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Study on Treatment of Blood from Abattoir using Microbial Fuel Cell (MFC) Technology with Production of Green Energy

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Abstract: Zero energy technologies and sustainable energy production are the two major concerns of present day researches. Microbial fuel cells (MFCs) are bioreactors that extract chemical energy stored in organic compounds, into electric potential, through bio-degradation. The core reason for the high strength of effluent generated from slaughterhouses is animal blood. The current study evaluates the potential of MFC technology to reduce the pollution strength of cattle blood in terms of chemical oxygen demand (COD). The current study was piloted in three stages using lab scale two chambered MFC: The first stage was to determine the best oxidising agent as compared to natural aeration from three accessible options, $KMnO_4$, diffused aeration and tape grass aquatic plant. $KMnO_4$ was found to be the superlative with a 30% reduction in COD in 100 hrs batch reactor and a maximum power of 0.97 mW using 125 mL livestock blood. The second stage of the study optimised the concentration of $KMnO_4$. At 500 mg/L $KMnO_4$ concentration, 50% COD removal efficiency was acquired in a batch reactor of 60 hrs with an average energy output of 1.3 mW. In the final stage on the addition of coconut shell activated carbon with an Anolyte at a rate of 40 mL/125 mL of substrate COD removal efficiency increased to 74.9%.

Key words: Adsorption, bio-energy, cattle blood, microbial fuel cell, wastewater treatment.

Introduction

Industrial development and population growth have brought about intensified need for fossil fuels for energy. For the past few decades, researchers are focusing more on fresh solutions for alternate energy sources, due to the depletion of non-renewable energy sources like fossil fuels and drastic changes in the climate. The inevitable byproduct of industrialisation is wastewater, generated from diverse industrial sectors (Halakoo et al., 2015). The energy intense, conventional wastewater treatment systems, demand the energy efficient alternative treatment technology, which will make the process/operation sustainable. In the recent past, anaerobic technologies are gaining increased attention for wastewaters treatment. At the same time, use of wastewater as a clean energy source with minimal or zero carbon dioxide emission is also growing attention due to global environmental concerns and energy insecurity. Microbial fuel cell technology utilises waste as a fuel for producing electricity (Sabat et al., 2013; Teli et al., 2016). In this approach, wastewater is considered as a resource, which, rather than using energy and producing waste solids to dispose off, will be regarded as a production plant, where wastewater is cleaned for the effective re-use and electricity is produced from the biodegradable organic pollutants with a lower carbon emission (Sreedharan and Pawels, 2016). MFC effectively uses micro-organisms naturally present or grown in wastewater as the catalyst to generate electricity during the degradation of waste organic matter. Thus, in MFC, wastewater treatment and electricity generation takes place simultaneously and hence will diminish the treatment cost.

Wastewater discharge from slaughterhouse is moderate to high strength containing about 45% soluble and 55% suspended organic contaminants. The major source of organics in wastewater is animal blood (Manjunath et al., 2000; Omole and Ogbiye, 2013). Animal blood contains 50 to 70% plasma and 30 to 50% cellular elements like red blood cells, white blood cells, platelets, etc. depending on the animal species (Bah et al., 2013). Ekman (1976) reported that cattle blood contains glucose (280-530 mg/L), urea (100-230 mg/L), and some inorganic elements like Na, Ca, K, Mg, P, etc. Blood is an unavoidable waste product of the meat processing industry, up to 4% of the animal weight. Blood produced in an abattoir, is a challenging waste product because of its clouting nature, very high pollution strength and the high volumes generated. It causes unhygienic conditions when discharged directly into the soil or water bodies (Bah et al., 2013). Wang et al. (2018) reported the suitability of slaughterhouse blood in an anaerobic digester with the production of methane as biogas.

Microbial Fuel Cell Technology

Microbial fuel cell is a microbial device that generates electrical potential during the oxidation of organic compounds with the help of microorganisms. A conventional MFC consist of anode and cathode, separated by a proton/cation exchange membrane. Microbes oxidise the organic substances anaerobically and produce protons and electrons within the anode chamber. Electrons are transferred to the anode and conducted to the cathode by the external circuit. The generated protons are migrated through the membrane to the cathode chamber (Sabat et al., 2013). Oxygen acts as the electron acceptor in the cathode chamber due to its strong oxidation potential. Thus, electrons combined with oxygen and protons, migrated through the membrane, forming H_2O as a clean by-product (Rabaey and Verstraete, 2005; Rahimnejad et al., 2015). The passage of electrons through an external circuit, creates bio-electricity.

Experimental investigations are done on MFCs to generate electricity directly from complex organic wastewater such as, domestic wastewater (Hays et al., 2011; Sreedharan and Pawels, 2016), sanitary effluent (Castroet al. 2014; Ieropouloset al. 2013), rice mill wastewater (Behera et al., 2010), dairy wastewater (Patil et al., 2011), molasses wastewater (Zhong et al., 2011), cheese whey (Antonopoulou et al., 2010), etc. Investigations are going on worldwide in MFC systems using wastewaters, being the most promising electron donors because of it's free availability and sustainable nature (Behera et al., 2010; Gil et al., 2003). Several recent researches proved that coconut shell activated carbon is a promising low cost adsorbent material used in the treatment of both organic and inorganic contaminants from wastewater (Jayan and Aryasree, 2019; Olafadehan et al., 2012). The present study tried to combine the effect of adsorption using coconut shell activated carbon to improve the treatment efficiency and generation of electric potential from MFC.

Experimental Investigations

Slaughter houses in sub-urban and rural areas discharge blood and untreated wastewater into the environment. Fresh blood coagulated and putrefied causing an offensive odour as well as sanitary and environmental issues. The present study was conducted to treat cattle blood using MFC technology. The potential developed between the electrodes is an added benefit of this technology.

Materials

A two chambered model of MFC was designed in Acrylic. Both cathode and anode chambers having a capacity of 125 ml each. Chambers were connected through a 30 mm diameter hole, where the cation exchange membrane (CMI-7000 Membranes International Inc., NJ, USA) separates the chambers. The chambers were coupled using nuts and bolts. To prevent leaks rubber gaskets were used as spacers and sealed using silicone sealant.

In this study fresh cattle blood, collected from a local slaughter house and treated at source with Sodium citrate as anti-coagulant, was used as substrate in an anode chamber. Light gauge copper wires, connected with Graphite electrodes, were used for the external circuit of MFC. Options like $KMnO_4$ solution, diffused aeration (using aquarium pump), Tape Grass Aquatic Plant and natural aeration were compared in cathode as oxygen sink at the end of the electron transport chain. Potassium permanganate ($KMnO_4$) was tried as the chemical electron acceptor in cathode chamber, being the safest chemical form even used as a disinfectant, compared to plenty of other chemical oxidising agent like potassium ferricyanide ($K_3[Fe(CN)_6]$), potassium dichromate ($K_2Cr_2O_7$), Fe^{3+}, Hg^{+}, Cu^{2+}, etc (He et al., 2015; Ucar et al., 2017). The last stage of investigation used coconut shell activated carbon along with the Anolyte, cattle blood, to modify the treatment efficiency of MFC.

Methodology

Experimental investigations were done in three stages: Stage one compared different modes of supplying electron acceptors in the cathode chamber. 1500 mg/L of $KMnO_4$ solution, Dissolve oxygen by diffused aeration, tape grass aquatic plant and distilled water taken in an open cathodic chamber proving possibility for natural surface aeration. The potential difference between electrodes was measured using digital multimeter. Initial and final COD of the blood samples were evaluated, using the standard titrimetric method, to obtain the treatment efficiency of MFC within 100 hrs time period. Voltage and current measurements were taken for a period of 5 hrs. at one hour interval daily and average daily voltage, current and produced power were calculated. Figure 1 shows the experimental configuration of MFC.

According to the first stage study, the chemical oxidising agent, $KMnO_4$, is found to be the most effective Catholyte media. The second stage of the study was a 60 hrs batch reactor, using different concentrations of $KMnO_4$. COD was evaluated to represent the treatment efficiency of MFC. Current and potential differences between electrodes were measured using digital multimeter, at 2 hrs interval.

The second stage of the study derived 500 mg/L of $KMnO_4$ to be the most effective concentration in terms of COD removal and bio-energy generation. But due to the limited COD removal efficiency, the third stage of investigation combined the effect of MFC with adsorption using coconut shell activated carbon. With 60 hrs of batch study both current and electric potential were measured at 2 hrs interval.

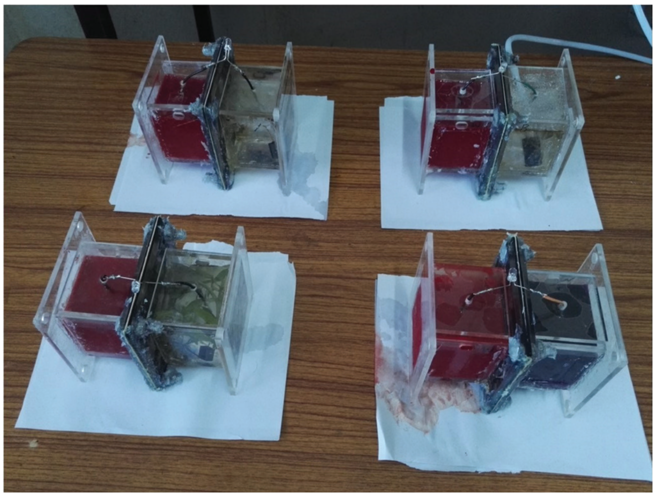

Figure 1: Two-chambered MFC Experimental setup.

In all stages of the experiment samples of blood were kept closed in anode chambers in an anoxic condition to develop anaerobic degradation. The control sample was also kept under the same environmental conditions to compare the treatment efficiency of MFC with respect to natural anaerobic degradation.

Results and Discusssion

Comparison of Different Oxidising Agents in the Cathodic Chamber

Cathodic media plays a vital role in the treatment efficiency and bio energy production of MFC. Figure 2 represents voltage generation from MFCs using cattle blood as substrate in the anodic chamber of MFC, with different oxidising agents in the cathode chamber. Chemical oxidising agent, $KMnO_4$, is found to be the best oxidising agent with maximum voltage and power generation compared to diffused aeration, tape grass aquatic plant and natural aeration in distilled water. MFC using $KMnO_4$ produced an average daily voltage in the range of 0.95 V to 1.22 V.

Figure 3 represents the calculated power generation as the product of voltage and current measurements of cells using multimeter. The maximum value of average daily power was 0.97 mW from the MFC chamber of using 125 mL cattle blood as substrate and $KMnO_4$ as an oxidising agent. Average power generation was found to be 0.88 mW, equivalent to the power density of 7 W/m^3 cattle blood treated.

Treatment efficiency of MFC is represented in Figure 4, in terms of % COD reduction of cattle blood. A total of 30% reduction in COD is found with $KMnO_4$ as an oxidising agent, the chamber from which maximum power was obtained. Natural anaerobic reduction of

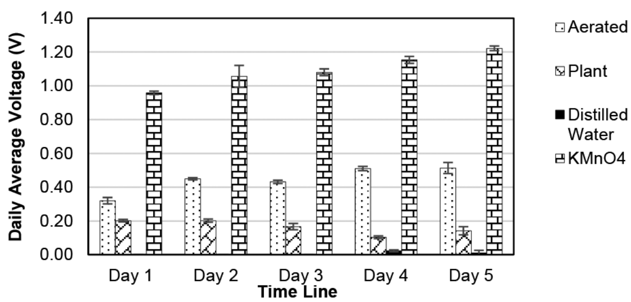

Figure 2: Voltage development in MFC using different oxidizing agents in the cathodic chamber

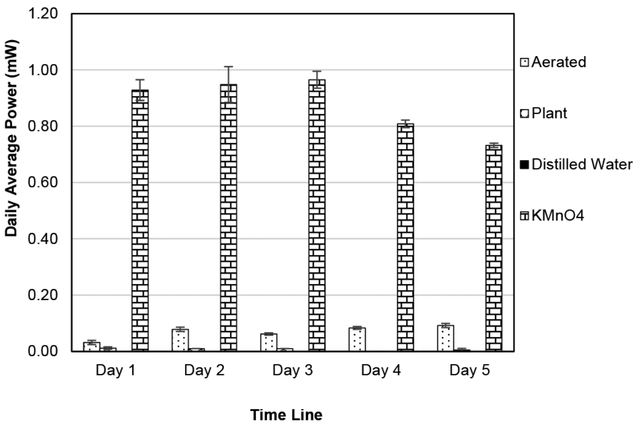

Figure 3: Power production from MFC using different oxidiszing agents in the cathodic chamber.

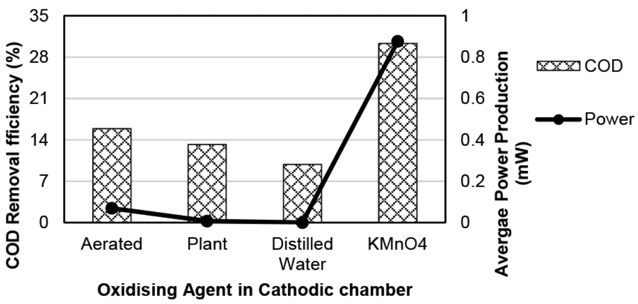

Figure 4: COD removal efficiency of MFCs compared to average power generation.

sample kept as control under similar anoxic, time and temperature condition found to be 7.64%. Better biodegradation was found in all MFC cells, compared to natural biodegradation even with lower power generation than $KMnO_4$ in the cathodic chamber.

Comparison of Concentration of $KMnO_4$ as Oxidising Agent in Cathodic Chamber

Different concentrations of $KMnO_4$ solution ranging from 0 mg/L to 1500 mg/L were used in the cathodic chamber to find out the optimum concentration of $KMnO_4$ for maximum biodegradation and power generation from MFC. Distilled water (0 mg/L) showed very little potential difference below the measurable level. Figure 5 shows the voltage generated between the electrodes at different concentrations of $KMnO_4$ in the cathodic chamber. A concentration of 250 mg/L showed a measurable potential difference in the range of 0.2 to 0.6 V. A total of 500 mg/L concentration of $KMnO_4$ produced maximum steady state potential 1.18 V to 1.2 V from 20^{th} hour of the batch reactor. A slightly reduced steady voltage is shown in all other higher concentrations of $KMnO_4$.

Power generation was calculated from the measured values of voltage and current (Figure 6). The maximum value of power was obtained from MFC with a $KMnO_4$ concentration of 500 mg/L. As the current was lowered in higher concentrations of $KMnO_4$, the power was effectively reduced at higher ranges of $KMnO_4$ concentrations. The maximum power obtained was 1.48 mW from MFC with $KMnO_4$ concentration of 500 mg/L in the cathodic chamber. Effective generation of power can be represented as 1.30 mW or power density as 10 Watt/m^3 of waste cattle blood.

Figure 7 represents the COD removal efficiency of MFC with different concentrations of $KMnO_4$. Compared to natural anaerobic biodegradation 9%

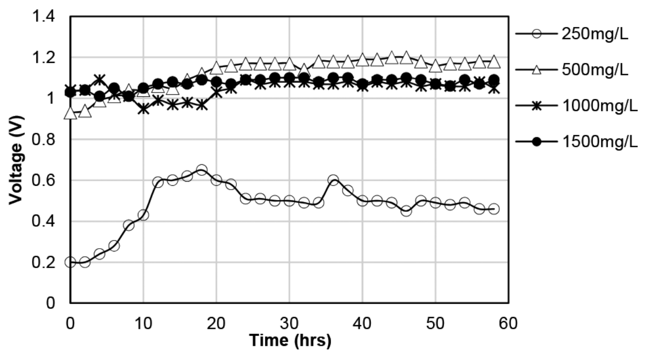

Figure 5: Voltage development in MFC using different concentrations of $KMnO_4$.

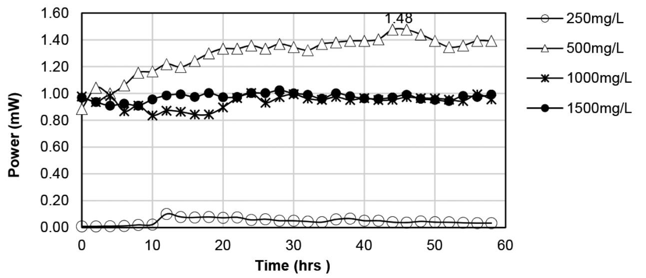

Figure 6: Power production from MFC using different concentrations of $KMnO_4$.

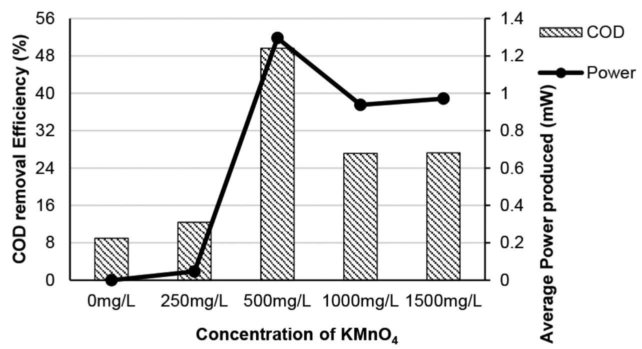

Figure 7: COD removal efficiency of MFC compared to power generation using different concentrations of $KMnO_4$.

reduction in COD in MFC without any oxidising agent, MFC with $KMnO_4$ concentration of 500 mg/L could reduce about 50% of COD. Maximum power generation coincides with maximum COD removal efficiency of MFC at $KMnO_4$ concentration of 500 mg/L. Even with other $KMnO_4$ concentrations in MFC, better biodegradation was found compared to natural anaerobic biodegradation. Electricity generation and H^+ ion migration provide a better condition for anaerobic degradation in the anodic chamber of MFC.

Coconut Shell Activated Carbon in MFC

Activated carbon was added to the anode chamber of MFC with cattle blood in terms of volume in three reactors. Compared to 20 mL, MFC added with 30 mL and 40 mL coconut shell activated carbon generated better electric potential from the cell. They produced potential in the range of 1.3 V consistently for a period of 30 hrs. MFC with 40 mL activated carbon produced a slightly higher potential. After crossing the 40 hrs reactor period, a slight reduction in potential was noticed with slight discolouration indicating the consumption of $KMnO_4$ solution. Figure 8 represents the potential generation from MFC added with coconut shell activated carbon.

Figure 9 shows the power generation from MFC. MFC with the highest content of activated carbon generated a slightly lower current, hence lower power.

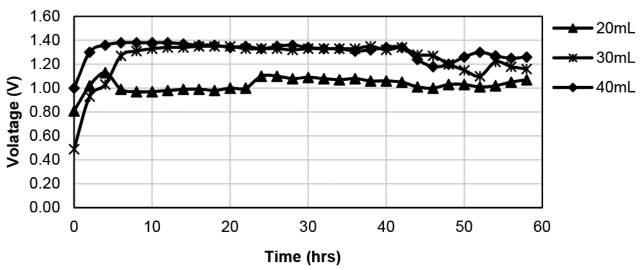

Figure 8: Voltage development in MFC with addition of activated carbon.

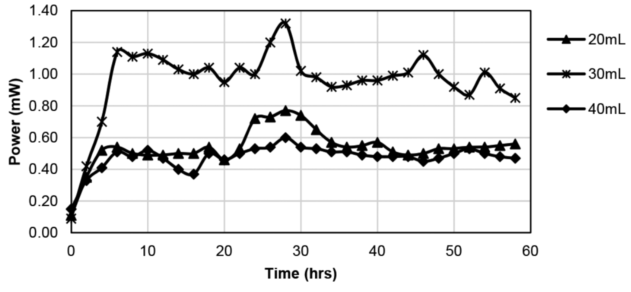

Figure 9: Power production from MFC with addition of activated carbon.

Maximum power was generated from MFC with 30 mL of activated carbon. This is indicated by higher internal resistance and lower substrate volume by the addition of excess activated carbon. Figure 10 clearly indicates that the combination of MFC and activated carbon improves the treatment efficiency of cattle blood. The combined effect of adsorption and anaerobic biodegradation could achieve a 74.9% COD removal efficiency for high strength cattle blood. But the addition of excess activated negatively affects on power generation potential of MFC by reducing the holding capacity of Anolyte.

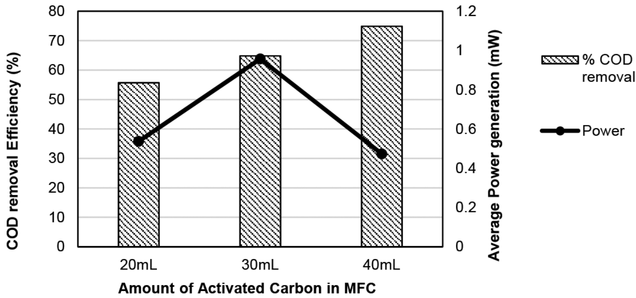

Figure 10: COD removal efficiency of MFC compared to power generation with addition of activated carbon.

Conclusion

According to Omole and Ogbiye (2013), the dung/partially digested food and blood which count about 5% of the total cattle slaughtered at abattoirs constitutes the greatest threat to the environment. Out of which dung will be converted and utilised as manure. Cattle blood, even though collected in liquid form, coagulated immediately. Hence, its mixing makes the wastewater more complex with higher strength of COD. Microbial fuel cell is a technology of the day with multiple benefits, found suitable for reduction in strength characteristics in order to reduce pollution problem. Conventional aerobic treatment systems are energy intensive creating higher treatment costs and anaerobic degradation is very slow. MFC, being a zero energy system with the production of power during treatment, is a more sustainable way of treating wastewater. From the results, it is clear that at an optimum concentration of 500 mg/L $KMnO_4$ in the cathodic chamber, maximum power of 1.48 mW or 11.84 Watt/m^3 was produced with almost 50% reduction in COD for cattle blood having raw average COD of 250,000 mg/L. Combination of adsorption with MFC is found to be an excellent option for better COD removal efficiency, even with lower power generation.

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