Feasibility Study on Treatability of Dairy Wastewater Employing Dual Compartment Microbial Fuel Cell

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Abstract - Renewable and green energy resources are paramount to environmental sustainability. For sustainable development waste management is effectively important and treatment of industrial wastewaters is necessary. In this study Dual Compartment Microbial Fuel Cell (DC-MFC) was designed for the treatment of dairy wastewater that included anodic and cathode section separated by a filter media filled of glass wool and glass bead. Three different electrodes were used such as aluminium, copper and stainless steel. The effluent was examined to evaluate the pollutant decrease (BOD, COD and TDS). The maximum removal efficiency of COD, BOD and TDS was respectively achieved at 92.2%, 88.02% and 76.3% at organic loading rate (OLR) equal to 2.188 kgCOD/m^3 d and hydraulic retention time (HRT) equal to 25.75 h for using copper electrode. The results showed that DC-MFC is good alternative for treating dairy industry wastewater.

***Key Words*: Dual compartment microbial fuel cell, dairy industry wastewater, membrane less, mediator less, electrode configuration.**

1. INTRODUCTION

The rising concern over protection of environment and depleting energy resources has made it inevitable to taken over the waste management system from merely treating the waste to new horizon of recovery of energy from waste [1, 2]. Microbial fuel cell (MFC) is a promising technology which produces electricity and simultaneously removes the pollutants from the wastewater. The MFC is a bio-electrochemical system exploiting bacterial oxidation of biodegradable organic matter, to generate electricity [3-5]. The microorganisms generally present in anode chamber of fuel cell act as biocatalyst and generate electrons (e^-) and protons (H^+) by way of anaerobic respiration of organic substrate. The electron transfer through the anode integrated with an external circuit to cathode and protons diffuse through the proton exchange membrane (which separates cathode and anode chamber) into the cathode chamber where they combine with help of mediator. The potential between the respiratory system and electron acceptor generates the current and voltage needed to make electricity [6]. The potential advantages of Microbial fuel cells (MFCs) compared to traditional technologies such as activated sludge are reduced operational costs, due to passive oxygen diffusion to the cathode (no wastewater aeration), reduced sludge production, and electricity production. Tremendous advances have been made in recent years in increasing power densities by improving reactor configurations and developing new electrode materials.

2. MATERIALS AND METHODS

2.1 Fabrication of Reactors

The DC-MFCs used in the present study were made of acrylic plexiglass. Laboratory experiments were conducted using DC-MFCs, with dimensions 33 cm length, 15 cm width and 15 cm height with a working volume of 6.975 L capacity. Plexiglass DC-MFC's were used because of its high durability and stability compared to normal glass material. The inlet and outlet were provided in the reactor of diameter 1 cm. The inlet was positioned at the bottom to allow influent feeding into the anode chamber. The outlet was positioned at the top of the cathode chamber to allow effluent out of the reactor.

2.2 Electrodes

In the present study, different electrode materials were used such as Aluminium, Copper and Stainless Steel. Each chamber consists of two electrodes in series of spacing 3 cm and the sizes of electrodes were 8cm (height) X 3cm (width) and 1mm thickness. The electrodes of both compartments were kept at a distance of 9 cm from each other.

2.3 Filter Media

The anode and cathode chamber were separated by 3 cm length perforated acrylic plexiglass plate filled with glass wool and glass bead acted as filter media to allow liquid from the anode to the cathode compartment. Also it helps in ion exchange from anode to cathode compartment.

2.4 Wastewater Samples

In the present study dairy wastewaters were used as substrate to the microorganisms because dairy wastewater is rich in biodegradable organics (sugar contributes 97% of total COD) and nutrients. The wastewaters were collected from Mysore Milk Union Ltd, Mysuru, India. The wastewater collected from the industry were initially analyzed for BOD, COD, TS, TDS, oil and grease, nitrate, phosphate and pH concentrations.

2.5 Experimental Procedure

In the present study, wastewater samples were collected from dairy industry. Experiments have been conducted in 3 phase; phase 1: includes Aluminium electrode; phase 2: includes Copper electrode and phase 3: includes Stainless steel electrode. Each phase consist of 2 cycles. The electrodes of both compartments were kept at a distance of 9 cm from each other. Each chamber consists of two electrodes in series of spacing 3 cm. The electrodes were connected externally with a copper wire. Two DC-MFC units have been fabricated and used for conducting laboratory experiments. Dairy wastewaters having varied concentrations has been used as substrate and also contains certain anaerobic microbes which insist in degradation of organic matter present in the wastewater. Since the present study is based on membrane less and mediator less hence mediators have not been used. The lid was attached to the reactor using electric tape which keeps the chamber in anaerobic conditions. The schematic diagram and the experimental setup of DC-MFC used in the present study are shown in Figures 1.

2.6 Analysis

DC-MFC experiments have been carried out using different electrode materials over a period of 7 days (one cycle). The DC-MFC was operated providing head flow from feed tank to the DC-MFC via rubber tube. The wastewater was continuously fed under varying feeding rate. The feed rate was fixed to 7.5 L/day (cycle-1, 3 and 5) and 6.5 L/day (cycle-2, 4 and 6) using different electrode materials to investigate its performance. BOD, COD and TDS concentrations were analyzed on daily basis before and after treatment. The voltage and current was monitored daily.

Fig 1: Experimental Setup of Dual Compartment – Microbial Fuel Cells.

3. RESULTS AND DISCUSSION

3.1 Characterization of Dairy Wastewater

In the present experimental study dairy industrial wastewaters were used as substrate. The wastewaters were collected from Mysore Milk Union Ltd, Mysuru, India was used. The wastewater sampled were initially analyzed for BOD, COD, TDS, SS, oil and grease, pH, nitrate and phosphate concentrations are given in Table 1.

3.2 The Effect of Organic Loading Rate

The DC-MFCs studies were carried out for varied operating conditions. The dairy wastewater was continuously fed into the anode chamber under varying feed rate such as cycle-1, 7.5 L/day and cycle-2, 6.5 L/day (Aluminium electrode), cycle-3, 7.5 L/day and cycle-4, 6.5 L/day (Copper electrode) and cycle-5, 7.5 L/day and cycle-6, 6.5 L/day (Stainless steel electrode) using different electrode materials to investigate its performance. In this study DC-MFCs were examined for different organic loading rates (OLR) and their effects on treatment. The highest COD removal was 84.2% using Aluminium electrode was achieved at OLR equal to 1.94 kg COD/m^3 d, for copper electrode maximum removal was 92.2% at OLR equal to 2.188 kg COD/m^3 d and for using Stainless steel, the maximum removal was 88.3% at OLR equal to 2.188 kg COD/m^3 d. The highest BOD removal was 83.2% using Aluminium electrode was achieved at OLR equal to 1.94 kg COD/m^3 d, for copper electrode maximum removal was 88.1% at OLR equal to 2.188 kg COD/m^3 d and for using Stainless steel, the maximum removal was 85.1% at OLR equal to 2.188 kg COD/m^3 d. The highest TDS removal was 72.3% using Aluminium electrode was achieved at OLR equal to 1.94 kg COD/m^3 d, for copper electrode maximum removal was 76.3% at OLR equal to 2.188 kg COD/m^3 d and for using Stainless steel, the maximum removal was 74.6% at OLR equal to 2.188 kg COD/m^3 d. The reason for higher values in the present study may be due to at higher OLR the system reaches maximum removal in shorter period and in low OLR the fuel cells need more time to reach maximum substrate degradation.

3.3 The Effect of Hydraulic Retention Time

One of the important parameter in wastewater treatment is hydraulic retention time (HRT). It determines the amount of dissolved oxygen and concentration of remaining substrate. In the present study to understand the influence of HRT on treatment, the DC-MFC was operated with dairy wastewater continuously with different HRTs such as 22.3 and 25.75 h. The higher removal efficiency was about 92.2% COD, 88.1% BOD and 76.3% TDS obtained at HRT equal to 25.75 h. This may be due to longer contact time between biofilm and organic material that can show the advantage of biofilm, substrate degradation, electron production and transfer to the anode surface as HRT increases [7].

3.4 Evaluation of Treatment Efficiency

The DC-MFC had the best remediation efficiency when it was operated in continuous feeding mode compared to batch mode. The DC-MFC system used in the present study was able to treat the wastewater. The parameters of dairy wastewater considered in this study are BOD, COD and TDS. The concentrations of effluent pollutants were measured on daily basis in every cycle. Totally there were six cycles, in which 3 different electrode materials were used and one electrode material was used for 2 cycles. The results show that in the cycle 1 and 2, using aluminium electrodes and the removal efficiency of cycle 1 increases with operation time from 21.9% to 71.2% for COD, BOD from 12.4% to 70.5% and from 15.6% to 69.2% for TDS (HRT 22.3 h and OLR 2.27 kgCOD/m^3 day) and for cycle 2, COD removal efficiency varied from 39.3% to 84.2%, BOD from 17.1% to 88.2% and from 19.8% to 72.3% for TDS at HRT 25.75 h and OLR 1.94 kgCOD/m^3 day (Chart 1, 2 and 3). In cycle 3 and 4, using copper electrodes, the removal efficiency of cycle 3 varied from 31.9% to 88.9% for COD, BOD from 31.9% to 85.6% and from 22.1% to 72.3% for TDS at HRT of 22.3 h and OLR of 1.819 kgCOD/m^3 day and for cycle 4, COD varied from 26.4% to 92.2%, BOD from 32.1% to 88.1% and from 27.6% to 76.3% for TDS at HRT of 25.75 h and OLR of 2.188 kgCOD/m^3 day (Chart 4, 5 and 6). In cycle 5 and 6, using stainless steel electrode material and the removal efficiency of cycle 5 varied from 26.2% to 83.3% for COD, BOD from 21.9% to 82.4% and from 19.8% to 73.5% for TDS at HRT of 22.3 h and OLR of 1.819 kgCOD/m^3 day and for cycle 6, at HRT of 25.75 hours and OLR equal to 2.188 kgCOD/m^3 day COD varied from 22.3% to 88.3%, BOD from 28.4% to 86.1% and from 23.5% to 74.6% for TDS (Chart 7, 8 and 9). Mansoorian et al (2016) have carried out experiment using dairy wastewater as substrate. The experimental result showed a maximum removal of COD and BOD was achieved at 90.46% and 81.72% [7]. Venkata Mohan et al (2010) have showed the results of experiment using single chamber MFC achieved maximum COD degradation of 95.49% using real field dairy wastewater [8]. Venkata Mohan (2009) have conducted study using two chamber MFC achieved maximum COD removal of 55.4% using glucose as substrate [9]. Venkata Mohan et al (2008) conducted study using synthetic wastewater observed higher substrate removal efficiency using of 74.20% COD at OLR of 0.559 kg COD/m^3 day [6]. Zhang et al (2008) carried out experiment using single chamber MFC achieved 40 to 80% removal efficiency by using urban wastewater as substrate [10]. In the present study higher substrate degradation may be due to longer contact time between biofilm and organic material and also due to the activity of both anaerobic and aerobic microbes in the anode and cathode chamber. On the other hand wastewater is continuously fed, the wastewater passes through both the chambers. The higher remediation efficiency observed in for continuous feeding thus suggesting that, the aerobic bacteria in the cathode chamber also aids in the degradation of substrate [11]. Reducing the flow rate of this allows the wastewater to flow through the MFC slower than when it is fed rapidly. The dairy wastewater thus spends a longer time in the MFC in contact with both anaerobic and aerobic bacteria. The bacteria thus get more time to completely degrade the organic

matter present in the wastewater. The comparison of performance of DC-MFC in different concentrations of fuel is given in Table 2.

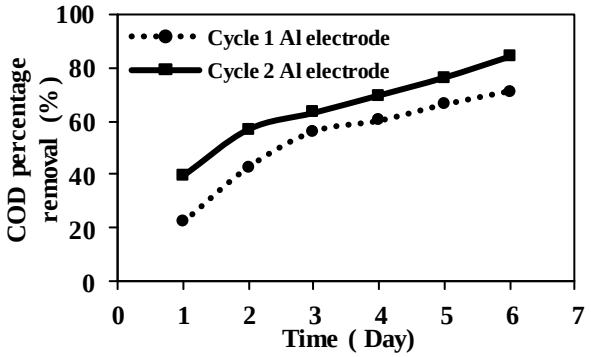

Chart-1: The removal efficiency of COD of dairy wastewater used as fuel by DC-MFC using Aluminium electrode

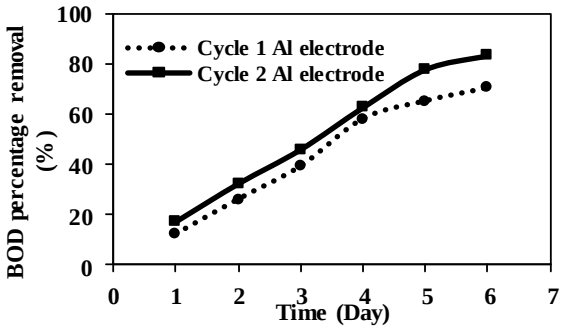

Chart-2: The removal efficiency of BOD of dairy wastewater used as fuel by DC-MFC using Aluminium electrode

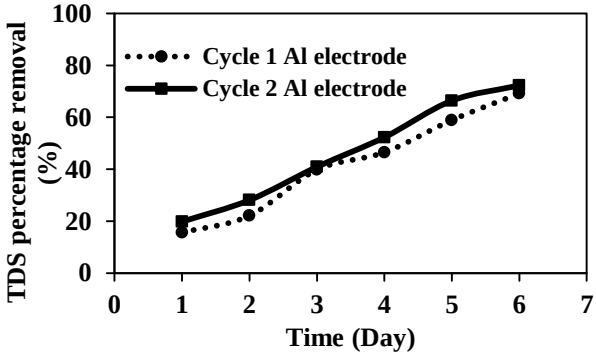

Chart-3: The removal efficiency of TDS of dairy wastewater used as fuel by DC-MFC using Aluminium electrode

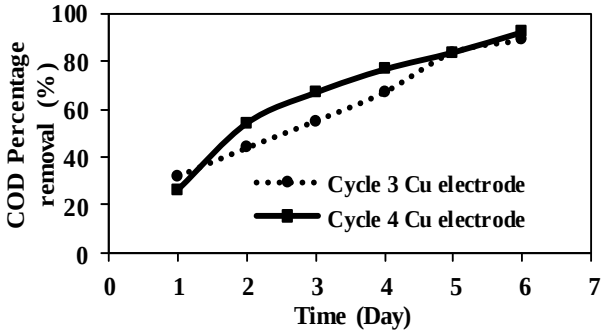

Chart-4: The removal efficiency of COD of dairy wastewater used as fuel by DC-MFC using Copper electrode

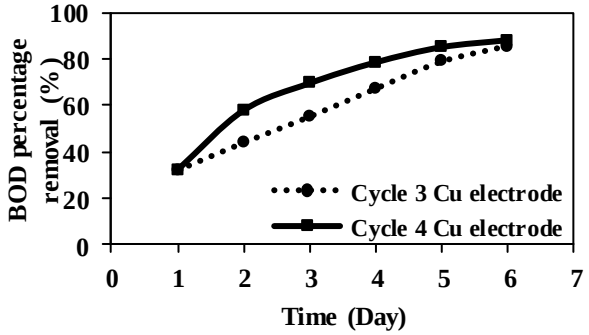

Chart-5: The removal efficiency of BOD of dairy wastewater used as fuel by DC-MFC using Copper electrode

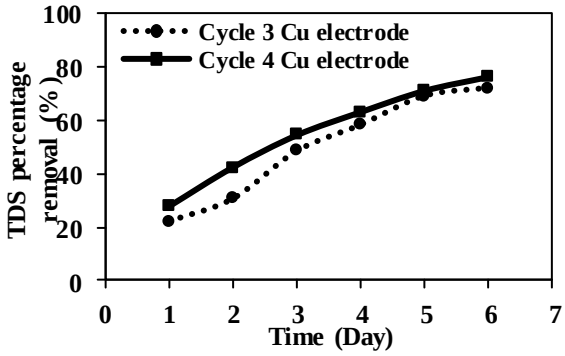

Chart-6: The removal efficiency of TDS of dairy wastewater used as fuel by DC-MFC using Copper electrode

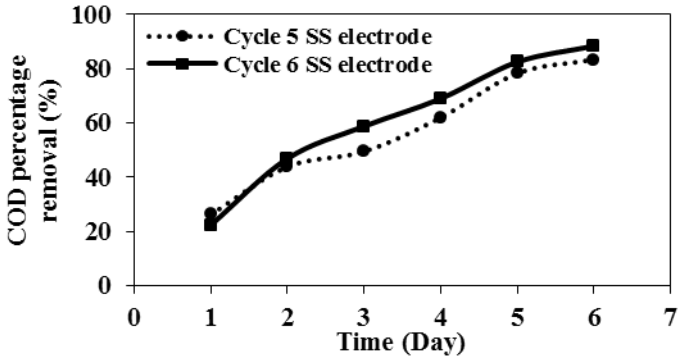

Chart-7: The removal efficiency of COD of dairy wastewater used as fuel by DC-MFC using Stainless Steel electrode

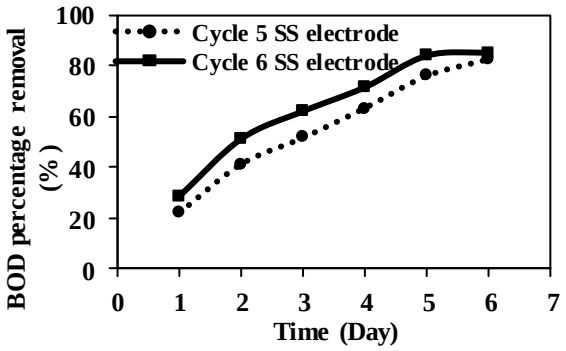

Chart-8: The removal efficiency of BOD of dairy wastewater used as fuel by DC-MFC using Stainless Steel electrode

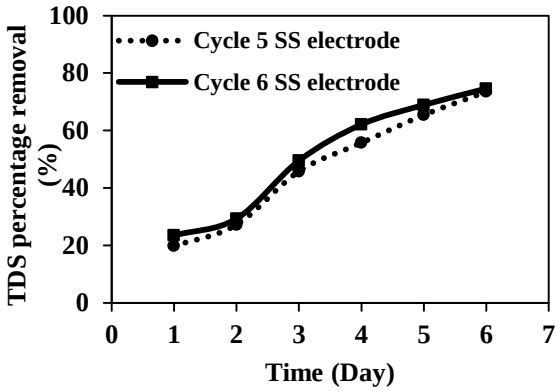

Chart-9: The removal efficiency of TDS of dairy wastewater used as fuel by DC-MFC using Stainless Steel electrode

Table 1: Initial Characterization of Dairy Wastewater

Sl. No.	Parameters	Raw Dairy Wastewater (Mysore Milk Union Pvt. Ltd.)
1	pH	6.6
2	Color	Brown
3	Conductivity	1536 µS
4	BOD	1258 mg/L
5	COD	3438 mg/L
6	TS	1296 mg/L
7	TDS	900 mg/L
8	Oil and grease	0.38 mg/L
9	Phosphate	14.95 mg/L
10	Nitrate	15.19 mg/L

Table 2: Comparison of the performance of MFCs in different concentrations of fuel

MFC type	Substrate	OLR (kgCOD/m³ d)		Max COD removal efficiency	Authors
Two chamber	Dairy wastewater	Cycle-2	1.94	84.2%	This study
		Cycle-4	2.188	92.2%	
		Cycle-6	2.188	88.3%	
Two chamber	Dairy wastewater	17.74 - 106.4		89%	[7]
Single chamber	Real field dairy wastewater	4.44		95.49%	[8]
Two chamber	Glucose	1.404 - 1.165		55.4%	[9]
Two chamber	Synthetic wastewater	0.559		74.20%	[6]
Single chamber	Urban wastewater	0.13 – 0.7		40-80%	[10]

3. CONCLUSIONS

This study has demonstrated effective treatment of dairy wastewater in DC-MFC under varied operating conditions. The maximum substrate removal obtained using Copper electrode was found to be 92.2% COD, 88.02% BOD and 76.3% TDS respectively, which is higher than the percentage removal obtained using Aluminium and Stainless steel electrode material. In the present study at higher OLR and retention time system reached maximum organic degradation (2.188 kgCOD/m³ d and 25.75 h). The experimental results of study show that membrane-less MFC are very effective for the treatment of wastewater.

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