

The Design of Microbial fuel cell (MFC)

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Abstract

The Microbial fuel cell, a technology that utilises the waste water to generate electricity with the help of action of microorganisms is widely being studied on as an alternative source to generate and fulfil the demand for electricity around the globe. The Design Prepared and tested by the Students of Department of Biotechnology, KIT's College of Engineering not only overcomes the limitations of the existing design but also provides greater output and a commercial design of the MFC. The main problems faced in the existing designs are low voltage and current production, corrosion, fluctuating current and voltage, non-commercial design and the results are not definitely reproducible. These problems are resolved by us by using novel metallic materials which helps to reduce some of the issues faced like fluctuating current and voltage and reproducibility of the results and irradiates most of them like are low voltage and current production, corrosion and non-commercial design. Since the Proposed design is commercial, with further and more detailed study it can be installed in industries that produce Microbial Waste water as a by-product to generate electricity and reuse the waste water for other processes after treatment.

Introduction to the Microbial fuel cell (MFC)

Introduction

Microbial fuel cell (MFC) is the biological fuel cell that utilizes the by-products of the biological metabolic pathways of the organisms to generate electricity. Organisms undergo Glycolysis, Citric acid cycle and ETC which generates e^- and H^+ ions that are used as electrons and protons for generation of electricity. But these ions are produced in very low concentrations and are inside the cells, and these ions migrate outside the cell body by natural process called membrane

transport. This phenomenon takes place multiple times inside the cell within span of seconds, but the concentration of the ions is not high enough for the electrodes to detect or adsorb it efficiently. Besides these ions are in organic form which makes it very difficult to adsorb it.

History

The conversion of biological waste water into electricity by the action of microorganisms was first hypothesized in the late 1870's. The studies conducted then were to understand the process of generation of electricity by microbial action. It was conformed later in late 1930's that this was as a result of H^+ and e^- liberated by the organism as a by-product during their various metabolic pathways and multiplication process but no results of the same were observed or recorded.

This technology gained fame in 1945 when a design for generation of electricity was proposed and generation of 0.0002 milliamp current was generated as a result of which this technology was considered to be alternative for the electricity generation. He used two containers, made of plastic were one consisted of waste water and other of Distilled water. These two chambers were connected using a potassium salt bridge which acted as Electron Bridge for transport of ions across the chambers and to the electrodes. He used copper and carbon as anode and cathode respectively in his design.

Various designs were there after suggested that showed promising results and new age's high-end devices helped understand the technology better. The best results were registered by using Copper as the anode and graphite as cathode. The results achieved were close to 0.8 milliamps.

Different methods utilized for generating electricity using MFC

Since the ions produced are in organic form and are very low in concentrations, it became imperative to create a properly defined method for using these ions and implementing it in a justified design. So, there were two methods that were studied by many researchers and were finally implemented in a modified design than the pre-existing one. There are two methods that were created namely mediated and non-mediated which utilized two different designs. In case of use of mediated mechanism for generation of electricity an electron/proton carrier is used. One of the best-known mediators are dyes like

trypan blue, neutral red, etc. which are widely used in cell counting and are also implemented in this case. But the dyes are generally toxic to cells and cause cell damage or cell death and hence are used rarely. The other mediators are salt agar bridges, that transfer the ions by carrying it onto the divalent ions or the divalent ions act as ions for the electrode. This mediation method using salt bridges require the cells to be maintained at anaerobic conditions and utilize two containers. This mechanism is applied where organisms with less or no electrochemical activity are used.

In case of mediator free mechanism, the use of a semi-permeable membrane for transfer of electrons is done. This method is more efficient as this mechanism utilizes the atmospheric O_2 along with the ions available in the waste water source. This mechanism requires anaerobic conditions at anode and aerobic at cathode. This mechanism is applied where organisms with high electrochemical activity are used.

Existing design

There are two designs that exist which utilise the two different mechanisms described earlier. Each design is based as per the requirements of the mechanism, organisms used and the source of waste water.

Design I

This design consists of two different chambers connected together by a bridge consisting of potassium salt bridge or sodium salt bridge.

This design is being used for more than 2 decades where mediated mechanism for generation of electricity is used. Some changes have been made in the last decade according to requirement and improvised technology available. The design available, utilizes the salt agar bridges rather than the dyes as they are known to be toxic along with the microorganisms that are less electrochemically active.

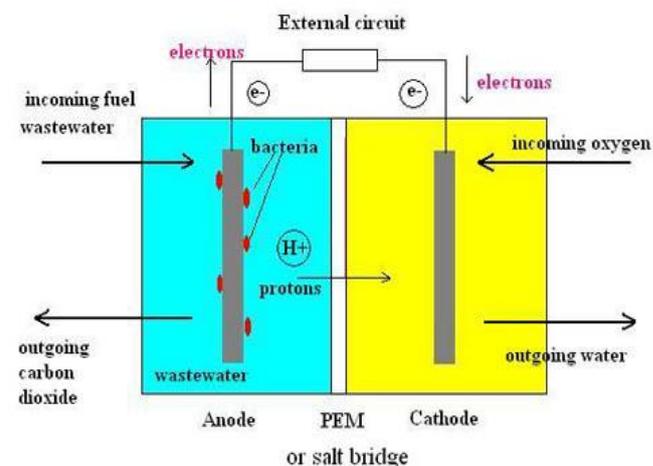
One of the containers consists of waste water or microbial rich water and other contains either aerated water or salt water or aerated waste water. The chamber consisting of waste water is maintained at an anaerobic condition, i.e. no oxygen supply is given to the container and the lids are air tight with an opening for methane and other gases produced by the organisms. The second chamber or container is constantly maintained under aerobic conditions that helps generate oxygen for aerated water or aerated waste water. These two containers or the chambers are connected with a salt- agar bridge, the composition of which is;

- 1% salt either NaCl or KCl
- 2.5% Agar

*The volume is made as per the requirement or the size of the salt-agar bridge.

Graphite is used as electrode for both anode and cathode which.

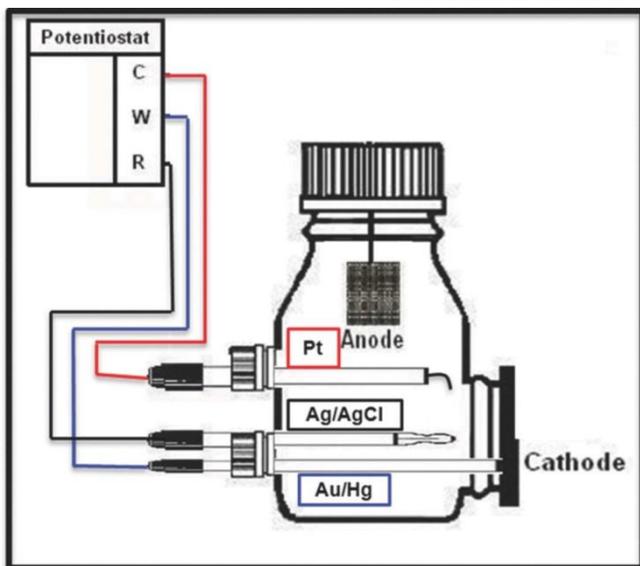
The schematic of the design I following the mediated mechanism of MFC is depicted by the fig.;



Design II

This design utilizes a single chamber where two internal chambers are created using semi permeable membrane which also mediates the transport of the electrons. This design is being used for less than decade and has proved to be more efficient than the previous design. It utilizes non-mediated mechanism of producing electricity using Waste water. As no salt bridge or dye is used as an electron carrier and existence of single chamber, transport of electrons is more efficient and loss of ions is very less. The design requires the anodic area which is separated by membrane to be maintained at anaerobic conditions whereas the cathode is partially immersed into the fuel cell so as to expose some part of it to the atmospheric oxygen. The anode used in this method is copper (Cu) or graphite whereas the cathode used is graphite with no other metal as exception. The entire container is made of polystyrene and the anodic metal, copper is completely immersed into the cell with a wire connected for output of current.

A schematic of the Design II following non-mediated mechanism of MFC is depicted by the fig.;

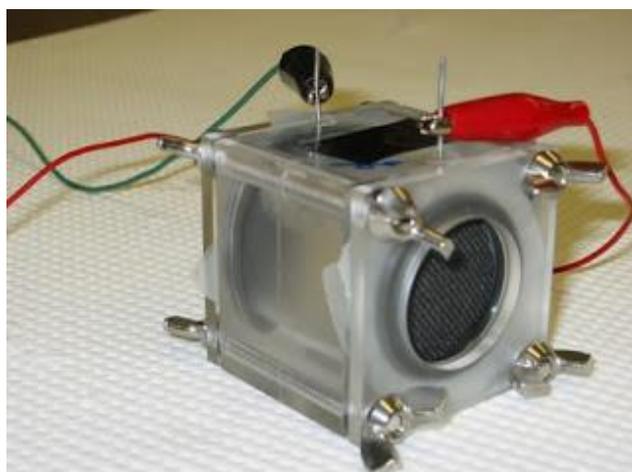


fabrication and the material of construction for cathode was decided.

In the following prototypes, all being single cylindrical chambered, the chamber itself acted as a cathode where anaerobic conditions were maintained and the anodes were inserted into the lid of the cylinder. Multiple anodes were inserted so as to produce maximum surface area contact with waste water and increase the output. The total number of electrodes were decided by the formula;

$$\text{No. of anodes required} = \frac{\text{total surface area of cathode in contact with waste water}}{\text{the total surface area of single anode}}$$

In the below mentioned prototypes, only the material of construction for cathode varies whereas the anodic material i.e. carbon remains same with the dimensions as 25mmx140mm and “230mmx25mm”.



Prototype I

The material of construction used was brass with the total capacity of the container being 1.6 litre whereas the volume utilised was 1 litre. The dimensions of the container were “80mmx80mm” and the total anodes inserted in the lid were 4. The results achieved are as mentioned in the table 1

Prototype II

The material of construction used was copper with the total capacity of the container being 1.6 litre whereas the volume utilised was 1 litre. The dimensions of the container were “80mmx80mm” and the total anodes inserted in the lid were 4. The results achieved were as mentioned in the table 1

Methods and materials for the designed prototypes of MFC

The active prototype is a single chambered design that uses the chamber itself as an electrode (cathode) which is made of metal and carbon as other electrode (anode). The design works on the non-mediated mechanism of MFC.

Most of the metals are an essential part of the organism’s nutrient requirement which when received in higher concentration than required, cell death occurs. Metals are highly oxidised by the organisms which results in the metals getting corroded easily over period of time. Hence choice of material for the chamber was decided on the basis of trial and error by using five different metals for designing the chamber or the cathodic area of the MFC and the output from all five prototypes were compared in regards of output, corrosion rate, efficiency, area of containers, working volume, and cost of

Prototype III

The material of construction used was iron with the total capacity of the container being 1.6 litre whereas the volume utilised was 1 litre. The dimensions of the container were “80mmx80mm” and the total anodes inserted in the lid were 6. The results achieved were as mentioned in the table 1

Prototype IV

The material of construction used was stainless steel with the total capacity of the container being 2.5 litre whereas the volume utilised was 2 litre. The dimensions of the container were “140mmx140mm” and the total anodes inserted in the lid were 7. The results achieved were as mentioned in the table 1



Prototype IV in working conditions.

From: 07/01/2017-9/01/2017

Prototype V

The material of construction used was Aluminium with the total capacity of the container being 7.2 litres whereas the volume utilised was 6 litres. The

dimensions of the container were “250mmx220mm” and the total anodes inserted in the lid were 10. The results achieved were as mentioned in the table 1



Prototype V



Results of prototype V

From 10/12/2017 – 15/12/2017



Constant Voltage reading of prototype V

From 12/01/2017 - 14/01/2017

Results and Discussions:

The results of prototype I to Prototype V were used to finalise the material of constructions for the cathode which is “Aluminium”. At the same time the anodic material was found to generate powdered dust which resulted in reduction of the output and the cross-sectional area of the anode itself.

Hence, the material of construction for the anode was decided to be changed in the future prototypes. With the studies conducted on this design, a better design was made and is under fabrication process as on today. The results recorded from the five prototypes are described in the table below.

Material of cathode	Working volume	No. of anodes used	Voltage reading (mV)	Constant VR (mV)	Time in hrs. for constant reading	Costing Rs.
Brass	1.00	4	6.12-8.8	6.8	4	1000
Copper	1.00	4	16.25-24.8	18.9	36+	1025
Iron	1.00	6	18.11-26	17.5	36+	1250
Stainless steel	2.00	7	10.25-21.22	15.9	2	1100
Aluminium	6	10	350-490	350	36+	1450

Table 1

With reference to the above results, we found that although the materials copper and iron produce good voltage, as being a good conductor, they are heavily affected by corrosion as a result of which the wear and tear of the apparatus is very high and replacement of chamber is required frequently and hence it was rejected as MOC for Cathode. Stainless steel with 20% chromium produced good electricity but failed to give constant reading. Hence, although having good resistance to corrosion, it was not accepted as a MOC for cathode.

The MOC used for the fifth prototype i.e. Aluminium, produced almost as good results as the copper along with showing good resistance to corrosion and producing a constant voltage for more than 36 hours, was finalised as a MOC for the cathode.

Conclusion

Cathodic MOC Aluminium give the best results among the other Cathodic materials tested during the experimentation giving a maximum voltage of 480 mV and a constant voltage of 350 mV for 36+ hours. Hence aluminium was finalised as cathodic material for the newly developed design for further enhancing the output. The process optimisation was carried out simultaneously by using a sparger to provide oxygen to the container during different trials. The anodic MOC, was found to be unfit for the process as it produced powered dust reducing the efficiency and “Graphite” was selected as a new MOC for anode to be used in future design. The process is currently being further optimized for attaining better output from same volume of waste water i.e. 6 litre which is currently used as a standard for comparison and optimization of both design and process.

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