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Research Article

Impact of Salt Concentration on Electricity Production in Microbial Hydrogen Based Salt Bridge Fuel Cells

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ABSTRACT
The need for alternate eco-friendly fuel is growing rapidly with depletion of non-renewable energy resources. Microbial fuel cells (MFCs) represent a new form of renewable energy by converting organic matter into electricity with the help of bacteria already present in wastewater, while simultaneously treating the wastewater. In the present study, varied salt concentrations of a salt bridge in a novel MFC design were analyzed. In the optimum salt concentration, the MFC produced a maximum current of 256µa. The results obtained were helpful in designing an optimized MFC. Cost reduction and increased yield are central to successful commercial employment of MFC.

Key Words: Salt bridge, Microbial fuel cell, Air cathode, Alternate fuel.

INTRODUCTION
Energy crisis in India is increasing every year, as there is continued hike in the prices of fuels and also due to depletion of fossil fuels to a greater extent (Rakesh Reddy *et. al.* 2007). The need for an alternate fuel has ignited extensive research in identifying a potential, cheap and renewable source for energy production. "The building of a sustainable society will require reduction of dependency on fossil fuels and lowering of the amount of pollution that is generated. Waste treatment is an area in which these two goals can be addressed simultaneously. As a result, there has been a paradigm shift recently, from disposing of waste to using it" (Chadhury and Lovely, 2003). Waste from household, industries and agriculture are ideal candidates of substrates for energy generation since they contain high levels of easily degradable organic material. The energy crisis in India has reached an alarming stage requiring immediate attention. Most of India's oil refineries are old and require huge capital investment to meet global standards, hence necessitating the urgent need for a viable alternate fuel (Venkata Mohan *et al.* 2007).

Microbial Fuel Cell (MFC) is a device designed for a novel purpose of electricity generation in the process of waste water treatment. Hence, it is an ideal solution for sustainable non renewable source of energy. MFC can be best defined as a fuel cell where microbes act as catalyst in degrading the organic content to generate electricity. MFCs operate by directly capturing the electrons generated when electrochemically active bacteria breakdown organic substrates. MFCs have gained significance in the last few decades due to their capability to produce energy, either as electricity or through hydrogen production, from renewable resources such as sewage waste and other similar waste sources. Microbial Fuel Cell (MFC) usually consists of two chambers, one anaerobic (anode) and the other aerobic (cathode). In the anaerobic chamber, substrate is oxidized by bacteria and the electrons transferred to the anode either by an exogenous electron carrier, or mediator (such as potassium ferric cyanide, thionine, or neutral red) (Delaney *et al*., 1984; Park and Zeikus, 2000; Rabaey *et al*., 2004), or directly from the bacterial respiratory enzyme to the electrode. In the latter case, the MFC is known as a mediator-less MFC (Kim *et al.*, 1999, 2002; Bond and Lovley, 2003; Gil *et al*., 2003; Chaudhuri and Lovley, 2003; Rabaey *et al*., 2003; Jang *et al*., 2004). The anaerobic chamber is connected internally to the aerobic chamber by a proton-conducting material (e.g. Salt bridge, membrane etc.) and externally by a wire that completes the circuit. In the aerobic chamber, electrons that pass along the circuit combine with protons and oxygen to form water. MFCs requiring exogenous mediators have limited practical applications because chemicals used as mediators are expensive and toxic to bacteria (Bond *et al.*, 2002; Bond and Lovley, 2003; Gil *et al*., 2003; Jang *et al*., 2004). Mediator-less mfcs have the potential to produce electricity from anaerobic sediments for marine devices (Reimers *et al*., 2001; Bond and Lovley, 2003) and electricity from sewage (Gil *et al*., 2003; Liu *et al*., 2004). Mediator-less MFCs have only recently been developed, and therefore the factors that affect optimum operation, such as the bacteria used in the system, the type of proton conductive material, and the system configuration, are not well understood. Bacteria in mediator-less MFCs typically have electrochemically active redox enzymes such as cytochromes on their outer membrane that can transfer electrons to external materials.

In normal microbial catabolism, a substrate such as a carbohydrate is oxidized initially without participation of oxygen when its electrons are released by enzymatic reactions. The electrons are stored as intermediates which are used in redox reactions: as a result, energy is released and is used to fuel further reactions for the living cell for maintenance and growth via bio-synthetic reactions. In microbial fuel-cells, anaerobic metabolism must be promoted at the anode in order to convert organic matter to electricity in an effective manner. Separating the microorganisms from the source of oxygen in a microbial fuel cell intercepts the flow of electrons to oxygen that microorganisms would catalyze if oxygen were available. This facilitates the transfer of electrons to the anode. Thus, this flow of electrons produces a potential difference generating electricity. Various design modifications employed throughout these years have given significant yields and opened up a new frontier in the multidisciplinary MFC research. This paper focuses on the study involving various concentrations of salt in salt bridge of a mediator-less MFC.

MATERIALS AND METHODS

Substrate Collection-Wastewater

Waste water which served as the substrate of the MFC was collected from SRM University-Sewage Treatment Plant (100000 cubic meter capacity). The source of the plant included wastes from hostels, toiletries etc. The inlet of the lamellar filter served as the substrate. This phase was selected so as to avoid the coarse and large particles found in raw waste water. The natural microbial consortium present in the waste water was used in the study.

MFC Components

Microbial Fuel Cell majorly constitutes Electrodes, Anodic and Cathodic Chamber and Salt Bridge. The Anodic chamber is an anaerobic chamber, which holds the substrate and the biocatalyst-Microorganisms. The cathodic chamber was maintained in aerobic condition. The salt bridge that forms a bridge between cathodic and anodic chamber facilitates the transfer of ions (protons). Carbon electrodes were used as anode and cathode.

MFC Construction

Salt Bridge-Immersed-Air Cathode MFC (SBIAC-MFC) consisted of a plastic container of capacity 2 liters which served as the anodic chamber (Fig 1). The anodic compartment contained the substrate and the carbon electrode (anode ~85cm^2). A similar carbon electrode which was used as anode served as cathode. The salt bridge served as an electrolyte in transfer of protons. The cathode was immersed in the salt bridge when it was in molten stage to ensure complete surface contact. The 50% cathode surface was exposed to atmospheric air. Salt bridge employed here was made with 5M NaCl and 10% Agar. The salt bridge was cast in a PVC pipe (12 cm X 2cm). Proper precautions were taken to ensure complete sealing of anodic chamber by means of applying epoxy and wax to ensure anaerobic conditions. The external circuit was completed by connecting a resistor (270 Ω) between the two leads of the electrodes.

MFC Operation

Substrate (waste water) was added in the anodic chamber and was completely sealed to maintain anaerobic condition. The fuel cell was sparged with CO_2 before sealing completely to ensure complete removal of oxygen. A batch configuration was employed and readings were taken for a period of 21 days. The readings were taken on a daily basis.

Optimization of Salt in Salt Bridge

Various Strong Salts for Salt Bridge Preparation: Two well known strong salts Sodium Chloride (nacl) and Potassium Chloride (kcl) were tested for efficacy to transport H^+ ions in the salt bridge. Two cells (SBIAC-MFC) with wastewater as substrate were setup with respective strong salt used for salt bridge fabrication (Fig 2). The cells were run for 21 days and readings were noted at regular intervals.

Molar Concentration of Salt: Salt bridges were prepared with various Molar concentrations 1, 3, 5, 7, 9M nacl and with agar concentration of 10%. The five fuel cells (SBIAC-MFC) with wastewater as substrate were setup with above mentioned varying salt concentrations in salt bridge (Fig 3). The fuel cells were run for 21 days and readings were noted at regular intervals.

Measurement of Output:

The output of the MFC was expressed by means of current (µa). For this purpose multimeter was used and was calibrated each time before use. Resistance of 270Ω was employed in all experiments and hence calculations were based on it. Readings from the multimeter were noted only after a steady and constant value was obtained, which took 3-4 hours. The multimeter was connected in series with MFC when measuring current.

RESULTS AND DISCUSSION

Optimization of Salt in Salt Bridge

Analysis of Various Strong Salts: In the experiment conducted by employing NaCl and KCl based salt bridge, the maximum current produced was 165 µa and 167 µa respectively.

Molar Concentration of Salt: The concentration of salt in salt bridge is highly critical in transporting the hydrogen ions. Maximum current of 256 µa was obtained in 1000 mm concentration of NaCl in Salt Bridge.

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Figure 1. SBIAC MFC

Figure 2. NaCl and KCl SBIAC MFC

Figure 3. SBIAC MFC with 1, 3, 5, 7, 9M Salt Bridge

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Table 1. Maximum current obtained with NaCl and KCl

Analysis of Various Salts	Maximum Current (μa)
KCl	167
NaCl	165

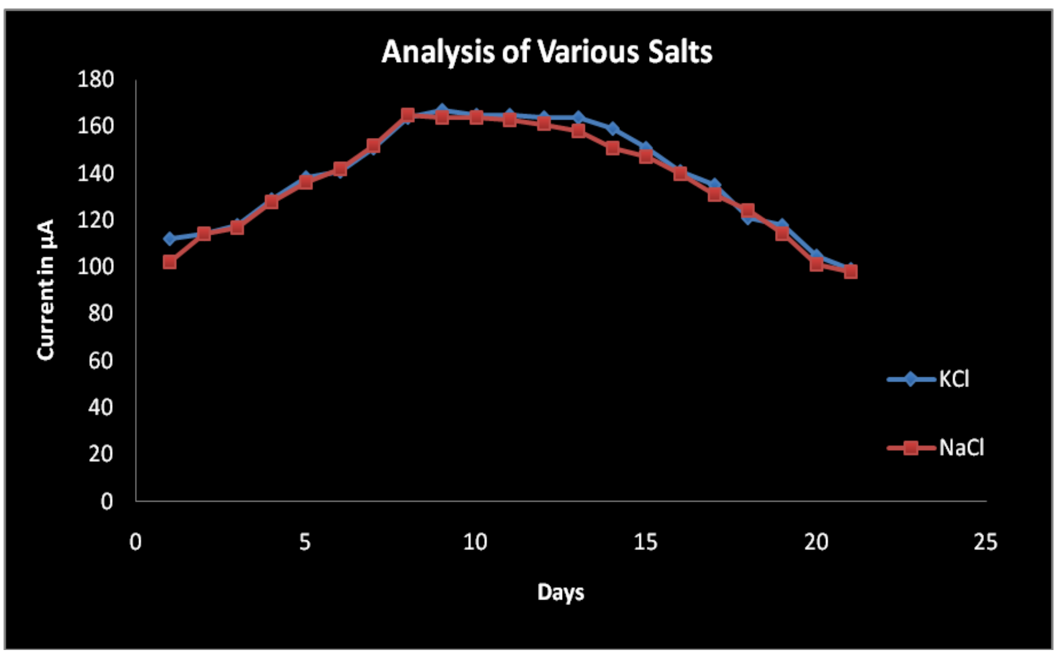

Figure 4. Graph representing current generated in SBAIC-MFC with various salts with respect to time (days)

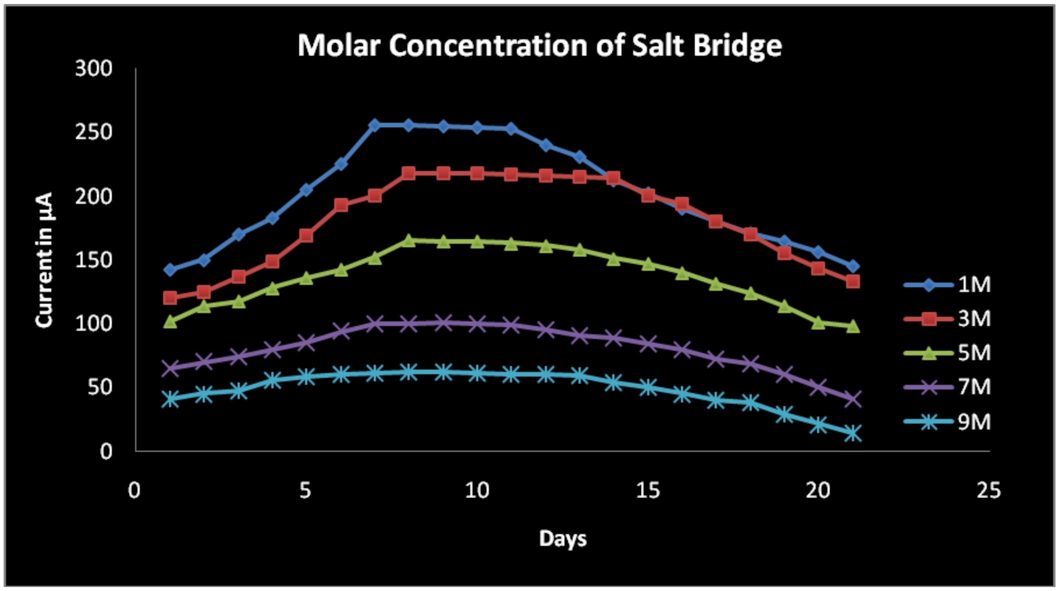

Figure 5. Graph representing current generated in various molar concentration of SBAIC-MFC with respect to time (days)

Table 2. Maximum current obtained with varied Molar Concentrations of NaCl in Salt Bridge

Molar Concentration of Salt Bridge	Maximum Current (µa)
1M	256
3M	218
5M	165
7M	100
9M	62

The design of a Microbial Fuel Cell is highly critical and needs best optimization. The Two Chamber MFC used in primitive studies was replaced by the Salt bridge immersed air cathode MFC (SBIAC-MFC). The two chamber system has a disadvantage of increased internal resistance and whereas in the SBIAC-MFC, the internal resistance is significantly lowered. SBIAC-MFC is a novel design that increased the cathode potential with increased oxygen availability and enhanced surface area contact with the salt bridge. Large scale mfcs can basically employ SBIAC-MFC as it increases the output and also decreases the task of concern in chamber design, space and thereby cost. As the main engineering application for mfcs will likely be electricity production from wastewater, minimizing the concern over the design, will be important for the operation of MFC systems. In the primitive systems, air was bubbled into the water to provide oxygen at the cathode (aqueous cathode), but the solubility of oxygen in water was observed to be low, limiting the performance of the cathode. Substantially, higher power densities can be achieved in systems with lower internal resistance and air cathodes. With oxygen as the electron acceptor at the cathode, the main technical challenge in improving power generation is to create a system architecture that minimizes resistance but, at the same time, allows for continuous flow of oxygen through the system.

The study involved Salt Bridge which is the most economical component in the SBIAC-MFC. For the first part of the study, KCl and NaCl were compared for use as strong salt in salt bridge. The study clearly showed that there was not much difference between these salts in terms of current output. Molar concentration of salt is critical since the transfer of protons through the salt bridge is facilitated by the dissociated ions in it. The experiments showed that, with increase in molar concentration the current decreases. Optimum results were obtained for salt bridge fabricated using 1M nacl. It produced a maximum current of 256µa. The membrane based MFC needs membrane replacement due to fouling which decreases the lifetime of its use in MFC. The salt bridge MFC also needs to be studied extensively, as the literature available on salt bridge based MFC is not sufficient. Bio-prospecting to enrich consortia that increases power could improve MFC performance by a variety of mechanisms, including greater rates of electron transfer with specific substrates, and electron transfer to the anode by bacteria distant from it in the bio-film. However, the magnitude of electron transfer should be higher and earlier than the respiratory chain. Identifying a potential substrate that is enormously available, low cost, high energy yields and renewable for alternate energy production is imperative. Wastes with high organic content are a good candidature of choice in MFC as a substrate. Highly homogenized substrate and availability for microbial consortium can be attributed to the maximum current obtained.

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