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Impact of Salt Concentrations on Electricity Generation using Hostel Sludge Based Dual Chambered Microbial Fuel Cell

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Abstract

Electrical energy needs in Pakistan are expected to continue to rise. The use of petroleum as a source of energy still dominates, although oil reserves in Pakistan are increasingly being depleted. Therefore, there is a need to develop alternative source of sustainable energy, such as Microbial Fuel Cell (MFC). MFC shows another type of renewable energy by changing natural matter into power with the help of microbes. In the present study, varied salt concentrations of a salt bridge in novel MFC design were analyzed. Sewage sludge was utilized, which contains a lot of organic materials and is additionally one of the major sources of ecological contamination, as substrate MFC. *Saccharomyces cerverciae* sp. (44 g) was used as a biocatalyst. Methylene blue (10 ml) was used as a mediator and potassium ferricyanide (100 ml) was used as an oxidizing agent for the conversion of sewage sludge into voltage generation using lab-scale double chamber MFC. Varied salt concentrations (1M, 3M and 5M of KCl and NaCl) of salt concentrations of salt bridge in a novel MFC design were analyzed. The maximum generated voltage, current, power, power density and current density with 1M KCl were 0.451 V, 0.0451, 0.0175561 mW, 0.000226001 mW/m2, 10.5166661 μA/m2 respectively. The MFC was run for a period of 1 day and readings were noted at regular intervals. The results obtained were helpful in designing an optimized MFC.

Keywords: Salt bridge; Electrical energy; Microbial fuel cell; Sewage sludge

Introduction

Due to continuous depletion of the fossil fuels and constant increase in the fuel's price, the world is moving towards the energy catastrophe [1-3]. However, consumption of fossil fuels causes an increase in pollution level which is a major cause of global warming. So requisition of an alternate source of energy is increasing day by day which should be economical, reusable and clean [4,5]. The MFCs provide a promising technology to handle the above two problems by decomposing organic waste to using it [6,7]. For creating a practical world, we need to reduce the utilization of fossil fuels furthermore the pollutants generated. These two points could be accomplished together by treating bio-waste [8,9]. In 1911, MC Potter observed that bacteria can be used to produce electrical energy. However, insufficient research was done to advance this technology during 1911-1967. But in 1967, John Davis patents the first MFC technology and possible application and research on MFC was begun after 1990's. Most of the patent was issued in 2000's [9-11]. MFC may be best described as a bioreactor, where microbes act as biocatalyst in metabolizing the organic substances containing the organic carbon to generate electricity [12,13]. Electrons are produced by the oxidation of organic materials in which microbes act as catalyst [14,15]. The electrons thus produced are transferred to a terminal accepter such as O_2, nitrate and sulphate. These terminal electron accepters are get reduced by these electrons [16,17]. A new product is found which can leave the cells when terminal electron acceptors are diffused into the cells. However, there are some microbes specially yeast that can transfer their electrons in the outer space surrounding the cells which are accepted by the awaiting terminal electron acceptors [18,19]. These types of microbes are called exogenic and can be utilized to generate electricity within a MFC. The advantages of MFC are easily available exogenic materials which are used as substrate and microbes which act as biocatalyst [20]. It is a simple system and unlike the hydrogen fuel cells, a MFC does not require extremely synchronized division system. It is more effective than enzymatic fuel cell in harvesting electrons from transport system of microbes [21]. This MFC mainly consists of two chambers, one of the chambers, where, oxidation takes place is call anodic chamber (anode) and the other chamber where reduction takes place is called cathodic chamber (cathode) [12-15]. In the presence of oxygen, microbes oxidize organic compounds to produce CO_2 and H_2O, but if the reaction takes place in anaerobic environment then microbes decomposes organic materials to produce CO_2, while proton and electrons are produced simultaneously [22-24]. Electrons thus produced are transferred to the cathodic chamber via an external circuit while protons are transferred through salt bridge [23]. This flow of electrons generates voltages [24]. Unique design adjustments utilized these years have given huge yields and opened wild in the multidisciplinary MFC research [24,25]. The aim of this research is to take the inward assents of waste materials, like sewage sludge using double chamber MFC for electricity generation and concentrates on the study including different centralizations of salt in salt extension of an arbiter MFC. This paper focuses on the study involving various concentrations of salt in salt bridge of a mediator MFC.

Materials and Methods

Substrate collection-sewage sludge

Sewage sludge (1000 ml), which served as the substrate of the MFC was collected from the hostel of MUET Jamshoro, Pakistan.

Cathodic and anodic chamber

These chambers of the MFC were made up of plastic bottles. Two plastic bottles each of 1000 ml were used for this purpose. The

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bottle was washed with distilled water and then medium was filled in it. Methylene blue (10 ml), sewage sludge (1000 ml) as a sample and *Saccharomyces cervesiae* sp. (44 g) added to it.

Salt bridge

Salt bridge employed here was made with 5M NaCl and 10% Agar. The salt bridge was cast in a PVC pipe (12 cm × 2 cm). 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 (10 Ω) between the two leads of the electrodes.

Fabrication and operation of double chamber MFC

Salt Bridge-Immersed-Air Cathode MFC consisted of a plastic container of capacity 2 liters which served as the anodic chamber (Figure 1). The anodic compartment contained the substrate and the copper electrodes (6″ each). 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.

MFC operation

Substrate (sewage sludge), was added in anaerobic chamber (anodic chamber) and then it is sealed completely for the creation of anaerobic conditions. The MFC 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 6 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. A dual chambered MFC with sewage sludge as substrate were setup with respective strong salt used for salt bridge fabrication. The cells were run for 6 days and readings were noted at regular intervals.

Molar concentration of salt: Salt bridges were prepared with various Molar concentrations 1, 3, 5M KCl and NaCl and with agar concentration of 10%. A dual chambered MFC with sewage sludge as substrate was setup with above mentioned varying salt concentrations in salt bridge. The cells were run for 6 days and readings were noted at regular intervals.

Measurement of output: The output of the MFC was expressed by means of voltage (V). For this purpose a digital multimeter was used and was calibrated each time before use. Resistance of 10 Ω 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. The multimeter was connected in series with MFC when measuring voltage.

Results

Effect on voltage generation by variation in salts concentration

A two chamber MFC setup was adopted initially with 1M KCl solution to make the salt bridge. After that it was checked for 1M NaCl. Again KCl and NaCl were used in different concentration such as 3M and 5M for fabricating salt bridge. After comparing the results of difference KCl and NaCl concentrations, it was found that the salt bridge made up of KCl functions better than that of NaCl.

1M KCl and 1M NaCl: In this experiment, 1M KCl and 1M NaCl (Figures 2 and 3) were used to transport H^+ ions in the salt bridge. The voltage generation was recorded per twenty minutes through the whole day for the substrate sewage sludge. The maximum generated voltage obtained with 1M KCl and 1M NaCl was 0.451 V and 0.372 V (Tables 1 and 2) respectively. The MFC was run for a period of 1 day and readings were noted at regular intervals.

3M KCl and 3M NaCl: In the experiment, 3M KCl and 3M NaCl (Figures 4 and 5) were used to transport H^+ ions in the salt bridge. The voltage generation was recorded per day throughout the week for the sewage sludge. The maximum generated voltage obtained with 3M KCl

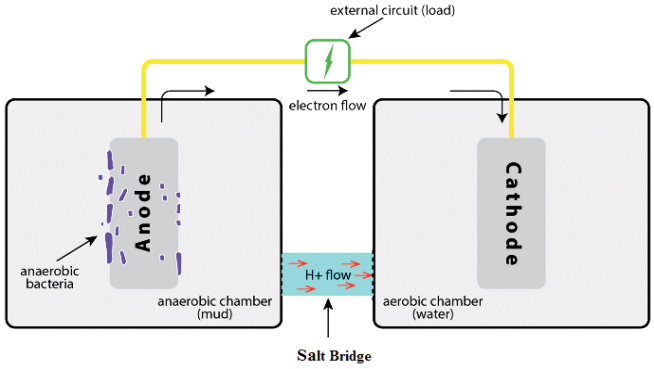

Figure 1: A dual chambered MFC with salt bridge.

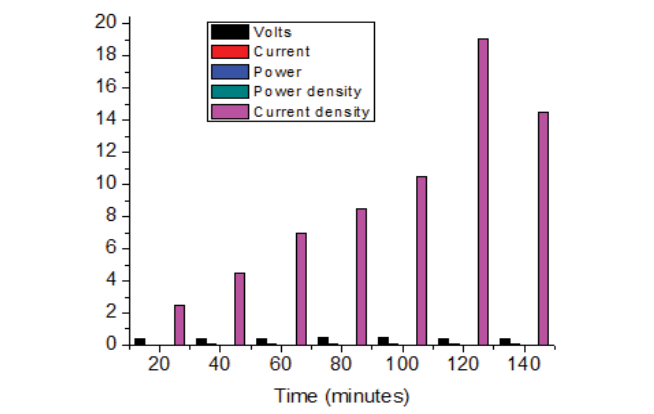

Figure 2: Maximum voltage obtained with 1M KCl.

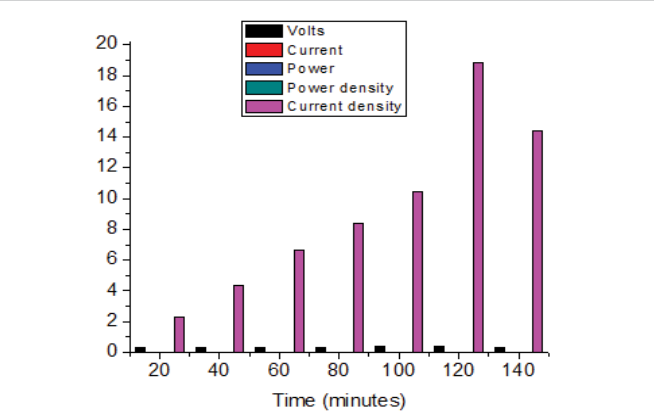

Figure 3: Maximum voltage obtained with 1M NaCl.

1M KCl					
Time (minutes)	**Voltage (V)**	**Current (μA)**	**Power (mW)**	**Power density (mW/m²)**	**Current density (μA/m²)**
20	0.419	0.0419	0.0175561	0.000195068	2.478651168
40	0.427	0.0427	0.0182329	0.000202588	4.488135488
60	0.434	0.0434	0.0188356	0.000209284	6.966786656
80	0.443	0.0443	0.0196249	0.000218054	8.507142954
100	0.451	0.0451	0.0203401	0.000226001	10.5166661
120	0.430	0.043	0.01849	0.000205444	19.02380906
140	0.425	0.0425	0.0180625	0.000200694	14.48576319

Table 1: Maximum voltage obtained with 1M KCl.

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80	0.443	0.0443	0.0196249	0.000218054	8.507142954
100	0.451	0.0451	0.0203401	0.000226001	10.5166661
120	0.430	0.043	0.01849	0.000205444	19.02380906
140	0.425	0.0425	0.0180625	0.000200694	14.48576319

Table 2: Maximum voltage obtained with 1M NaCl.

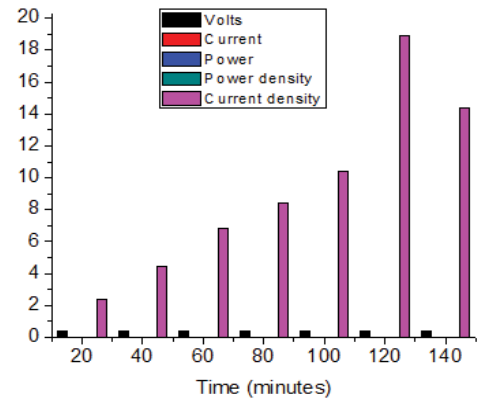

Figure 4: Maximum voltage obtained with 3M KCl.

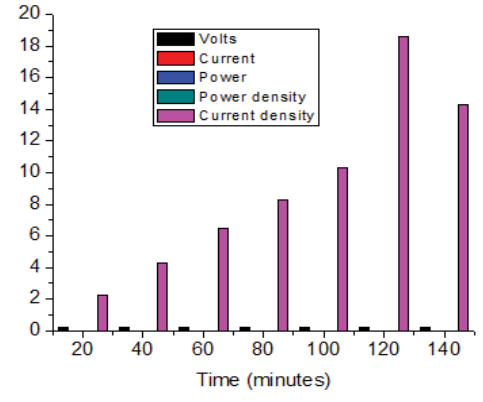

Figure 5: Maximum voltage obtained with 3M NaCl.

and 3M NaCl was 387 V and 248 V (Tables 3 and 4) respectively. The MFC was run for a period of 1 day and readings were noted at regular intervals.

5M KCl and 5M NaCl: In the experiment, 5M KCl and 5M NaCl (Figures 6 and 7) were used to transport H^+ ions in the salt bridge. The maximum generated voltage obtained with 5M KCl and 5M NaCl is 356 V and 232 mV (Tables 5 and 6) respectively. The MFC was run for a period of 7 days and readings were noted at regular intervals

Discussion

The design of a dual chamber MFC 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. The two chamber system has a disadvantage of increased internal resistance and whereas in the MFC, the internal resistance is significantly lowered. 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 air cathode MFC as it increases the output and also decreases the task of concern in chamber design, space and thereby cost. As the primary designing application for MFC will be electricity generation from sewage sludge, reduce the concern over the design, will be vital for the operation of MFC. The main challenge in improving voltage generation is to make framework plans that diminish resistance. The study involved Salt Bridge which is the most economical component in the dual chamber 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 voltage 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 voltage of 0.372 V. 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. However, the magnitude of electron transfer should be higher and earlier than the respiratory

1M NaCl					
Time (minutes)	**Voltage (V)**	**Current (μA)**	**Power (mW)**	**Power density (mW/m²)**	**Current density (μA/m²)**
20	0.281	0.0281	0.0078961	8.77344E-05	2.317083834
40	0.289	0.0289	0.0083521	9.28011E-05	4.326344901
60	0.316	0.0316	0.0099856	0.000110951	6.643428736
80	0.337	0.0337	0.0113569	0.000126188	8.382183088
100	0.372	0.0372	0.0138384	0.00015376	10.42319216
120	0.356	0.0356	0.0126736	0.000140818	18.80537525
140	0.349	0.0349	0.0121801	0.000135334	14.39621543

Table 3: Maximum voltage obtained with 3M KCl.

3M NaCl					
Time (minutes)	**Voltage (V)**	**Current (μA)**	**Power (mW)**	**Power density (mW/m²)**	**Current density (μA/m²)**
20	0.224	0.0224	0.0050176	5.57511E-05	2.251473351
40	0.228	0.0228	0.0051984	0.00005776	4.25605616
60	0.235	0.0235	0.0055225	6.13611E-05	6.507529511
80	0.237	0.0237	0.0056169	0.00006241	8.26637931
100	0.248	0.0248	0.0061504	6.83378E-05	10.27901874
120	0.238	0.0238	0.0056644	6.29378E-05	18.54539805
140	0.230	0.023	0.00529	5.87778E-05	14.25834878

Table 4: Maximum voltage obtained with 3M NaCl.

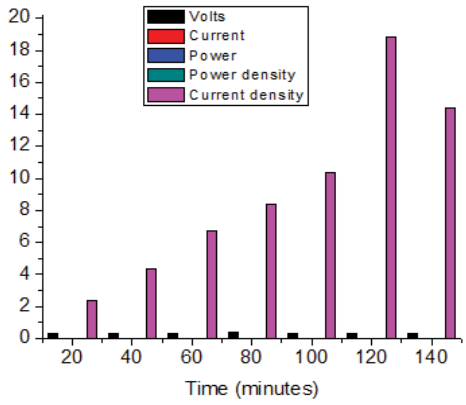

Figure 6: Maximum voltage obtained with 5M KCl.

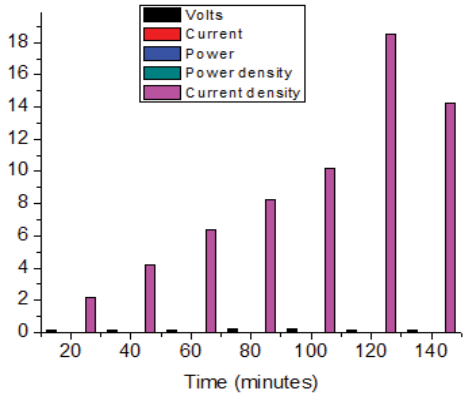

Figure 7: Maximum voltage obtained with 5M NaCl.

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.

5M KCl					
Time (minutes)	**Voltage (V)**	**Current (μA)**	**Power (mW)**	**Power density (mW/m^2)**	**Current density ($μA/m^2$)**
20	0.317	0.0317	0.0100489	0.000111654	2.358860554
40	0.319	0.0319	0.0101761	0.000113068	4.361189168
60	0.329	0.0329	0.0108241	0.000120268	6.720049722
80	0.356	0.0356	0.0126736	0.000140818	8.404414418
100	0.343	0.0343	0.0117649	0.000130721	10.38919562
120	0.341	0.0341	0.0116281	0.000129201	18.79361004
140	0.324	0.0324	0.0104976	0.00011664	14.36701424

Table 5: Maximum voltage obtained with 5M KCl.

5M NaCl					
Time (minutes)	**Voltage (V)**	**Current (μA)**	**Power (mW)**	**Power density (mW/m^2)**	**Current density ($μA/m^2$)**
20	0.175	0.0175	0.0030625	3.40278E-05	2.195596528
40	0.176	0.0176	0.0030976	3.44178E-05	4.196732018
60	0.184	0.0184	0.0033856	3.76178E-05	6.392328546
80	0.232	0.0232	0.0053824	5.98044E-05	8.260642204
100	0.196	0.0196	0.0038416	4.26844E-05	10.21948428
120	0.189	0.0189	0.0035721	0.00003969	18.48012649
140	0.184	0.0184	0.0033856	3.76178E-05	14.20582322

Table 6: Maximum voltage obtained with 5M NaCl.

Conclusion

The study involved double chambered MFC using Salt Bridge which is the most economical component in the MFC. For the first part of the study, KCl and NaCl were compared for use as strong salt in salt bridge. 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 KCl and NaCl. It produced a maximum voltage 0.451 V and 0.372 V respectively. In this double chamber MFC using *Saccharomyces cerevisiae* was used as biocatalyst. Anode chamber was kept up in batch mode and another side cathode chamber was maintained at continuous mode. Our results have indicated that the salt bridge 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.

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