement, electrode size, separator and catholyte have to be carried out.
4. Pilot scale, continuous flow MFCs can be constructed and investigated for the retention time, treatment efficacy and power generation. The effect of MFCs connected in series on treatment efficiency can be studied.
5. MFCs may be modified and analyzed for the recovery of hydrogen gas. Also MFCs may be modified and studied for bioremediation and environmental sensors.
6. Rotational speed and percentage submergence of RBC may be varied and the treatment efficiency can be studied.
7. A multi-stage RBC can be constructed and analyzed for the treatment efficiency of spent wash.

8. Pilot scale studies may be conducted to assess the applicability of RBC for treatment of spent wash.
9. Cost analysis of both aerobic and anaerobic microbial treatment may be carried out to assess the economy of processes.

I sincerely thank Dr. N KRISHNAMURTHY, Visiting Professor, Department of Civil Engineering, SET-JU, for accepting me as his student and giving me an opportunity to work on this topic. I am grateful for his support and guidance that has helped me to expand my horizon of thought and expression and successful completion of my work.

REFERENCES

[1] Bruce. E. Logan, "Microbial Fuel Cells", John Wiley & Sons Inc., New Jersey, 2008.

[2] Mohan S. V, Raghavulu S. V, Srikanth S and Sarma P. N:, "Bioelectricity production by mediatorless microbial fuel cell under acidophilic condition using wastewater as substrate: Influence of substrate loading rate", Current Science, Vol. 92, No. 12, 2007, pp 1720-1726.

[3] Abhilasha S. M and Sharma V. N:, "Bioelectricity production from various wastewaters through microbial fuel cell technology", Journal of Biochemical Technology, Vol. 2, No. 1, 2009, pp133-137.

[4] Ann D. Christy, Cellulose Conversion to Electricity in Microbial Fuel Cells: Challenges and Constraints, May 29, 2008, Microbial Fuel Cells First International Symposium.

[5] Du Z, Li H and Gu T, "A state of the art review on microbial fuel cells: A promising technology for wastewater treatment and bio energy", Biotechnology Advances, Vol. 25, 2007, pp 464–482.

[6] Logan B. E, Aelterman P, Hamelers B, Rozendal R, Schroder U, Keller J, Freguiac S. Verstraete W and Rabaey K, "Microbial fuel cells: methodology and technology", Environmental Science and Technology, Vol. 40, No. 17, 2006, pp 5181-5192.

[7] Logan B. E and Regan J. M, "Microbial fuel cells - challenges and applications", Environmental Science and Technology, Vol. 40, 2006, pp 5172-5180.

[8] Park D. H and Zeikus J. G, " Electricity Generation in Microbial Fuel Cells Using Neutral Red as an Electronophore", Applied and Environmental Microbiology, Vol. 66, No. 4, 2000, pp 1292–1297.

[9] Rabaey K, Boon N, Siciliano S. D, Verhaege M and Verstraete W, "Biofuel Cells Select for Microbial Consortia That Self-Mediate Electron Transfer", Applied and Environmental Microbiology, Vol. 70, No.9, 2004, pp 5373-5382.

[10] Niessen J, Schroder U and Scholz F, "Exploiting complex carbohydrates for microbial electricity generation – a bacterial fuel cell operating on starch", Electrochemistry Communications, Vol. 6, 2004, pp 955–958.

[11] Min B, Cheng S and Logan B. E, "Electricity generation using membrane and salt bridge microbial fuel cells", Water Research, Vol. 39, 2005, pp 1675–1686.

[12] Allison Nicole Rhoads, "A microbial fuel cell using biomineralized manganese oxides as a cathodic reactant", MS thesis, 2005, Montana State Univeristy, Bozeman, Montana.

[13] Chaudhuri S. K and Lovely D. R, "Electricity generation by direct oxidation of glucose in mediatorless Microbial Fuel cell", Nature Biotechnology, 2003.

[14] Karmakar S, Kundu K and Kundu S, "Design and Development of Microbial Fuel cells", Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology, A. Mendez- Vilas (Ed), 2010, pp 1029-1034.

[15] Logan B.E, "Simultaneous wastewater treatment and biological electricity generation", Water Science & Technology, Vol. 52, 2005, pp 31–37.

[16] Rabaey K, Lissens G, Siciliano S. D and Verstraete W, "A microbial fuel cell capable of converting glucose to electricity at high rate and efficiency", Biotechnology Letters, Vol. 25, 2003, pp 1531–1535.

[17] Borole A. P, O'Neill H, Tsouris C, and Cesar S, "A microbial fuel cell operating at low pH using the acidophile Acidiphilium cryptum ", Biotechnology Letters, Vol. 30, 2008, pp 1367–1372.