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Generation of electricity from dye industry wastewater in dual chamber fed batch operating microbial fuel cell

M. Dinesh Kumar
daviddinesh2009@gmail.com
Anna University Regional Campus, Tirunelveli, Tamil Nadu

M. Gunasekaran
mgunat@gmail.com
Anna University Regional Campus, Tirunelveli, Tamil Nadu

J. Rajesh Banu
rajeshces@gmail.com
Anna University Regional Campus, Tirunelveli, Tamil Nadu

ABSTRACT

Dye wastewater causes a major problem while discharging into the environment due to the presence of various toxic content. In this study, dye wastewater is treated using dual chamber MFC with the generation of electricity. The power generation and pollutant removal efficiency in the dye wastewater treatment using dual chamber MFC was examined at different HRT, which varied from 35 - 7 days. The maximum TCOD and SCOD removal of 66.10% and 57.94 % respectively were attained at the HRT of 35 days. In 20 days HRT, the maximum power density of 96.85mWm-2 and coulombic efficiency of 60.54% was procured.

Keywords— *Dual chamber MFC, Dye wastewater, Nafion membrane, Activated carbon fibre felt, Power density, Current density*

1. INTRODUCTION

Wastewater from industries is not easily discharged into the land and water bodies due to the presence of toxic content. Many stringent regulations are available and numerous advance treatment systems are identified to control the pollution. Due to the pollution and unsustainability of fossil fuels, the alternative energy is required in the future. MFC is an alternative system for sustainability energy recovery and pollution control treatment system. MFCs are a biochemical system in which electricity is produced by oxidizing the organic matter present in the wastewater [1]. A microbial fuel cell is an emerging technology for a sustainable treatment system to produce electricity through chemical reduction and catalytic oxidation during the treatment. MFC is not only used to produce electricity but also for wastewater treatment, thereby reducing the waste and toxic content in them [2]. MFC also useful in the production of alternative fuel production such as Hydrogen gas. Textile industry generates high-volumes of wastewater containing various chemicals used in dyeing, printing and finishing processes. Since effluents of dyeing units are highly toxic and dangerous; they must be treated with the right technologies to nullify its harmful effect on the environment. The characteristics of effluents may vary with the types of raw material used in the dye process, which renders a challenge in the adoption of the apt wastewater treatment technology. Dye effluents have high Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), colour, salt content and toxic content, which is difficult to treat. Moreover, dyes are highly visible material and thus even minor release into the environment may cause the appearance of colour that makes them aesthetically unacceptable which adversely affects environment due to its immense colour and toxicities.

In MFC, microorganisms are used as a catalyst to oxidize the organic and inorganic compounds in wastewater. During the MFC operation, substrate degradation produces the electrons and protons, in which electrons are transferred through the external circuit. The protons diffuse through the separator like PEM and contact with the oxygen and form H_2O. Several studies have already reported the application of MFC in the treatment of different real wastewater such as alcohol distillery wastewater [3], dairy industry wastewater [4], seafood processing wastewater [5], and surgical cotton industry wastewater [6]. Previous studies [1, 7] reported the treatment of dye wastewater in MFC with granular activated carbon as an electrode. In this study, dual chambered MFC the anode compartment consists of an Activated carbon fibre felt (ACFF) as an anode with microorganisms (inoculum) and wastewater whereas the cathode consists of ACFF with buffer solution. The objective of this study is (1) To treat the dyeing wastewater at different HRT in a fed-batch mode using dual chamber microbial fuel cell. (2) To evaluate the power generation along with the organics removal from the wastewater.

2. MATERIALS AND METHODS

2.1. Initial characteristics

The dye wastewater was collected from Tirupur district, Tamilnadu, India. The wastewater is stored at 4°c. The physic-chemical Characterization of dye wastewater such as pH, Total Solids, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Total Chemical Oxygen Demand (TCOD), Soluble Chemical Oxygen (SCOD) was analyzed based on Standard methods as detailed in APHA [8]. The initial characteristics of dye wastewater are given in Table 1.

Table 1: Initial characteristics of dye industry wastewater

S. No.	Parameters	Range
1.	pH	9.02 ± 0.2
2.	Total solids (mg/L)	8130 ± 150
3.	Total dissolved solids (mg/L)	5650±100
4.	Total suspended solids (mg/L)	2510±100
5.	Chemical oxygen demand (mg/L)	2200 ± 50
6.	Soluble chemical oxygen demand (mg/L)	1325±50
7.	Chlorides (mg/L)	2030 ± 100
8.	Total alkalinity (mg/L)	640 ± 50

2.2. Microbial fuel cell construction

Dual chamber MFC consists of two chambers: anode and cathode made up of plexiglass. Each of the chambers had a height of 11.2 cm and diameter of 7 cm contributing to an effective volume of 500ml. Anode and cathode are interconnected with a flange gasket, which holds the proton exchange membrane (Nafion 117). The Activated carbon fibre felt (ACFF) is a highly porous material used in this study for electrode material which favors the formation of biofilm [6] with the high specific surface area, well in adsorption and electric capability during the wastewater electrochemical treatment [9]. The projected surface area of an activated carbon fibre felt was 169 cm^2 (13*13) used as anode and cathode. The two electrode was placed at a distance of 5cm which is connected to an external circuit using insulated copper wires with a resistor. The measurement of voltage and current is done through a digital multimeter.

2.3 MFC operation

MFC operation in this study operated under the fed batch mode, wastewater is fed into the anode chamber and the phosphate buffer is introduced into the cathode chamber. TCOD of the dye wastewater was diluted in the range of 800 mg/L and then introduced into the anodic compartment. Inoculum used in this study is taken from the secondary clarifier of municipal wastewater treatment plant. Anode chamber in MFC was inoculated with both inoculum and dye wastewater under anaerobic conditions. To prevent the growth of methanogens, 2 mol m^{-3} of BES (2 e bromoethane sulfonate) is added to the anode chamber. After the acclimatization, the experiment was operated in different HRT from 35 days, 30 days, 25 days, 20 days, 15 days, 10 days, and 7days. In every HRT, COD removal efficiency, solids removal and power generation were verified.

2.4 Current production and voltage measurement

Voltage production of the microbial fuel cell by varying HRT was measured using a digital multimeter and the generation of current was calculated by the Eq.1

Ohm's law, $$I = V/R \tag{1}$$

Where, I = Current (A), V= Voltage (V) and R = Resistance (Ω) was calculated. Power density $P_{Density} = P/\alpha$ (mW m^{-2}) and current density ($I_{Density}$) = I/α (mA m^{-2}), (where α = anode surface area) were calculated. The coulombic efficiency (CE) of the MFC was calculated using the formula stated by Logan [10].

$$CE = 8\ I / (F\ q\ \Delta\ COD) \tag{2}$$

Where 8 is a constant, I = Current (A), F = Faraday number (C/mol), q = Influent wastewater (m3/s), Δ COD = COD removal (g/L). The polarization curve for each HRT was obtained by changing the external resistance in dual-chambered MFC.

3. RESULTS AND DISCUSSION

3.1 Effect of COD consumption rate on power generation

TCOD and SCOD concentration of dye wastewater were in the range of 800 ± 50 mg L^{-1} and 550 ± 50 mg L^{-1} respectively whereas the wastewater is introduced into the reactor. The reactor is operated under the fed-batch mode where the HRT was taken as 35 days, 30 days, 25 days, 20 days, 15 days, 10 days and 7 days. Figure 1 shows that the efficiency of TCOD removal of 66.10% and 52.59% were obtained at the HRT of 35 and 20 days.

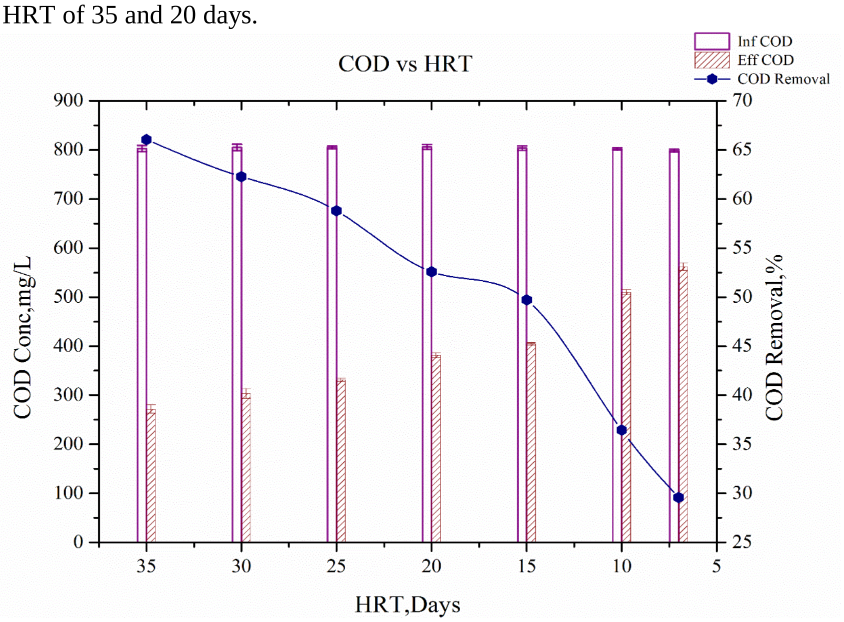

Fig. 1: TCOD concentration and its removal efficiency

Microorganism needs carbon sources to maintain their metabolism, and thus results in high COD removal. In fed-batch operation the flow rate might vary by the HRT, thereby rendering reduced time for the microorganism present in the anode chamber to degrade the organic matter. Therefore, the maximum HRT with low flow rate results in more COD removal and the minimum flow rate will fallouts less COD removal [11]. In accordance with that the less COD removal of 29.58% obtained in 7 days HRT. Figure 2 depicts the SCOD removal efficiency achieved at different HRT of the dye wastewater in the dual chamber MFC.

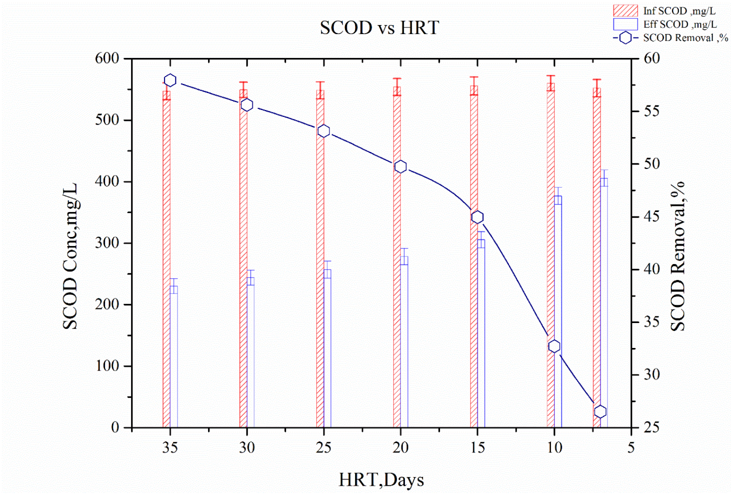

Fig. 2: SCOD removal efficiency at different HRT

The maximum removal of SCOD 57.94 % was achieved at the 35 days HRT, besides the minimum removal of 26.51% achieved at 7 days HRT. Similarly, Kalathil et al 2011 [1] discussed the treatment of dye wastewater using dual chambered MFC with granular activated carbon as both anode and cathode whereas the glass wool used as PEM. The authors achieved the COD removal of 71% and 76% in anode and cathode respectively. TCOD removal in wastewater can also be attributed to the adsorption of organics by a large number of microspores on the surface of the activated carbon fibre felt (ACFF) electrode. The substrate oxidized by the microbial community where attached to the electrode. In MFC anode chamber act as an anaerobic reactor which may be rich in methane-producing bacteria, this may lead to the less power production. The low coulombic efficiency obtained in MFC point out the presence of methanogens and high SCOD removal also indicate the less presence of electron genic bacteria [13] to prevent this BES is added in the anode chamber. Table 2 shows some of the SCOD removal treating dye wastewater using various electrode materials.

Table 2: Comparison of COD removal treating dye wastewater using various electrode materials

S. No	Type of Reactor	Anode	Cathode	COD removal	Reference
1.	Dual chamber	Granular activated carbon	Granular activated carbon	76%	[1]
2.	Single chamber	Granular activated carbon	Granular activated carbon	71%	[12]
3.	Dual chamber	Plain carbon felt	Granular graphite	89%	[21]
4.	Dual chamber	Graphite bars	Graphite bars	84%	[22]
5.	Dual chamber	Activated carbon fibre felt	Activated carbon fibre felt	66.10%	This study

3.2 Effect of HRT on Total suspended solids removal

The concentration of the total suspended solids in dye wastewater varied in the range of 2510±100 mg/L. Figure 3 shows the suspended solids removal of 63.43% and 41.27% at the HRT of 35 and 7 days. Initially, at 35 days HRT, the solids removal was maximum of 63.43% due to the wastewater retained for more days with least flow rate whereas at 7 days HRT the flow rate maximize and the wastewater is retained for minimum days. At the minimum loading of 35 days HRT, the solids attached on the electrode slowly degraded by the organism while at maximum loading the electrode fully clustered with solids and disturbed the removal efficiency. It implies the HRT role in the wastewater treatment of fed-batch mode dual chambered MFC.

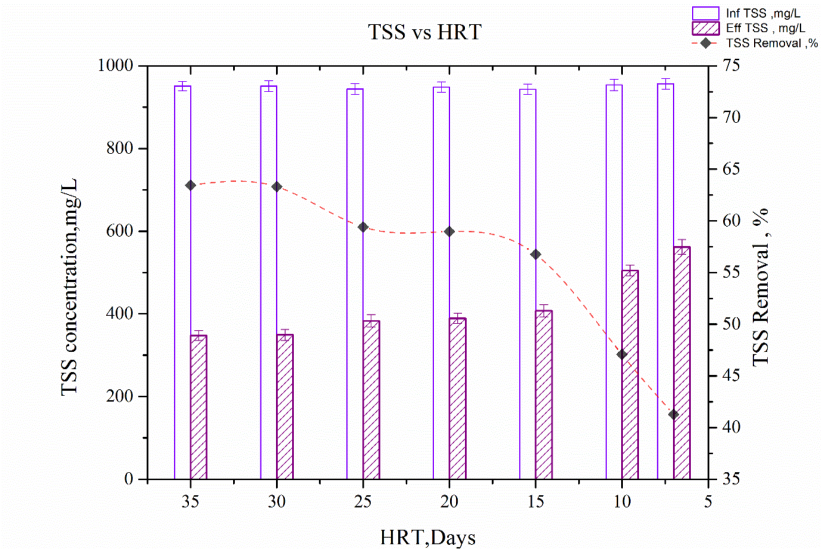

Fig. 3: TSS concentration and removal efficiency at different HRT

3.3 Power generation in MFC at different HRT

The power generation in the dual chamber fed-batch mode MFC was analyzed by varying different HRT from 35 days to 7 days. At the HRT of 35 days, the voltage was 235 mV at that period power density of 8. 94 mWm^{-2} was procured (figure 4). The highest power density of 96.85 mWm^{-2} was achieved at the HRT of 20 days with the voltage of 649 mV. During MFC operation substrate degradation takes place by the direct anodic oxidation mechanism where the pollutant attached on the surface of the anode and degraded resulted in terms of COD removal and generation of electrons and protons. Then the electrons transferred through cathode via external circuit [14] and generate current while the PEM diffuse the protons. The electrode distance had a considerable effect on the internal resistance and power generation when the electrode distance has been reduced then the power density may increase. This is because when the electrodes are in the longer distance there maybe ohmic loss [15]. The flow rate increased in decreasing HRT affects the power production and results in the low power density of 26.60 mWm^{-2} at the voltage of 389 mV (Fig. 5). The internal resistance of 302 Ω was recorded at the maximum power density of 98.85 mWm^{-2} at the HRT of 20 days. In this study, Activated carbon fibre felt (ACFF) act as both anode and cathode. As compared to the other electrodes, the porous structure of ACFF can increase the area of electrodes [16] which results in excellent electric adsorption capability and enhanced biofilm formation while treating dye wastewater. Due to the high specific area of ACFF, the biofilm was formed densely at the anode, which may help in the increase of power generation in the MFC operation. The power density reduction in the least HRT related with minimum time for substrate degradation at a maximum flow rate which contains toxic content. In MFC operation, low internal resistance is a significant part of the power generation. Electrode distance, electrode type, reactor configuration and loading rate are various factors which determine the internal resistance in the MFC process [17].

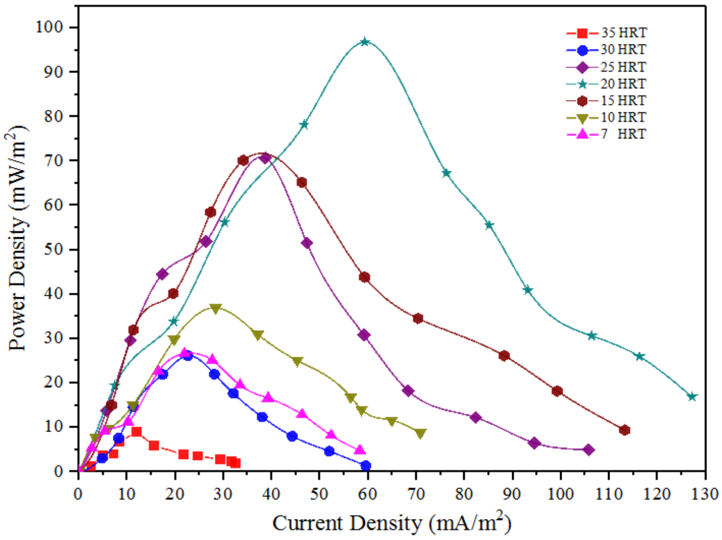

Fig. 4: Power density vs. current density at different HRT in days

A polarisation curve provides useful information to understand the behaviour of MFC and to estimate maximum power that can be delivered and its internal resistance [10]. It represents the cell voltage as a function of the current density. At the HRT of 35 days, the power density and current density of 8.94 mW/m^2 and 32.41mA/m^2 respectively was procured. The maximum power density, current density, and voltage values are 96.85mW/m^2, 127.16 mA/m^2 and 649 mV respectively obtained at 20 days HRT. While transferring the electron from the anode to the cathode chamber, energy loss occurs at both the electrodes. This change in energy level can be measured in terms of electrode potential. The current in the MFC was calculated and recorded by dividing the obtained voltage to the specified resistance. At 7 days, the power density, current density, and voltage values are decreased to 26.60mW/m^2, 58.27mA/m^2 and 389 mV respectively.

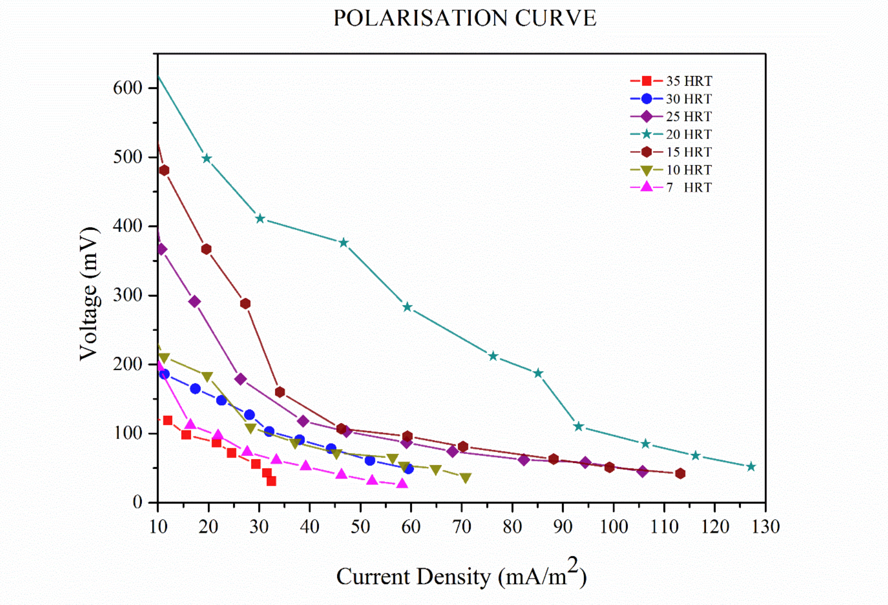

Fig. 5: Voltage vs. current density at different HRT in days

3.4 Coulombic efficiency

The ratio of the actual charge generated to the theoretical charge generated if the substrate is completely converted to electricity is known as coulombic efficiency. The coulombic efficiency was increased due to the presence of electro genic bacteria, but it may gradually decrease due to the presence of other bacteria [6]. At 35 days HRT, the coulombic efficiency and power density production of 21.61% and 8.94mWm^{-2} were achieved as shown in Fig. 6. Due to the effective role of electro genic bacteria at the anode chamber, the power generation was maximum at the HRT of 20 days along with the highest coulombic efficiency of 60.54%. The least coulombic efficiency of 17.56 %.was obtained at the HRT of 7 d at a maximum flow rate.

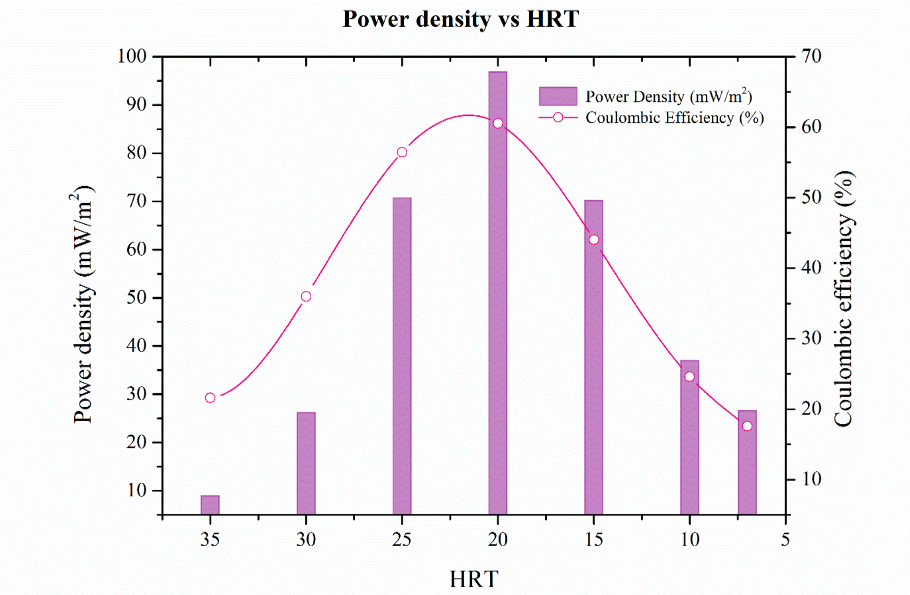

Fig. 6: Coulombic Efficiency and Power density at different HRT

4. CONCLUSION

The dual chamber MFC operated at fed batch mode to treat the dye industry wastewater accomplished generation of electricity along with the removal of organic matter. The maximum power density of 96.85 mW/m^2 was achieved at the HRT of 20 days with the coulombic efficiency of 60.54%. The maximum TCOD and SCOD removal of 66.10% and 57.94% respectively were achieved at the 35 days HRT. As a result, this study concluded that the MFC could be a suitable alternative for the removal of biodegradable components present in the dye industry wastewater with the power generation.

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