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Utilizing Dairy Wastewater For Electricity Generation USing Environment-Friendly Double Chambered Microbial Fuel Cell

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ABSTRACT

Microbial Fuel Cells (MFCs) provide a novel bioprocessing strategy to produce sustainable energy and wastewater treatment. It produces electricity and under certain conditions, biogas from biodegradable compounds and simultaneously reduces carbohydrates and complex substrates in wastewater. MFC with saline catholyte was used in this laboratory scale study. Salt-bridge of dimensions of 5 cm length and 2 cm diameter was used in a plastic MFC unit with electrodes manufactured to the same dimensions (5×5). Dairy waste water was used as the substrate, with its microorganism as the biocatalyst. The dual chambered MFC was operated at room temperature. The study was carried out in three experiments. In the first experiment, the maximum voltage of 0.36 V and current of 0.35A was generated. In experiment 2 and 3 the maximum voltages were 0.42 V, 0.46 V and maximum current were 0.36A and 0.42A respectively were obtained per liter of the dairy wastewater. The MFC was operated for 7 days while the performance was monitored every 1 hr. The main aspects of MFC research are to produce the cost of treatment as well as simplifying operational or functional conditions. MFCs can be the next generation of fuel cell technology and thus might play an important role in energy conservation, electricity generation, bio-hydrogen production, biosensors and wastewater treatment as well as in alternate fuel utilization using microbes to generate electricity.

Keywords: Microbial fuel cell, Salt Bridge, wastewater

Introduction

Global industrialization and rapid rise in the non-sustainable use of fossil resources is increasing the amount of CO_2 that enters the atmosphere leading to a warming of the planet and resulting in climate changes [1-3]. Moreover, rising population and increasing consumption, and land use, have caused a rapid acceleration of climate change over the past twenty years [4-6]. Parallel to the global warming issues, the rapid depletion of fossil fuels is leading to increased global tension towards resource availability [7, 8]. Most of the human race is striving for growth, development and urbanization, with a corresponding enhance energy requirements [9-11]. Energy generation from waste can simultaneously help to meet the world's energy needs, reduce pollution and reduce the cost of wastewater treatment [20]. Microbial fuel cell (MFC) have attracted global interest as a source of energy supplying electricity generated from organic and inorganic matters in wastewater, while concurrently treating the wastewater. An MFC is a device that employs microorganisms to generate electricity from side to side oxidation of organic materials which results in a reduction in wastewater contaminants [21]. MFC's generate electricity by harnessing the electron transport chain of bacteria under controlled condition [3]. They have the potential to generate electricity from a wide variety of organic wastes while oxidizing the wastes to less harmful forms. Research into developing efficient [22]. MFC's remains a very current field, with both engineering and biological challenges yet to be met [5]. The basic design of most microbial fuel cells consists of an anaerobic anode chamber containing a feed source and inoculated with a mixed microbial culture, and an anode chamber which contains an oxidizing agent such as dissolved oxygen of ferricyanide. Being deprived of a direct electron acceptor for respiration, the bacteria in the anode chamber donate electrons to the anode, which are then transferred via a conductor to the cathode, where reduction occurs [11-13]. Charge balance is maintained by migration of H^+ across a proton exchange membrane. MFC's may be broadly classified into two categories depending on the means of electron transfer between the bacteria and the anode [23]. Mediated fuel cells contain an artificial mediator in the anode chamber [5]. Bacteria transfer electrons to the mediator in solution, which is then regenerated at the anode. This mechanism of electron transfer has several disadvantages relating to the cost and toxicity of artificial mediators [7]. The second category of MFC's does not contain an artificial mediator but relies on natural electron transfer processes of the bacteria [1]. While these processes are as yet poorly understood, they are thought to include direct electron transfer by membrane-bound enzymes as well as synthesizes of natural mediators [24, 25]. Because not all substrate is completely oxidized, with some mass necessarily being used for biosynthesis, then not all high energy electrons supplied in the substrate are transferred to the cathode and available to do work [12]. The percentage of electrons which are transferred is expressed in terms of columbic efficiency, which is essentially a percentage ratio of the number of electrons supplied against the number of electrons transferred [2]. This parameter is a useful measure of the overall efficiency of the MFC. The power output of MFC is also a useful quantity to measure [12]. This is measured in terms of a polarization curve, which shows the relationship between current and voltage over a range of resistances. By the relationships V=IR and P=IV, where V is voltage, I is current, R is resistance, and P is power, then observations of current, voltage and resistance can be

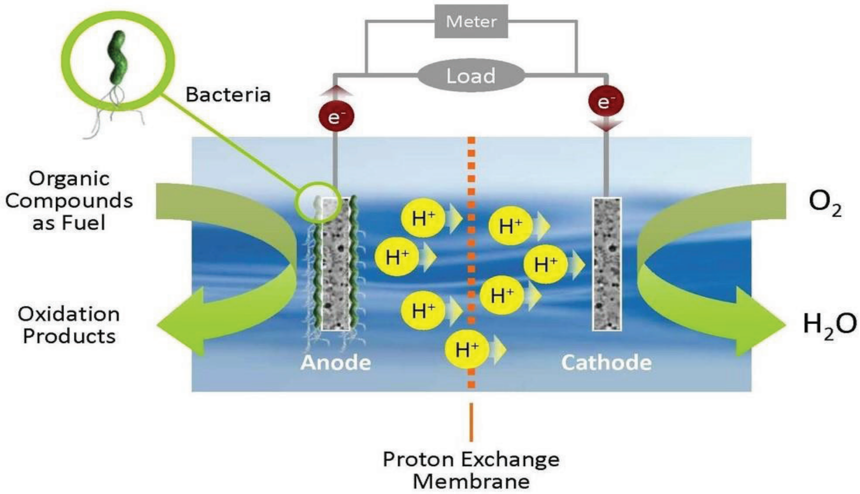

Fig. 1: Double chambered MFC [12]

manipulated to give information about power output [9-11]. The aim of this work is to design a dual chambered MFC using dairy wastewater as a substrate to generate electricity. It can provide basic data for the industrial application of MFC.

MATERIALS AND METHODS

A double chambered MFC with substrate dairy wastewater in the anodic chamber run for 7 days to observe the characteristics of generated voltage and current. The construction of double-chambered MFC device requires inexpensive materials.

Table 1: MFC fabrication prerequisites

S.No	Materials	Quantity
1.	PVC bottles (2000 mL)	2
2.	PVC pipe (5cm)	1
3.	Copper rods (5×5)	2
4.	Dairy wastewater	1000 mL
5.	Copper wire	0.5 m
6.	Aluminum clips	2
7.	Digital multimeter	1

Table 2: Characteristics of Dairy wastewater

pH	BOD (mg/L)	COD (mg/L)	TSS (mg/L)
5.5	654	1487	329

Substrate collection – sewage sludge

Dairy wastewater (1000 mL), which served as the substrate of the MFC was collected from Qasimabad Dairy Hyderabad and analyzed that sample and analyzing result is given in table 2.

Cathodic & anodic chamber

These chambers of the MFC was made up of plastic bottles. Two plastic bottles each of 1000 mL were used for this purpose. The bottle was washed with distilled water and then the medium was filled in it. Methylene blue (10 mL), sewage sludge (1000 mL) as a sample and *Saccharomyces cerverciae* sp. (44 g) added to it.

Salt bridge

Salt bridge employed here was made with 5M NaCl and agar salt concentration from 7% to 12%. The salt bridge was cast in a PVC pipe (12 cm X 2 cm). Proper precautions were taken to ensure complete sealing of anodic chamber by means of applying epoxy and wax to ensure anaerobic conditions [3]. 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 (Fig 1). The anodic compartment contained the substrate and the copper electrodes (6″ each). The salt bridge served as an electrolyte in the transfer of protons [6]. The cathode was immersed in the salt bridge when it was in the molten stage to ensure complete surface contact [11]. The 50% cathode surface was exposed to atmospheric air. The configuration of fabricated MFC is given in Table 1.

MFC Operation

Substrate (dairy wastewater), was added in an 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.

Fabrication and operation

Firstly, two chambers were taken of plastic materials (approximately 2000 mL each). Dairy wastewater was obtained from a well renowned firm. Other apparatuses were arranged from nearby shops. In one chamber, 1000 mL of distilled water was taken and in 2nd chamber 1000 mL of dairy waste water was added. Carbon rods were inserted in both the cylinders, anodic chamber contained dairy waste water and cathodic chamber contained distilled water. Readings were taken for setup without any mediator or microorganisms and readings were taken down after a long period of every 1 hr. In the same setup microorganisms (yeast) were added and in similar way readings were noted. In the last setup microorganisms along with mediator (methylene blue -10 mL) were added to the anode containing dairy waste water and changes in the voltage were observed.

Results and Discussion

MFC was operated for 7 hrs and DC voltage and current was measured using a digital multi-meter. The data collected was graphed using OriginPro 8.0 software.

Table 3: Experiment -1

Materials	Anodic chamber	Cathodic chamber
Substrate	Dairy wastewater - 1000 mL	-
Microbes	No	No
Mediator	No	No
Distilled water	-	1000 mL
Electrode	Copper rod (5×5)	Copper rod

Table 4: Measures of current, and voltage

Time (hr)	Current (A)	Voltage (V)
01	0.20	0.16
02	0.21	0.19
03	0.23	0.27
04	0.25	0.31
05	0.27	0.34
06	0.35	0.36
07	0.31	0.30

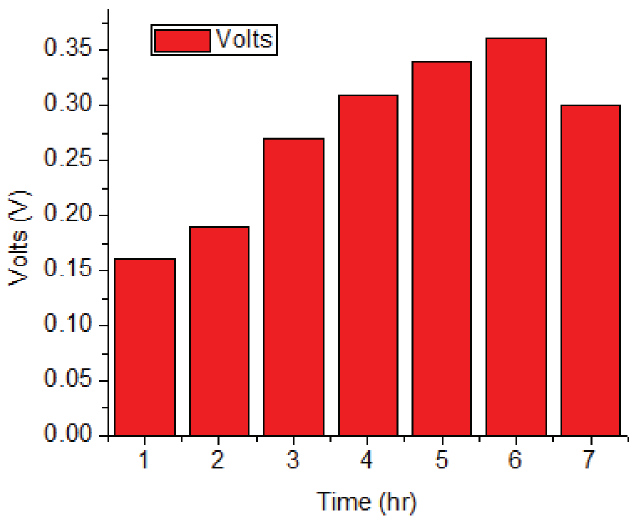

Fig. 2: Voltage generation from dairy wastewater versus time (hr)

Created voltage seemed to be calculated for the duration of progress curve although goes in some sort of positioned voltage cycle in addition to minimize for the reason that the minimize because the startup goes into decline period because of the demise of microorganisms attributing towards the weariness of nutrition within the particular holding chamber [9]. The generated voltage shows a hike from day 7, which could be for the reason that concentration of agar boosts, the gel is extremely polymerized, suppressing the particular inter possibility of the segregated chamber liquids [10]. Extremely polymerized gel, in addition, inhibits the particular admittance of indigenous as well as oxygen from the cathode chamber by the salt bridge penetration, keeping the anaerobic conditions of the anodic chamber [3]. A decrease in the creation of voltages was analyzed after day 6 of operation, for the reason that salt bridge extremely polymerized minimizing the sizing, limiting the movement of the proton through the salt bridge. The maximum generated a voltage at day 6 was 0.36 V, 0.42 V and 0.46 V in all three experiments respectively. The maximum generated current at day 6 was 0.35 A, 0.36 An in and 0.43 A in all three experiments respectively.

Factors affecting electricity generation

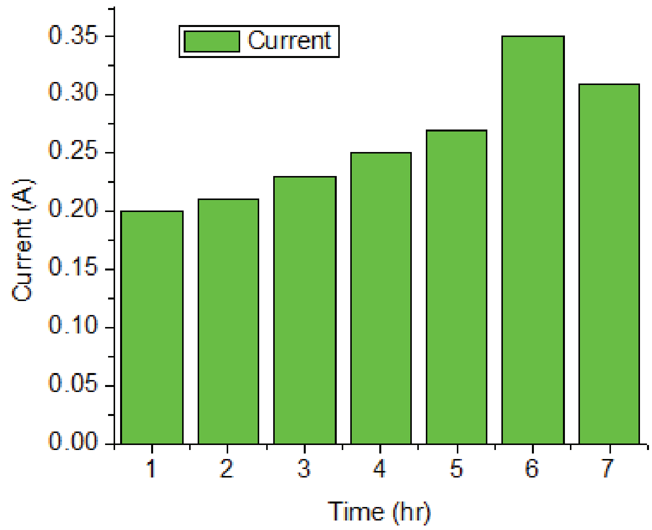

Fig. 3: Current generation from dairy wastewater versus time (hr)

Table 5:Experiment - 2

Materials	Anodic chamber	Cathodic chamber
Substrate	Dairy wastewater - 1000 mL	-
Microbes	Yeast	No
Mediator	No	No
Distilled water	-	1000 mL
Electrode	Copper rod (5×5)	Copper rod

Table 6: Measures of current, and voltage

Time (hr)	Current (A)	Voltage (V)
01	0.30	0.26
02	0.31	0.29
03	0.33	0.37
04	0.35	0.34
05	0.38	0.43
06	0.36	0.42
07	0.35	0.41

Table 7: Experiment- 3

Materials	Anodic chamber	Cathodic chamber
Substrate	Dairy wastewater -1000 mL	-
Microbes	Yeast	No
Mediator	Methylene blue – 10 mL	No
Distilled water	-	1000 mL
Electrode	Copper rod (5×5)	Copper rod

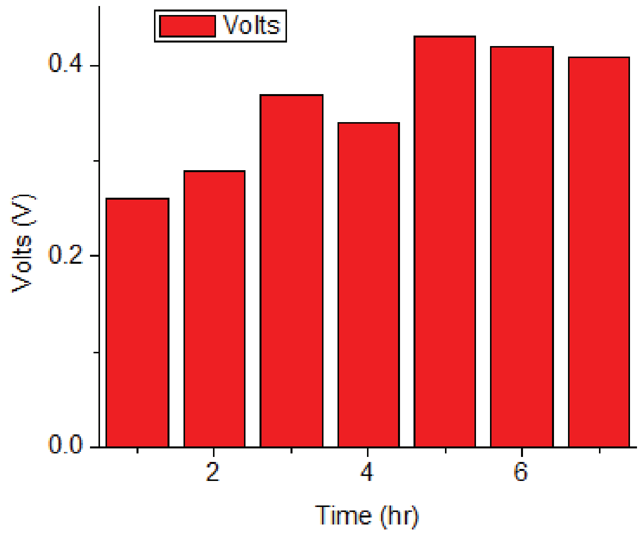

Fig. 4: Voltage generation from dairy wastewater versus time (hr)

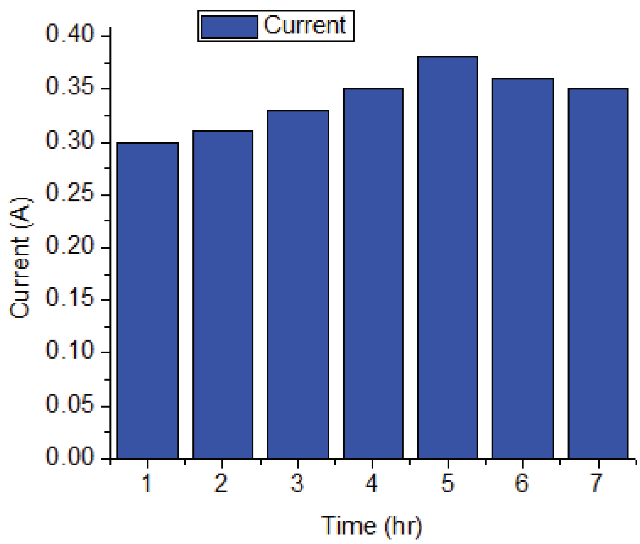

Fig. 5: Current generation from dairy wastewater versus time (hr)

Table 8: Measures of current, and voltage

Time (hr)	Current (A)	Voltage (V)
01	0.41	0.36
02	0.43	0.39
03	0.45	0.37
04	0.46	0.41
05	0.48	0.44
06	0.43	0.46
07	0.42	0.40

Impact of oxygen flow rate on voltage generation

The impact of oxygen flow rate on voltage generation during working of MFC was examined at different oxygen flow rates from 15 to 60 psi yielding in voltage generation between 0.729 V and 1.00 V respectively (Fig. 6). These results show that voltage generation enhances as the oxygen flow rate was increased and reached the maximum of around 2.5 V at oxygen flow rate of 45 psi before showing decline afterwards. This indicates that at the higher air flow rate, power generation capacity decrease due to the higher rate of oxygen flow rate in air diffused down to the vicinity of the anode, which probably disturbed the anaerobic microbes living on the anodic surface [13].

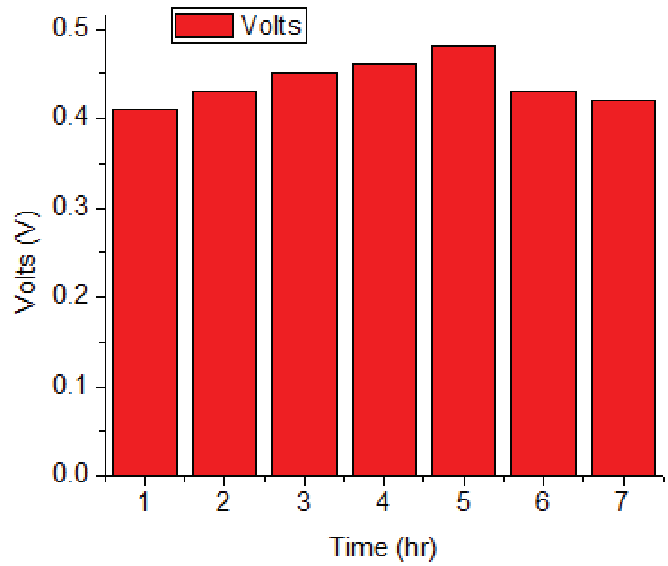

Fig. 6: Voltage generation from dairy wastewater versus time (hr)

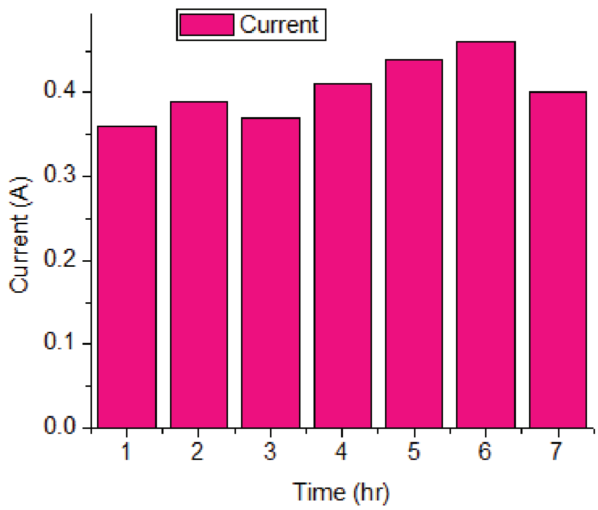

Fig. 7: Current generation from dairy wastewater versus time (hr)

Impact of pH on voltage generation

pH is a significant factor that affecting the activity of microbes. Growth and development of microbe's maximum at optimum pH. Fig.7 shows the maximum output of voltage was recorded at pH 8.5. The experiments show that at pH 6 and below, activities of microbes minimum when compared with the result recorded at higher pH. This is by the neutralization of proteins or active sites under acidity. These results demonstrate that there is also the impact of pH on voltage generation using sewage sludge in MFC.

Impact of substrate (dairy wastewater) concentration on electricity generation

Power production was observed to increase by enhancing the concentration of substrate (Fig.8). Starting from about

10% substrate concentration, generated voltage at 10% concentration was 0.725 V. At 70% substrate concentration, voltage was increased up to 2.5 V and then voltage was declined by decrease in substrate concentration of 100%, the generated voltage at 100% substrate concentration was 1 V. This is due to the decline in the activity of the microbes owing to various factors such as pH. This was probably due to the reduction in the activity of the enzymes owing to various factors such as pH. This also indicates that higher concentration of the substrate could actually affect the anode performance significantly resulting in simultaneous lesser power production [15].

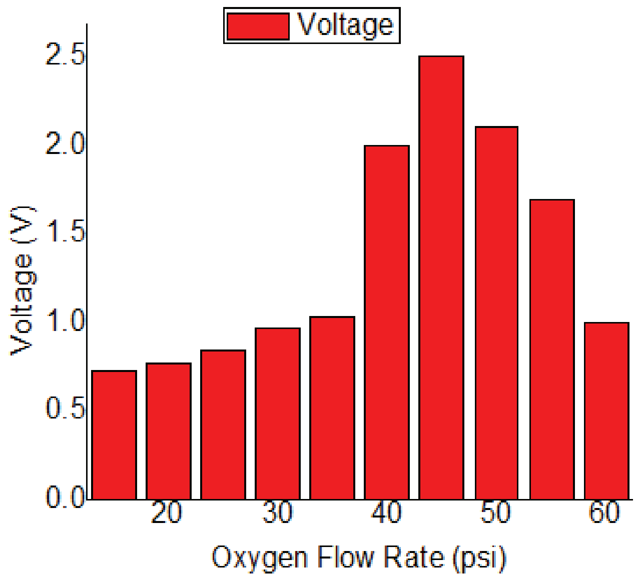

Fig.8: Impact of oxygen flow rate on voltage generation

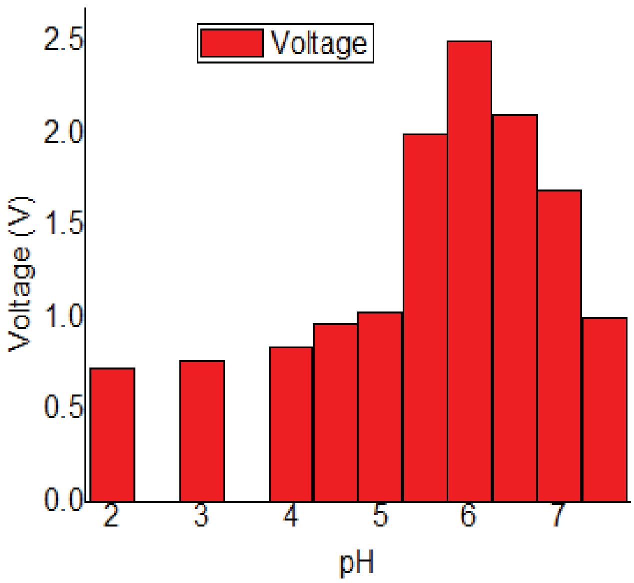

Fig. 9: Impact of pH on voltage generation

Impact of Agar concentration

In this experiment, the maximum voltage generated increased with increase in agar concentration. A maximum of 2.5V was obtained with 20% agar concentration (Fig. 9). The movement of O_2 from higher to lower concentration takes place in cathode was reduced by increased agar concentration and hence the increase in voltage generation [21].

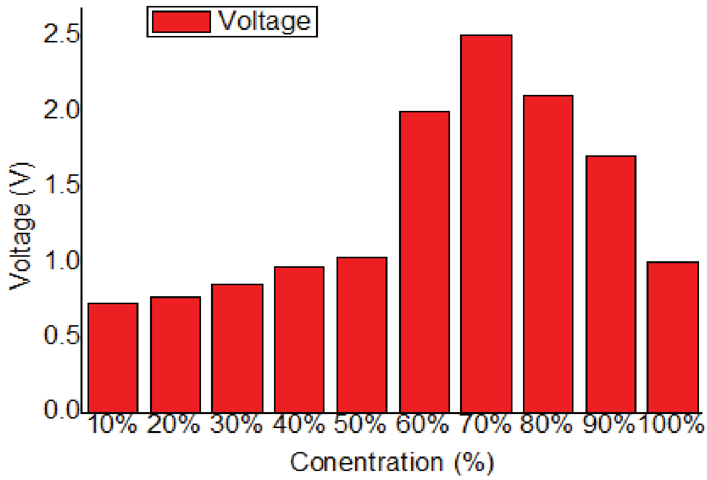

Fig. 10: Impact of substrate concentration on voltage generation

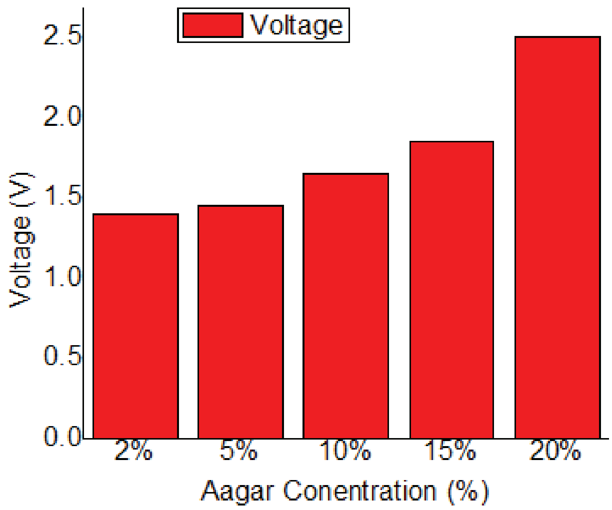

Fig. 11: Impact of concentration of agar on voltage generation

Conclusion

The world is facing serious sustainability challenges. Natural resources such as fresh water and fossil fuels are rapidly becoming in short supply [11]. The heavy reliance on fossil fuels is further resulting in environmental concerns, especially global warming. Wastewater is also a growing issue. In this context, energy produced from a potential organic bio-waste is an attractive option [2]. Keeping this view, the present work has been undertaken to produce electrical energy from dairy wastewater as bio-waste in MFC. In the first phase of project work, a MFC was successfully constructed using two 2000 mL bottles, which were operated as cathode and anode chambers. The salt bridge was made using KCl and agarose. Copper rods were used as electrodes in MFC. In the second phase, the experiment was conducted to generate energy from locally available dairy wastewater, which was used as a substrate for MFC. The whole system was connected to a digital voltmeter for obtaining précised readings of voltage and current. The maximum generated a voltage at day 6 was 0.36 V, 0.42 V and 0.46 V in all three experiments respectively. The maximum generated current at day 6 was 0.35 A, 0.36 A and 0.43 An in all three experiments respectively. Overall, this study has shown that the fabricated microbial fuel cell can be used for the generation of electricity from cow dung and possibly other waste. The mediator enhances the transfer of electrons and thus increasing the acquired voltage [18]. The more the dairy wastewater chambers are kept for degradation, better the results are obtained up to a certain limit.

Scope of Improvement

Experiment using various microbes and different electrodes at different operating conditions and effect of temperature on the system and microbes and fuel cell along with various waste water like industrial waste water, also at various pH conditions behavior of system will be conducted in the future. However, this technology is only at the research stage and more research is required before household MFCs can be made available. Finding alternatives to hazardous electron mediators and researching new microbes are the aspects on which we must focus. The present studies contribute to the on-going pursuit of the most productive microbial fuel cell.

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