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Optimization and performance evaluation of microbial fuel cell by varying agar concentration using different salts in salt bridge medium

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ABSTRACT

Purpose: Comparative study of various agar-agar ($C_{14}H_{24}O_9$) percentage and different salts concentration in the salt bridge is carried out to check the efficiency of microbial fuel cell.

Design/methodology/approach: Dual chambered microbial fuel cell was used for the overall experiments. Anode and cathode chambers were made of 500 ml plastic jar. Salt bridge was fabricated with agar-agar technical and 3 M NaCl in a PVC pipe of 2 cm long. Chemical Oxygen Demand, pH and electrical conductivity of wastewater were examined. Oxygen was supplied in the cathode chamber using the aquarium pump. Voltage (open circuit voltage) was observed using digital multimeter. Graphite rods were used as anode and cathode electrodes.

Findings: Salt bridge was constructed of 3 M NaCl with 5, 7.5, 10 and 12 percent variation of agar amounts in MFC. The maximum outputs were observed 301, 306, 325 and 337.25 mV with the variation of agar 5, 7.5, 10 and 12 percentages respectively as well as chemical oxygen demand (COD) removal efficiency was observed 47.92, 56.25, 52.08 and 64.58 percentages respectively. The optimum agar concentration was found to be 12 percent and a maximum voltage of 337.25 mV and COD removal of 64.58 percent was achieved. After the optimization of agar percentage two salts i.e., Sodium chloride and potassium chloride were analysed. This study also reveals that the NaCl salt bridge is more efficient than KCl salt bridge for the same agar concentration. The maximum voltage for NaCl and KCl were 319 and 312 mV respectively.

Research limitations/implications: The amount of electricity production is low and field scale implementation is difficult using microbial fuel cell. The research is still on progress in this field.

Originality/value: here is very little research with salt bridge and MFC. Comparative study of different mole of salt is available but agar variation is not yet studied.

Keywords: Agar, Energy production, Microbial fuel cell, Salt bridge, Wastewater

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

Wastewaters are widely produced on a daily basis from domestic and industrial sources across the globe; posing numerous difficulties such as wastewater collection, treatment, disposal and adverse impact on the environment. Therefore, the development of sustainable and energy-efficient wastewater treatment systems is required after as a reasonable solution these difficulties. Conventional biological treatment is most widely used in developing country like India. To maintain food to microorganism ratio in biological treatment a huge amount of oxygen is required which is about 0.3-0.6 kWh/m^3 [1]. Biological treatment consumes energy about 26% of the net financial load for a wastewater treatment plant [2]. Aeration in the biological reactor alone requires approximately 47-70% of total energy. In India, total energy consumption requires is about 0.40 kWh/m^3 for biological treatment which is huge [3]. Therefore some special technics are required which consume less energy with high treatment efficiency. Several electrochemical devices like fuel cells, biochemical electrolysis, microbial electrolysis cell, etc. can convert biochemical energy into electrical energy efficiently [4-10]. Recent research on microbial electrochemical technologies has shown initial success for simultaneous treatment of wastewaters with the recovery of clean energy and reclaiming usable water. Microbial electrochemical technologies, i.e. microbial fuel cells (MFCs), are enticing and surprising attention due to their dual functions of energy generation and waste removal from wastewaters [11-14]. Therefore, MFCs can be a promising technology to resolve various difficulties in wastewater treatment. Microbes are fed in the anode with the substrate (e.g., domestic, industrial, leachates, etc.) to enhance the performance of microbial fuel cells. It provides an opportunity for the feasible production of energy from biodegradable organic matters while treating wastewater. MFC has the capability to transform biochemical energy into electrical energy with bacterial catalysis from complex organic matter [15-18]. Currently, MFC is considered as a sustainable technology for the generation of energy [19-23]. The basic function of the salt bridge is to maintain ion balance between both chambers. Salt bridge mainly consists of salt and agar, where salt concentration act as ion equalizer. Agar is an inert gel and prevents from intermixing of solutions in-between both chambers [24-28].

Comparative study of various agar-agar ($C_{14}H_{24}O_9$) percentage and different salts concentration in the salt bridge is carried out to check the efficiency of MFC. There is no study conducted for variation of agar in salt bridge. Initially, for the fabrication of salt bridge, different agar percentage was examined with 3M NaCl. Afterward analysing optimum agar percentage, different salts were analysed to check the performance of MFC.

2. Materials and methodology

Dual chambered microbial fuel cell was used for the overall experiments. Anode and cathode chambers were made of 500 ml plastic jar (locally available). Salt bridge was fabricated with agar-agar technical (Merck) and 3 M NaCl (Fisher Scientific) in a PVC pipe of 2 cm long. COD of the wastewater was analysed using COD digester (HACH-DB200). Furthermore, pH and electrical conductivity were also examined using pH-meter (Labman, LMPH-10) and conductivity meter (Aquapro) respectively. Oxygen was supplied in the cathode chamber using the aquarium pump (SOBO, SB-348A). Graphite rods were used as anode and cathode electrodes. Setup of dual-chambered MFCs with the salt bridge was fabricated as shown in Figure 1. Initially, the percentage of agar is varied from 5, 7.5, 10 and 12 in four different experimental setups with 3 M NaCl salt bridge. The total surface area of electrodes was 37.7 cm^2. Electrodes spacing were 11 cm c/c from each other.

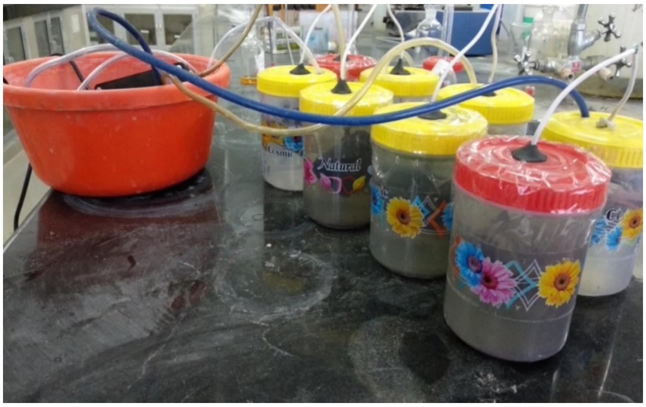

Fig. 1. Microbial fuel cells with different % of agar in a salt bridge

The working volume of both chambers was 400 ml. Anode chamber was filled with the substrate (Domestic wastewater) and the cathodic chamber was with 400 ml tap water. The substrate was collected from the sewage treatment plant, NIT Hamirpur. The study was batch mode and all experiments were carried out at ambient temperature. Salt bridges with 4 cm length and 2.5 cm diameter were constructed for each MFC. Aeration in the cathode chamber was provided at a pressure of 2·0.2 MPa with an aquarium pump. Initial characteristics like pH, electrical conductivity, total settable solids, sludge volume index, chemical oxygen demand and oxidation-reduction potential of domestic wastewater were examined and results are shown in Table 1.

The morphology of the graphite rod was analysed using a scanning electron microscope (SEM). Surface morphology of carbon materials is an important parameter for the performance evolution of MFC. SEM images of tested graphite rod at different magnifications as shown in Figure 2.

Table 1.
Initial characteristics of domestic wastewater

pH	EC	TSS	SVI	COD	ORP
6.7	1038 µS	215 ml/l	139.42 ml/mg	480 mg/l	-92 R.mV

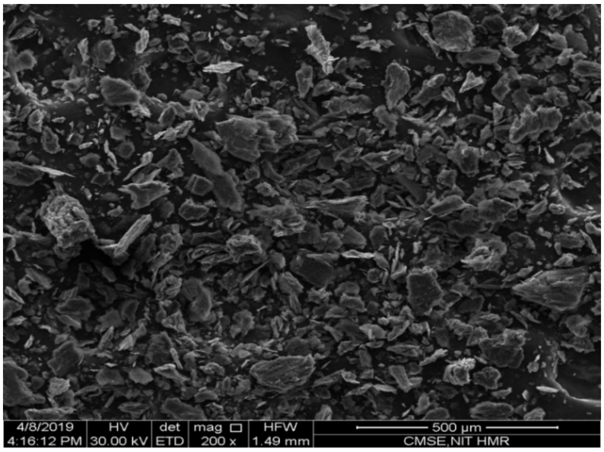

Fig. 2. SEM image of the tested anode and cathode graphite rod as an electrode

Finally, different salts were used as ion exchange catalyst in salt bridge. Two salts namely sodium chloride (NaCl) and potassium chloride (KCl) were chosen because they both have high ion exchange capability. Two dual-chambered MFC were constructed using the salt bridge as a membrane. Salt bridge was prepared of 3M NaCl and 3M KCL with 12 percent agar concentration.

3. Results and discussion

3.1. Effect of agar concentration in a salt bridge

The two-chambered MFC was operated in batch mode by adding domestic wastewater as a substrate into anode reactor. Figure 3 shows the measured open circuit voltage (OCV). The OCV readily increase from first to 5th day for all agar percentages. Afterward, voltage shows steady-state conditions for the next four days with 7.5, 10 and 12 percent of agar but 5 percent agar starts decreasing from the fifth day of operation. 12 percent of agar gave the overall best performance among all. The maximum output of 5, 7.5, 10 and 12 percentage of agar were 301, 306, 325 and 337.25 mV respectively. 5 and 10 percent of agar achieved maximum voltage on the 5th day of operation while 7.5 and 12 percentages of agar obtained it on the 7th day.

3.2. Effect of salts in a salt bridge on electricity production

After optimization of agar percentage, two salts (Sodium chloride and Potassium chloride) were compared to check the performance of microbial fuel cell with optimized 12 percent of agar.

Both reactors show continuously increase in voltage up to 7th day of operation. Potassium chloride showed a higher voltage output up to 7th day, but after the 7th day sodium chloride has a higher output than of potassium chloride. The maximum voltage for NaCl and KCl were 319 and 312 mV respectively as shown in Figure 4.

3.3. COD removal efficiency

COD removal efficiency for 5, 7.5, 10 and 12 agar percentages were 47.92, 56.25, 52.08 and 64.58 percent respectively. The 12 percent of agar content shows the highest COD removal efficiency with domestic wastewater and graphite electrodes, while NaCl has higher removal efficiency than KCl in the second run of MFC.

The potential of hydrogen (pH) slightly moves towards alkaline behaviour. Electrical conductivity is much higher as compared to initial EC; it is basically due to free electrons present in the anode chamber. ORP is a measure of the ability or potential of wastewater to permit specific biological reactions. The ORP value shows biological reactions changes from de-nitrification to BOD degradation with free molecular oxygen.

Final characteristics of domestic wastewater are shown in Table 2.

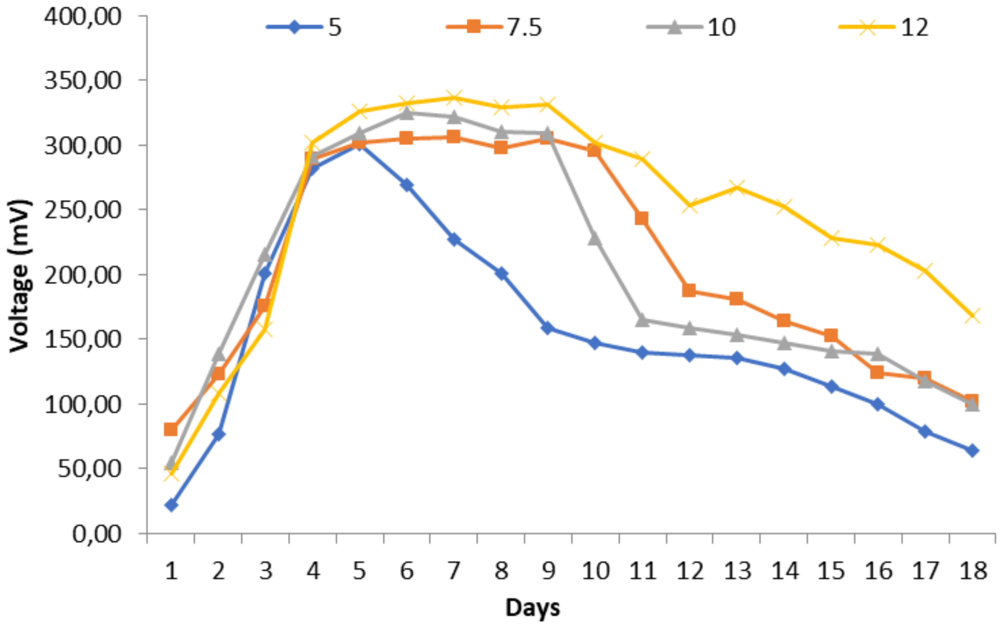

Fig. 3. Voltage output with different agar percentages

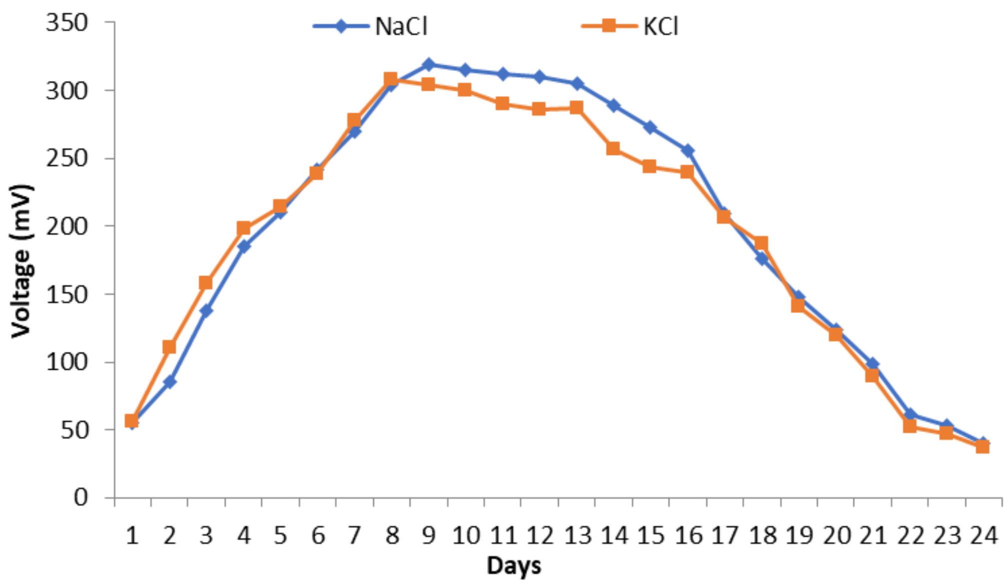

Fig. 4. Variation of salts in a salt bridge with 12 percent of agar

Table 2.
Final characteristics of domestic wastewater

Characteristics	5%	7.5%	10%	12%
pH	7.2	7.1	7.2	7.2
EC	3820	4300	3605	4200
ORP	214	229	224	228
COD	250	210	230	170

4. Conclusions

The current study highlights the various parameters affecting the performing ability of MFC, in terms of both productions of electricity and COD removing efficiency. On the basis of the results obtained, 12 percent of agar percentage gave the overall best performance among four. Salt bridge was fabricated of 3M NaCl with 5, 7.5, 10 and 12 percent variation of agar amounts in MFC. The maximum outputs were observed 301, 306, 325 and 337.25 mV with the variation of agar 5, 7.5, 10 and 12 percentages respectively as well as chemical oxygen demand (COD) removal efficiency was observed 47.92, 56.25, 52.08 and 64.58 percentages respectively. This shows 12 percent of agar content has higher efficiency among all. There are number of alternative members available but finding the most efficient and economical membrane is still a challenge. Salt bridge has shown good performance and it is very cheap to construct but have a disadvantage of fouling due to its water solubility. Furthermore studies can be done on the durability of salt bridge with higher efficiencies. After the optimization of agar percentage two salts i.e., Sodium chloride and potassium chloride were analysed. This study also reveals that the NaCl salt bridge is more efficient than KCl salt bridge for the same agar concentration.

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