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ORIGINAL RESEARCH PAPER

Pollution reduction and electricity production from dairy industry wastewater with microbial fuel cell

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ABSTRACT

Taguchi L_9 orthogonal array was implemented to select optimum values of process parameters and to attain the maximum removal of pollutants and power generation from dairy industry wastewater using double chambered salt bridge microbial fuel cell. The maximum chemical oxygen demand reduction, current, voltage, power, current density and power density in double chambered salt bridge microbial fuel cell from dairy industry wastewater was found to be 86.30 %, 16.10 mA, 886.34 mV, 14.27 mW, 1219.69 mA/m^2 and 1081.06 mW/m^2 respectively for the optimum value of 1M NaCl concentration, 10 % agar concentration and 0.10 m salt bridge length. Double chambered salt bridge microbial fuel cell was not only removed chemical oxygen demand and produced power, but it also removed other pollutants at the maximum level against the best optimum value of process parameters from the dairy industry wastewater. The proposed regression model was used to select the right combination of process parameters for obtaining a maximum reduction of pollutants and simultaneous power production from the dairy industry wastewater.

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INTRODUCTION

Large quantities of wastewater generated day by day from rapid urbanization and industrialization and the management of large quantities of wastewater are highly imperative. The utilization of wastewater is increasing attention because of the depletion of fossil resources to meet the growing energy demand. Getting the energy from wastewater is an important task to meet the present energy needs since wastewater has a more energy storage reservoir (Liu and Cheng, 2014). The energy stored in the wastewater depends on the characteristics of wastewater and characteristics differ from industries to industries based on the processes used for manufacturing the various products (Drisya and Manjunath, 2017a). In order to compensate for the reducing energy sources to meet the requirements of urbanization and industrialization, it is a necessity to find alternate more economically sustainable energy sources. Energy production from wastewater is considered a justifiable approach for meeting the growing energy demands (Pant, *et al.,* 2010). Some technologies used for reducing the cost of wastewater treatment and recovering useful products. Microbial fuel cell (MFC) is one of such techniques to meet the energy demands for simultaneous treatment and power production from wastewater (Oliveira, *et al.,* 2013). MFC produces electricity to meet the energy demand through the metabolic activities of the microorganisms in the substrate (Fradler, *et al.,* 2014; Akshay, *et al.,* 2016). Anaerobic conditions are essential for digesting substrate by organisms and producing the electrons (Moqsud, *et al.,* 2013). The anaerobic treatment method of wastewater converts the chemical energy into H_2, CO, and methane, which in turn used as fuel for producing the electricity. In the case of MFC, chemical energy is directly used to produce electricity along with the treatment of wastewater (Logan, 2010). Thus, in the present scenario, MFC is one of the promising technologies to meet the increasing energy demands and to reduce fossil fuel consumption (Shahgaldi, *et al.,* 2014). Most of the fuel cells produce electricity from fossil fuels; however, the MFC produces electricity from COD in the organic matter of wastewater. The operating cost of wastewater treatment is reduced in MFC because it is used to convert the chemical energy stored in the organic matter of substrate directly and the same is used for producing the electricity (Dewan, *et al.,* 2010). The MFC consists of an anode and cathode chambers such that anode chamber is filled by any wastewater as substrate either with or without inoculum and the cathode chamber is filled by electrolyte with or without a supply of oxygen (Li, *et al.,* 2014). These two chambers are connected either by the Nafion proton exchange membrane (Rahimnejad, *et al.,* 2012) or by agarose salt bridge (Sarma, *et al.,* 2019), NaCl for transferring electrons and protons between them. Both anion and cation exchange membranes instead of proton exchange membrane used for performing the MFC using ocean water to produce electricity (Jafary, *et al.,* 2017). In MFC, electrons are passing through the external electrical circuit and protons are passing through proton exchanger from anode chamber to the cathode chamber, where electrons combine with oxygen to form water. In the anode chamber, microorganisms grow exponentially with the help of inoculum along with the substrate used. MFC generates electricity by using the organic sources of wastewater including glucose, acetate, ethanol, protein, cellulose, and polysaccharides. MFC is not only producing electricity but it is also used to treat the wastewater (Pant, *et al.,* 2010). Furthermore, mediators like methylene blue and neutral red used in the anode chamber enhance the transfer rate of protons and electrons to the cathode chamber from the anode chamber through either membrane (Ghasemi, *et al.,* 2016) or salt bridge. The mediators are nontoxic to the microorganisms, stable in both oxidized and reduced form and not biologically degradable. The electrons from microorganisms' cells are squeezed out during metabolism by the mediators and the mediators enhance the liberation of electrons from microorganisms to the electrode in the anode chamber. Sufficient organic matter and micro-organisms available in the substrate of the anode chamber may not have the mediator for supplying more electrons, and thus some of the MFCs are performed without a mediator. The performance of the mediator less MFC depends on the surface area of the electrode used. Mediator-less microbial fuel cells are normally used special microorganisms (Li, *et al.,* 2013a) that able to release electrons to the anode depends on the quantity and characteristics of substrate and inoculum available in the anode chamber (Venkata Mohan, *et al.,* 2007). Some of MFCs were performed with mediators (Sevda and

Sreekrishnan, 2012; Khare, 2014; Parkash, *et al.,* 2015) and without mediators (Li, *et al.,* 2013b; Adeleye and Okorondu, 2015; Ali, *et al.,* 2018; Sahana and Manjunath, 2018; Sarma, *et al.,* 2019). More surface area of the electrode and good quality of the substrate, more transfer of electrons from anode to cathode chamber through either membrane or slat bridge, and external circuit and vice versa. Single chambered MFC (Khare, 2014) and double chambered MFC (Parkash, *et al.,* 2015) were performed for producing electricity from synthetic wastewater (Sevda and Sreekrishnan, 2012), food wastewater (Li, *et al.,* 2013b), biscuit factory wastewater with vermicompost (Khare, 2014), hostel wastewater (Adeleye and Okorondu, 2015), dairy industry wastewater (Parkash, *et al.,* 2015; Drisya and Manjunath, 2017a, Sahana and Manjunath, 2018), wastewater (Ali, *et al.,* 2018) and vegetable slurry (Sarma, *et al.,* 2019). Graphite rod (Sevda and Sreekrishnan, 2012; Ali, *et al.,* 2018), carbon rod (Khare, 2014), stainless steel rod (Drisya and Manjunath, 2017b; Sarma, *et al.,* 2019), copper electrode (Parkash, *et al.,* 2015; Adeleye and Okorondu, 2015; Sahana and Manjunath, 2018), and granular graphite (Li, *et al.,* 2013a), were used as anode and cathode for producing electricity through external electrical circuit. In addition to the above, graphite plates, carbon paper, carbon cloth and carbon granules were also used for increasing the power generation from any wastewater. Though MFC was operated with various process parameters, the selection of the optimum value of those process parameters only yields the maximum output using wastewater. The conventionally designed optimization may not give satisfactory results on the selected parameters, but the Taguchi method of optimization technique provides satisfactory results toward the target since it is based on the ideas drawn from the design of experiments. The MFC also performed by using response surface methodology (RSM) (Sedighi, *et al.,* 2018 ; Aravind *et al.,* 2016), artificial neural network (ANN) (Ali, *et al,* 2018) approach and neural network (NN) approach (Feng, *et al.,* 2013) for producing current, voltage and power. In this study, the Taguchi approach was chosen for optimizing the double chambered salt bridge microbial fuel cell (DCSB-MFC) using different NaCl concentration, agar concentration and salt bridge length with other selected process parameters from dairy industry wastewater to obtain the maximum pollutants reduction and power production. The Taguchi orthogonal array can facilitate the selection of an optimum value from the process parameters to achieve the maximum reduction of pollutants and maximum production of power from dairy industry wastewater. The relationship between selected parameters and their performance was analyzed using the signal to noise (S/N) ratio and the most influencing parameter among the selected parameters was identified by analysis of variance (ANOVA). The optimum parameters were used for conducting the control experiment to check the maximum output. The regression analysis was used to develop the mathematical model on COD reduction and power production and it predicts the wide range of operating parameters combination. This study was conducted in the Environmental Engineering Laboratory of Vel Tech High Tech Dr. Rangarajan Dr. Sakunthala Engineering College, Chennai, Tamil Nadu, India in 2019.

Table 1: The Characteristics of Dairy Industry Wastewater

Sl.No.	Parameters	Values*
1	pH	8.5 – 9.8
2	Colour	White colour
3	Total suspended solids (mg/L)	1428.2 ± 30
4	Total dissolved solids (mg/L)	3625.1 ± 70
5	BOD_5 (mg/L)	2850.5 ± 56
6	COD, mg/L	4321.4 ± 95
7	Nitrate (mg/L)	48.1 ± 6
8	Phosphate (mg/L)	55.2 ± 9
9	Oil and grease (mg/L)	915.5 ± 16
10	Sulphate (mg/L)	780.8 ± 24
11	Chloride (mg/L)	82.8 ± 11
12	Ammonia (mg/L)	15.2 ± 3

*average of three trials

METHODS AND MATERIALS

Wastewater collection

The dairy industry wastewater collected from Ambattur Dairy Products in Chennai, Tamil Nadu (The latitude is 13° 6′ 51.54″ N and the longitude is 80° 8′ 52.99″ E) was collected using the airtight container and it was used as a substrate for bioelectrical generation using DCSB-MFC. The sludge obtained from the primary clarifier of the dairy industry wastewater treatment plant was filled in the anode chamber, used as inoculum. The anode chamber was sealed to create an anaerobic condition before testing the DCSB-MFC using the dairy industry wastewater. The characteristics of dairy industry wastewater are presented in Table 1.

Experimental setup

The schematic diagram and photographic view of DCSB-MFC is shown in Fig. 1a and 1b, respectively. The sludge collected from the primary clarifier of the dairy industry wastewater treatment plant is used for enhancing the electron supply. The culture in the sludge along the culture in the substrate (dairy industry wastewater) converts the chemical energy into electrical energy directly during the metabolic activities. The double chamber batch mode salt bridge MFC was designed for this study consists of two chambers of 5 L capacity and the two chambers were connected by the salt bridge. The anode and cathode chambers were sterilized by washing with double distilled water and followed by ethyl alcohol. The length of the salt bridge varied from 0.05 m

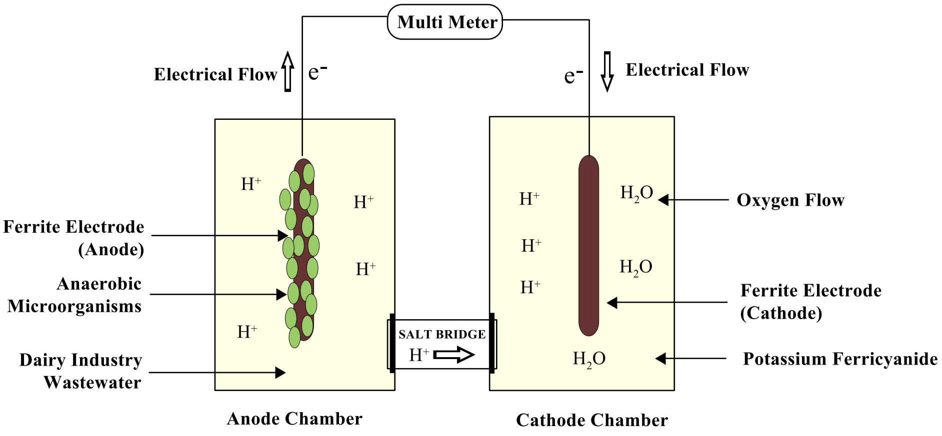

Fig. 1a: Schematic diagram of double chambered salt bridge microbial fuel cell

Fig. 1b: Photographic view of double chambered salt bridge microbial fuel cell

to 0.15 m with a constant diameter of 0.02 m. The various salt bridge lengths were prepared by mixing of different NaCl concentrations of 1M, 2M and 3M, and agar concentration of 5 %, 10 %, and 15 %. The mixture of various combinations of NaCl and agar concentrations was boiled at low flame for 5 min. and then the mixture was poured into the PVC pipe and sealed. Finally, the sealed salt bridge was kept in a refrigerator for solidification (Sarma, *et al.,* 2019).

The ferrite rod was used as anode and cathode in both anode and cathode chambers because of more strength and high electron transfer capacity characteristics. The copper wire was connected between the anode and cathode chambers externally and the salt bride was connected between anode and cathode chambers to make the system a closed circuit. The sterilized anode chamber was filled with 4.75 L dairy industry wastewater. No mediator was used for enhancing the liberation of electrons from the microbial cell. The pH of a substrate in the anode chamber and electrolyte in the cathode chamber was maintained with neutral value by adding sodium hydroxide and sulphuric acid. Nitrogen gas was used to remove the air inside the anode chamber and make the anode chamber in anaerobic conditions. The sterilized cathode chamber is filled with a 1M $K_3Fe(CN)_6$ solution as an electron acceptor. The oxygen was supplied (10 m^3/h) to the cathode chamber for increasing the oxygen content of the electrolyte. Digital multimeter was used for measuring the voltage and current generation from dairy industry wastewater using DCSB-MFC. The power, current density, and power density were calculated using the Eqs. 1, 2 and 3, respectively.

$$\text{The power (P)} = I \times V \tag{1}$$

$$\text{The Current Density (CD)} = \frac{I}{A} \tag{2}$$

$$\text{The Power Density (PD)} = \frac{P}{A} \tag{3}$$

In Eqs. 1, 2 and 3, ‘P’ is the power in Watt (W), ‘V’ is the voltage in Volt (V), ‘I’ is the current in Amps (A), ‘A’ is the total area of anode electrode in m^2, ‘CD’ is the current density in A/m^2 and ‘PD’ is the power density in W/m^2. The measured voltage and current are the open-circuit configurations. APHA, (2017) experimental procedures were followed in this study for determining various characteristics such as pH, colour, TSS, TDS, BOD, COD, nitrate, phosphate, sulphate, chloride, ammonia and oil and grease present in the dairy industry wastewater using MFC (before and after treatment). The percentage reduction of various pollutants was calculated (Sivakumar, 2015) using the Eq. 4.

$$\text{The Percentage Reduction (\%)} = \frac{C_i - C_f}{C_i} \text{x}100 \tag{4}$$

in which, C_i and C_f are the initial (mg/L) and final (mg/L) concentrations of various pollutants in dairy industry wastewater using DCSB-MFC.

Operation of DCSB-MFC

This study utilized the dairy industry wastewater for producing bioelectricity in DCSB-MFC. The DCSB-MFC was operated in batch mode for the duration of 10 days to observe the voltage and current generation from the dairy industry wastewater. The microorganisms of a substrate in the anode chamber utilize the sugar from organic matter for their metabolisms and convert the chemical energy into electrical energy directly. The electron from the anode moved through the external circuit to the cathode and proton moved through the salt bridge between the anode and cathode chambers for bioelectricity production from dairy industry wastewater. Thus, the microorganisms in a substrate are acted as biocatalyst for producing the electrons. The voltage and current generated in DCSB-MFC were recorded with the help of a digital multimeter. The power, current density, and power density were calculated using the Eqs. 1, 2 and 3. The various pollutants concentration was determined as per the procedure stipulated by APHA, (2017). The average of three trials was considered the observed value corresponding to all measurable parameters.

Taguchi method

The conventionally designed optimization may not give satisfactory results on the selected parameters, but the Taguchi method of optimization technique provides satisfactory results toward the target since it is based on the ideas drawn from the design of experiments. Taguchi technique also reduces the number of trials conducted in the Laboratory to achieve the target through experiments (Venkata Mohan, *et al.,* 2009b; Sarma, *et al.,* 2019). In this study, L_9 (3x3) Taguchi orthogonal array was implemented.

Table 2: Process parameters and their levels

Process parameters	Levels		
	1	2	3
NaCl molar concentration (A)	1M	2M	3M
Agarose concentration (B)	5 %	10 %	15 %
Salt bridge length (C)	0.05 m	0.10 m	0.15 m

The selected levels for the process parameters were NaCl molar concentration of 1M, 2M, and 3M, agar concentration of 5 %, 10 % and 15%, salt bridge length of 0.05 m, 0.10 m and 0.15 m.

Signal to noise (S/N) ratio

The logarithmic function of the S/N ratio is used to optimize the process design and reduce the variability. The maximum value of the S/N ratio in each level against the process parameters can be used to minimize the undesirable and uncontrollable factors. In this study, the S/N ratio was used to select the optimum value of process parameters for reducing the pollutants and producing the power from the dairy industry wastewater using DCSB-MFC. Larger the better category (Eq. 5) was chosen to optimize the performance of the DCSB-MFC for maximum reduction of pollutants and power production from dairy industry wastewater (Venkata Mohan, *et al.,* 2009b; Sarma, *et al.,* 2019).

$$\frac{S}{N} = -10 \text{ x} \log 10\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \tag{5}$$

In Eq. 5, 'n' is the number of observations and 'Y' is the response corresponding to the selected process parameters.

Analysis of variance (ANOVA)

Analysis of variance is used to know the individual effect and interaction effects of independent variables on dependent variables for getting the maximum output. ANOVA is also used to know the most influencing an independent variable on a dependent variable to achieve the response at the maximum level. The Minitab 18 (version 18.1) package was used for analyzing the data obtained from the experimental investigations for this study.

Statistical analyses

SPSS Statistics (Version 26) software was used in this study for doing the statistical analyses against the all observed values from the performance of DCSB-MFC using dairy industry wastewater.

RESULTS AND DISCUSSION

Experimental investigations were carried out for reducing the pollutants and producing the power simultaneously from dairy industry wastewater in DCSB-MFC with the various process parameters viz., ferrite electrode, ferrite electrode surface area of 0.0132 m^2 (0.2 m length and 0.02 m diameter), dilatation ratio of "0" (the raw dairy industry wastewater concentration), the operating temperature of 28 °C (room temperature), no mediator, no additional electron transfer microorganisms, an oxygen flow rate of 10 m^3/h, 1M $K_3Fe(CN)_6$ electron acceptor against different NaCl molar concentration, agarose concentration and length salt bridge. The different process parameters and the levels were chosen for this study is presented in Table 2. The Taguchi orthogonal arrays were framed according to the three process parameters viz., NaCl molar concentration, agarose concentration and salt bridge length at three different levels. The parameters and levels assigned to the L_9 orthogonal arrays and are presented in Table 3. The experiments were conducted with three trials to make the system consistency and the average value only considered as a maximum value obtained from this study against each observable parameter. The larger the better category was implemented in this study to get the optimized parameters at various levels. The experiential results using Taguchi L_9 Orthogonal arrays on COD removal,

Table 3: Taguchi orthogonal arrays (L_9)

Experimental runs	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	3
5	2	2	1
6	2	3	2
7	3	1	2
8	3	2	3
9	3	3	1

current, voltage, power, current density, and power density from dairy industry wastewater in DCSB-MFC are presented in Table 4.

Fig. 2 shows the COD reduction percentage obtained from dairy industry wastewater using DCSB-MFC for the experimental Run 2. From Fig. 2, it may be observed that the combination of 1M NaCl concentration, 10 % agar concentration and 0.10 m slat bridge length yielded the maximum reduction of COD from dairy industry wastewater. The maximum COD reduction percentage observed in Run 2 was 82.33 % and the corresponding removal concentration of COD from the substrate was found to be 3557.47 mg/L (an initial concentration of 4321.1 mg/L). Thus, the optimum process parameters combination for which maximum reduction of COD occurred are 1M NaCl concentration, 10 % agar concentration and 0.10 m slat bridge length (Run 2) followed by various other combinations as mentioned in Run 5, Run 1, Run 3, Run 9, Run 8, Run 6, Run 4, Run 7 respectively (Table 4). The least COD reduction percentage of 56.26 % was observed for Run 7. Fig. 3 depicts the voltage observed for the experimental Run 5 against the operation period of 10 days in DCSB-MFC from the dairy industry wastewater since Run 5 only produced maximum voltage than other experimental Runs. From Fig. 3, it could be seen that the maximum voltage was found to be 843.43 mV (Table 4) from the dairy industry wastewater for the combination of 2M NaCl concentration, 10 % agar concentration and 0.05 m slat bridge length in DCSB-MFC. The maximum voltage corresponding to the maximum power generation from dairy industry wastewater using DCSB-MFC was 711.78 mV (Run 2), but the maximum current observed was

Table 4: L_9 orthogonal designs, levels of three parameters and experimental results

Experimental runs	Experimental design			Experimental results					
	A	B	C	COD removal (%)	Current (mA)	Voltage (mV)	Power (mW)	Current density (mA/m²)	Power density (mW/m²)
1	1	5	0.05	78.31	10.32	818.80	8.45	781.82	640.15
2	1	10	0.10	82.33	14.85	711.78	10.57	1125.01	800.76
3	1	15	0.15	76.31	9.76	754.10	7.36	739.39	557.58
4	2	5	0.15	59.23	8.76	713.47	6.25	663.64	473.48
5	2	10	0.05	80.24	11.56	843.43	9.75	875.76	738.64
6	2	15	0.10	65.45	8.32	644.23	5.36	630.30	406.06
7	3	5	0.10	56.26	7.58	679.42	5.15	574.24	390.15
8	3	10	0.15	72.17	9.05	766.85	6.94	685.61	525.76
9	3	15	0.05	74.39	9.38	754.80	7.08	710.61	536.36

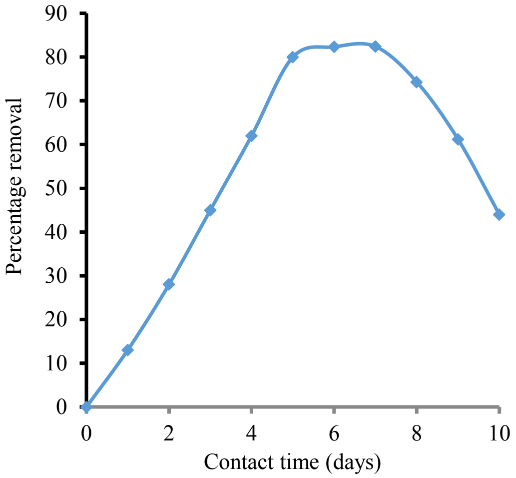

Fig. 2: COD removal percentage for the run 2

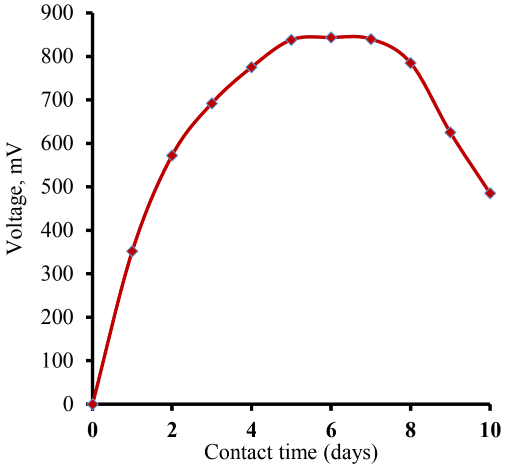

Fig. 3: Voltage production for the run 5

14.85 mA (Run 2) and this observed maximum current contributed the maximum power out from DCSB-MFC, whereas, the observed maximum voltage was 843.43 mv from Run 5 (Table 4). The least voltage was found to be 644.23 mV for Run 6 with the combination of 2M NaCl concentration, 10 % agar concentration and 0.05 m slat bridge length in DCSB-MFC.

Figs. 4 and 5 indicate the current and power generation respectively for the experimental Run 2 against the operation period of DCSB-MFC from dairy industry wastewater since Run 2 produced the maximum current and power than other experimental Runs. From Figs. 4 and 5, it could be seen that the maximum current and power generation were found to be 14.85 mA and 10.57 mW respectively (Table 4) from the dairy industry wastewater for the combination of 1M NaCl concentration, 10 % agar concentration and 0.10 m slat bridge length using DCSB-MFC. The least current and power generation was found to be 7.58 mA and 5.15 mW respectively for the Run 7 with the combination of 3M NaCl concentration, 5 % agar concentration and 0.10 m slat bridge length using DCSB-MFC. Figs. 6 and 7 showed the maximum current density and power density obtained from the experiential Run 2. From Figs. 6 and 7, it may be found that the maximum current density and power density

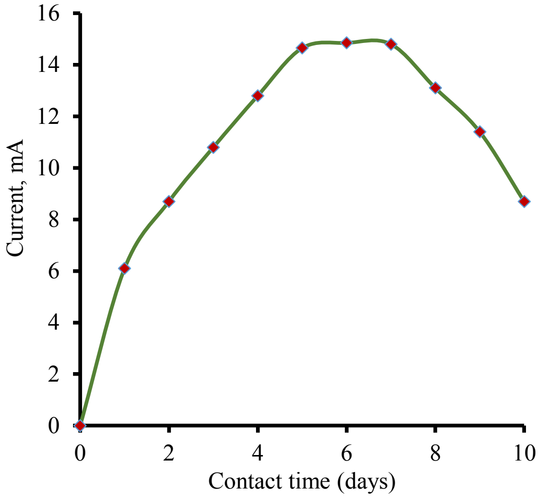

Fig. 4: Current production for the run 2

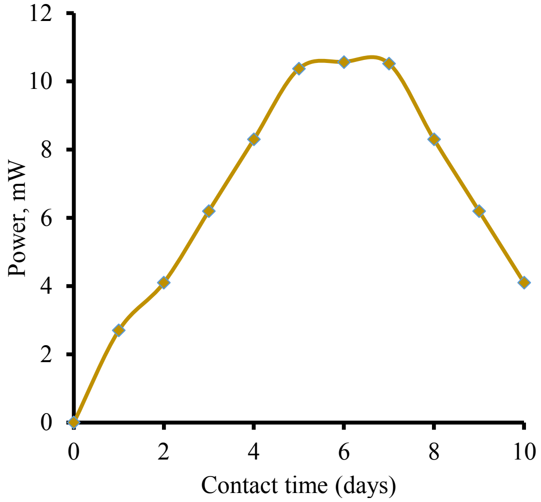

Fig. 5: Power production for the run 2

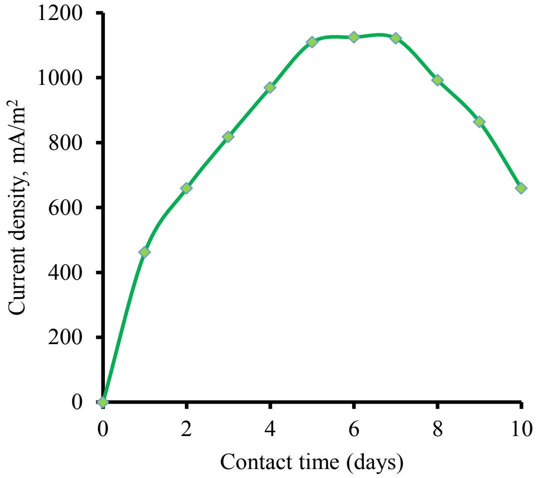

Fig. 6: Current density for the run 2

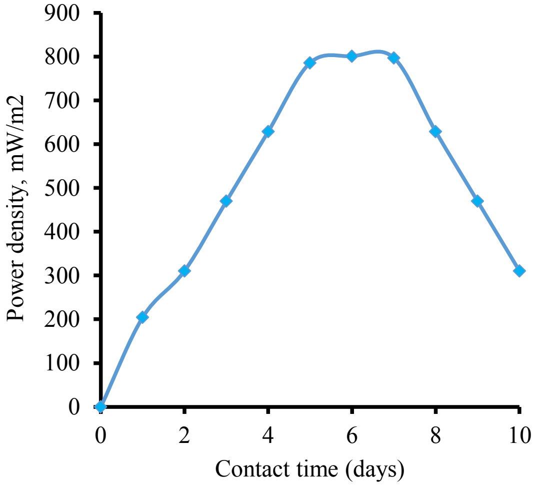

Fig. 7: Power density for the run 2

was 1125.01 mA/m^2 and 800.76 mW/m^2 respectively (Table 4). The trend of current density (Fig. 6) and power density (Fig. 7) was similar to that of current and power respectively (Figs. 4 and 5). From Table 4, 1M of NaCl concentration, 10 % of agar concentration and 0.05 m slat bridge length were considered as optimum process parameters value (Run 2) and produced the maximum current, voltage and power production from the sugarcane industry wastewater using DCSB-MFC.

The organic matter in the substrate is utilized by the microorganisms during their metabolisms, results there is an electron gain in the ferrite electrode of anode chamber. Thus, the voltage generation is based on substrate degradation (utilization) by the microorganism in DCSB-MFC. The rate of substrate degradation is directly related to the growth (in terms of numbers) of microorganisms in the substrate. If more numbers of microorganisms, more the liberation of the electrons from microorganism's cell to anode (ferrite) electrode in the anode chamber. The stable output was started after 2 h from the commencement of experimental investigations (Figs. 2 to 7). The substrate degradation corresponding to the maximum removal percentage of COD was observed to be 16.90 KgCOD/m^3 (at the end of day 6) from the dairy industry wastewater using DCSB-MFC (Fig. 8) and the substrate removal is a good agreement with the power generation (Fig. 4). From Fig. 8, it could be seen that as time increases the substrate degradation also increases and it got stabilized at the end of day 6. At the end of day 1 to day 10, dairy industry wastewater degradation (substrate) could be 2.67, 5.75, 9.24, 12.73, 16.42, 16.90, 16.87, 15.25, 12.56 and 9.03 kgCOD/m^3 respectively using DCSB-MFC. Based on the concentration gradient of COD in the substrate, there was a voltage generation gradient observed in the DCSB-MFC operation. The steady-state condition observed in this study, during the operation of DCSB-MFC produced the maximum current and voltage production and correspondingly computed the maximum power production from the dairy industry wastewater.

The interesting point is to be noted that the maximum value of COD reduction, voltage, current, power, current density, and power density were observed at the end of day 6 from the total operation period of 10 days using DCSB-MFC (Figs. 2 to 8). The trend of the COD reduction percentage, current, voltage and power production variation against the different contact times was the same (Figs. 2 to 8). The maximum value of percentage reduction of COD, current, voltage and power production was obtained for the period between 6 and 8, which is corresponding to the stationary phase of microbial growth in a substrate, because the biofilm was fully developed at the anode electrode during the stationary phase period. After 6 days, the percentage reduction of COD, the current, voltage and power production attain their maximum and maintain the same maximum COD reduction and power production for successive 3 days (small fluctuations occurred during those 3 days due to variation in metabolism of microorganisms). There was declined happened after 8 days, because of the death of microorganisms in the substrate (dairy industry wastewater). Beyond the stationary phase period, current and voltage

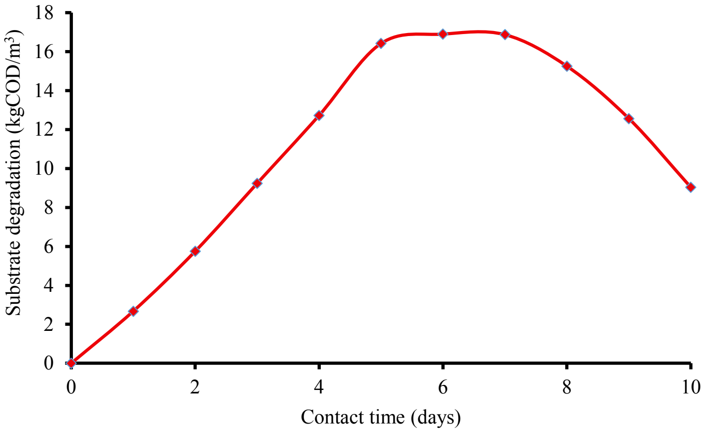

Fig. 8: Substrate degradation corresponding to the power production in MFC

values started to drop, which is corresponding to the decline phase of the microbial growth curve. The death microorganisms in the dairy industry wastewater as substrate contribute to the current and voltage reduction. The less reduction percentage of COD and power generation were observed for the Run 7 (except for voltage – Run 6) are due to poor transfer of electrons and protons between the anode and cathode chambers, less microbial activity of substrate in the anode chamber and less H_2 liberation activity of electrolyte in the cathode chamber. Thus, the current, voltage and power production depends on the microbial activity of substrate in the anode chamber and electrolyte in the cathode chamber. High microbial activity in the anode chamber and high liberation activity of electrolyte in the cathode chamber, more the voltage production in DCSB-MFC.

Taguchi L_9 orthogonal arrays and response for S/N ratio

The S/N ratio was obtained corresponding to the response of COD removal and power production. S/N Ratio for the response COD removal and power production using L_9 Orthogonal Designs from the experimental runs 1 to run 9 is presented in Table 5. From Table 5, it may be observed that the maximum S/N ratio was 38.31 for the response COD removal percentage and 20.48 for the maximum power production (Run 2) and the least S/N ratio was observed as 35.83 and 14.24 for the COD reduction and power production (Run 7) respectively (Table 5).

This study optimized the process parameters based on the larger the better category (Eqn.5) since the objective of this study is to maximize the pollutants reduction and power generation from the dairy industry wastewater using DCSB-MFC. The response (maximum COD removal and a maximum power of Run 1 to Run 9) for the signal to noise (S/N) ratio is presented in Table 6.

The average S/N ratio for NaCl molar concentration, agar concentration and salt bridge length in each level is shown in Figs. 9 and 10. According to the average maximum S/N ratio (Table 5), level 1, level 2 and level 1 exhibited the maximum value against the NaCl molar concentration, agarose concentration, and salt bridge length respectively for

Table 5: S/N ratio for L_9 orthogonal designs

Experimental runs	Experimental design			S/N ratio	
	A	B	C	COD Removal	Power
1	1	5	0.05	37.88	18.54
2	1	10	0.10	38.31	20.48
3	1	15	0.15	37.65	17.34
4	2	5	0.15	35.45	15.92
5	2	10	0.05	38.08	19.78
6	2	15	0.10	36.31	14.58
7	3	5	0.10	35.83	14.24
8	3	10	0.15	37.16	16.78
9	3	15	0.05	37.42	17.01

Table 6: The response for S/N ratio from run 1 to run 9

Levels	NaCl molar concentration (A)	Agar concentration (B)	Salt bridge length (C)
	Maximum COD reduction		
1	37.94	36.11	37.79
2	36.61	37.85	36.54
3	36.52	37.13	36.75
Delta	1.42	1.74	1.25
Rank	2	1	3
	Maximum power		
1	18.79	16.23	18.44
2	16.76	19.03	16.43
3	16.02	16.31	16.69
Delta	2.76	2.80	2.01
Rank	2	1	3

both maximum power production and COD reduction percentage from dairy industry wastewater using DCSB-MFC. The maximum S/N ratio for NaCl molar concentration, agarose concentration, and salt bridge length respectively was found to be 37.94, 37.85 and 37.79 for the response COD reduction (Fig. 9), and 18.79, 19.03 and 18.44 for the response maximum power production (Fig. 10) from dairy industry wastewater using DCSB-MFC. It may also be observed that the maximum delta variation exhibited by the agarose concentration and has more influence on the performance of DCSB-MFC for treating the dairy industry wastewater and simultaneous power production followed by NaCl molar concentration and salt bridge length (Table 5). According to the Taguchi approach, agarose concentration is the most dominant and salt bridge length is the least dominant parameter for the production of power and reduction of pollutants from dairy industry wastewater.

Analysis of variance (ANOVA)

The analysis of variance is used to know the process parameters were contributed significantly to obtain the maximum removal of pollutants and power production from the dairy industry wastewater using MFC. Hence, along with the S/N ratio, ANOVA analysis was done for this study. The ANOVA for all process parameters is presented in Table 7. From Table 7, it may be noted that the order of prevailing process parameters was observed as agarose concentration > NaCl molar concentration > salt bridge length. The results of ANOVA (Table 7) are an agreement with the results of the S/N ratio (Table 6).

Confirmation test

The best-optimized values could be observed as 1M of NaCl concentration, 10 % of agar concentration and 0.05 m salt bridge length (Table 6) for both maximum COD reduction and power production

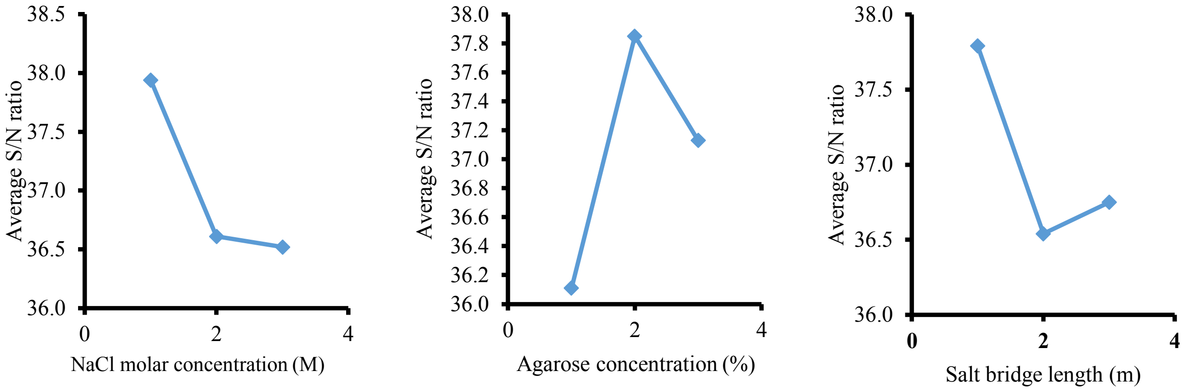

Fig. 9: Average S/N ratio for maximum cod reduction percentage

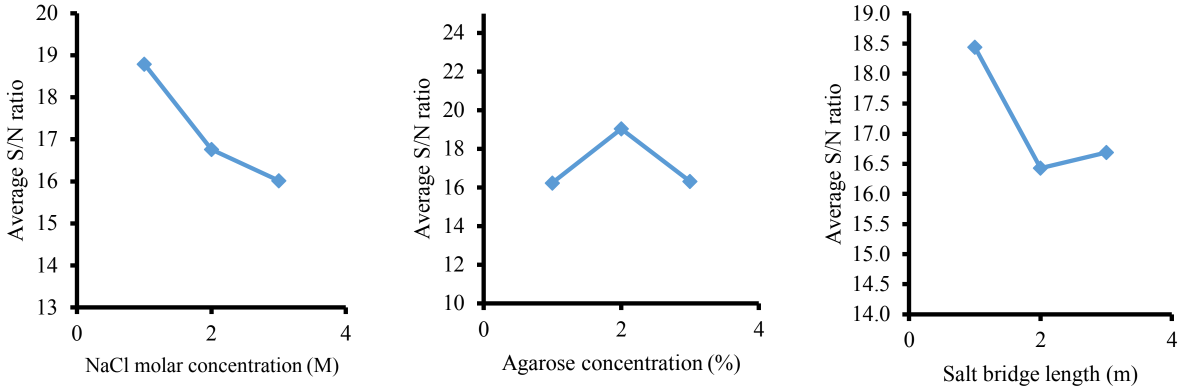

Fig. 10: Average S/N ratio for maximum power

from dairy industry wastewater using DCSB-MFC. These optimized values were observed at different levels, so it is necessary to conduct a confirmation test for obtaining the best output. The confirmation tests were conducted in MFC using optimized process parameters of 1M of NaCl concentration, 10 % of agar concentration and 0.05 m salt bridge length and other process parameters viz., ferrite electrode, the ferrite electrode surface area of 0.0132 m^2, salt bridge diameter of 0.02 m, the dilatation ratio of "0", the operating temperature of 28 °C, no mediator, no additional electron transfer microorganisms, an oxygen flow rate of 10 m^3/h, 1M $K_3Fe(CN)_6$ electron acceptor. The maximum COD removal, current, voltage, power, current density and power density for the combination 1M NaCl, 10 % agarose concentration and 0.05 m salt bridge from control experiments were found to be 86.30 %, 16.10 mA, 886.34 mV, 14.27 mW, 1219.69 mA/m^2 and 1081.06 mW/m^2 respectively from DCSB-MFC using dairy industry wastewater. The results of the confirmation experiment showed that there was an increment of 4.60, 7.76, 19.69, 25.93, 7.76 and 25.93 % for COD removal, current, voltage, power, current density, and power density respectively. Thus, the 1M NaCl, 10 % agar concentration and 0.05 m salt bridge are selected as best optimized parameters for treating and producing power from dairy industry wastewater using DCSB-MFC at the maximum level.

Verification test

In order to check the performance of DCSB-MFC on not only the removal of COD and power production from the dairy industry wastewater at the optimized parameters from the Taguchi approach but the performance of DCSB-MFC also checked to remove the other pollutants from dairy industry wastewater through verification test. The verification test was conducted with the best-optimized process parameters (from control test of Taguchi approach) of

Table 7: Analysis of variance (ANOVA) for maximum power and COD reduction

Source	Degree of freedom	Sum of square	Average of squares	F-Value	p-value	Percentage contribution
			Maximum COD reduction			
A	2	245.749	122.874	115.07	0.009	35.50
B	2	279.562	279.562	130.91	0.008	40.38
C	2	164.882	164.882	77.21	0.013	23.82
Error	2	2.136	2.136			0.31
Total	8	692.329				100.00
			Maximum power			
A	2	9.109	4.5545	5.50	0.154	33.09
B	2	12.285	6.1423	7.42	0.119	44.63
C	2	4.477	2.2385	2.71	0.270	16.27
Error	2	1.655	0.8273			6.01
Total	8	27.525				100.00

Table 8: The pollutants removal percentage of dairy industry wastewater using DCSB-MFC

Sl.No.	Parameters	Raw wastewater (mg/L)	Treated wastewater (mg/L)	Reduction (%)
1	Total Suspended Solids	1428.2 ± 30	141.37 ± 15	90.1
2	Total Dissolved Solids	3625.1 ± 70	648.8 ± 16	82.1
3	BOD_5	2850.5 ± 56	333.4 ± 8	88.3
4	COD	4321.4 ± 95	591.9 ± 6	86.3
5	Nitrate	48.1 ± 6	5.23 ± 0.22	89.1
6	Phosphate	55.2 ± 9	8.6 ± 0.46	84.2
7	Sulphate	915.5 ± 16	199.4 ± 5	78.2
8	Chloride	780.8 ± 24	152.8 ± 4	80.4
9	Ammonia	82.8 ± 11	6.4 ± 0.42	92.1
10	Oil and grease	15.2 ± 3	1.9 ± 0.12	87.2

1M NaCl concentration, 10 % agar concentration and 0.05 m salt bridge length along with other parameters viz., ferrite electrode, the ferrite electrode surface area of 0.0132 m^2, salt bridge diameter of 0.02 m, the dilatation ratio of “0”, the operating temperature of 28 °C, no mediator, no additional electron transfer microorganisms, an oxygen flow rate of 10 m^3/h, 1M $K_3Fe(CN)_6$ electron acceptor. The maximum removal percentage of TSS, TDS, BOD, COD, nitrate, phosphate, sulphate, chloride, ammonia, and oil and grease before and after treatment with DCSB-MFC using best-optimized parameters of 1M NaCl, 10 % agar concentration and 0.05 m salt bridge length is presented in Table 8. From Table 8, it could be seen that the maximum removal of TSS, TDS, BOD, COD, nitrate, phosphate, sulphate, chloride, ammonia, and oil and grease from dairy industry wastewater after treating with MFC were 90.1, 82.1, 88.3, 86.3, 89.1, 84.2, 78.2, 80.4, 92.1 and 87.2 % respectively. The above observations were determined by taking the average of three trials and obtained at the end of day 6 as similar to the maximum removal of COD and power production. The pH of dairy industry wastewater at the end of day 6 was found to be 7.5 ± 0.6. The performance of DCSB-MFC for the maximum reduction of pollutants and power production using dairy industry wastewater against the selected process parameters and optimized parameters of this study was compared with the previous studies. The voltage, current, power, current density and power density from various industry wastewaters using MFC are presented in Table 9.

The maximum voltage, current, current density and power density was found to be 718 mV, 0.61

Table 9. Comparison of voltage, current, power, current density and power density from various industry wastewaters using MFC

Sl.No.	Type of MFC	Substrate	Electrodes	Mediator	Voltage	Current	Power	Current density	Power density	References
1	Double Chambered	Synthetic Wastewater	Graphite Rod	Methylene Blue	718 mV	0.61 mA	0.4378 mW	122 mA/m^3	89.22 mW/m^3	Sevda, and Sreekrishnan, 2012
2	Double Chambered	Food Waste Leachate	Granular Graphite	Mediator Less	610 mV	0.0045 mA	2.738 mW	16315 mA/m^3	9956 mW/m^3	Li, *et al.,* 2013
3	Single Chambered	Biscuit Factory Wastewater	Carbon Rod	Methylene Blue	297 mV	-	-	-	-	Khare, 2014
4	Double Chambered	Dairy Industry Wastewater	Copper Electrode	Methylene Blue	460 mV	430 mA	-	-	-	Parkash, *et al.,* 2015
5	Double Chambered	Hostel Wastewater	Copper Electrode	Mediator Less	810 mV	-	-	-	-	Adeleye, and Okorondu, 2015
6	Double Chambered	Dairy Industry Wastewater	Stainless Steel Rod	Mediator Less	355 mV	0.081 mA	0.0287 mW	27 mA/m^3	9.585 mW/m^3	Drisya, and Manjunath, 2017a
7	Double Chambered	Dairy Industry Wastewater	Stainless Steel Rod	Mediators Less	502 mV	0.077 mA	0.0376 mW	25.67 mA/m^3	12.53 mW/m^3	Drisya, and Manjunath, 2017b
8	Double Chambered	Wastewater	Graphite Rod	Mediator Less	713 mV	-	-	-	-	Ali, *et al.,* 2018
9	Double Chambered	Dairy Industry Wastewater	Copper Rod	Mediators Less	-	-	0.0552 mW	-	4.473 mW/m^2	Sahana, and Manjunath, 2018
10	Double Chambered	Vegetable Slurry	Stainless Steel Mesh	Mediator Less	22.325 mV	4.75 mA	0.1061 mW	19.79 mA/m^2	0.4419 mW/m^2	Sarma, *et al.,* 2019
11	Double Chambered	Dairy Industry Wastewater	Ferrite Rod	Mediator Less	886.34 mV	16.10 mA	14.27 mW	1219.70 mA/m^2	1081.06 mW/m^2	This study

mA, 0.4378 mW, 122 mA/m^3 and 89.22 mW/m^3 respectively using 0.08 mM methylene blue as a mediator, graphite electrode and 5 % NaCl-10 % agar salt bridge using synthetic wastewater instead of real wastewater (Sevda and Sreekrishnan, 2012). The bioelectricity was produced without using nanoparticles in the salt bridge (Sevda and Sreekrishnan, 2012), and with silver nanoparticles (Drisya and Manjunath, 2017b). Khare, (2014) performed the single chambered MFC against the different salt concentrations. The maximum voltage generated from singled-chambered MFC was found to be 297 mV using 1M NaCl with 3 % agar salt bridge, methylene blue as a mediator between anode and cathode chambers and carbon rod as an electrode in both anode and cathode chambers from biscuit factory wastewater with vermicompost (Khare, 2014). The production of maximum power obtained on day 5 from the commencement of experiments. The maximum voltage of 810 mV was generated from the double chambered MFC from hostel wastewater using the copper electrode (Adeleye and Okorondu, 2015). The anode and cathode chambers of double chambered MFC were connected with the 1 % sodium chloride and 2 % agar salt bridge (Adeleye and Okorondu, 2015). After 14 days from the experimental period, with the operating working volume of 2 L hostel wastewater produced the maximum voltage (Adeleye and Okorondu, 2015), whereas, the maximum voltage generation was obtained after 5 days from the biscuit factory wastewater with vermicompost (Khare, 2014). The double chambered MFC was used for treating the dairy industry wastewater with volume of 2 L and producing electricity (Parkash, *et al.*, 2015). MFC was operated for duration of 7 days at the pH of 6, oxygen flow rate in cathode chamber of 45 psi with 5 M NaCl and 20 % agar salt bridge and cow dung as inoculum. Copper electrode anode and air cathode were used in MFC for producing maximum voltage and power using the dairy industry wastewater (Parkash, *et al.*, 2015). The voltage and current of 360 mV and 320 mA respectively was obtained for no mediator and no microorganisms in MFC, the voltage and current of 420 mV and 360 mA respectively was observed for no mediator and substrate native microorganisms in MFC and the voltage and current of 460 mV and 430 mA respectively was noticed for mediator and no microorganisms in MFC (Parkash, *et al.*, 2015). The MFC was performed using silver nanoparticles in salt bridge and stainless steel electrodes for obtaining maximum power from the dairy industry wastewater (Drisya and Manjunath, 2017b). The maximum voltage and current obtained from the studies (Drisya and Manjunath, 2017b) were 355 mV and 0.081 mA respectively using NaCl-agar salt bridge. The 384 mV voltage and 0.089 mA current produced using NaCl-agar salt bridge with 0.001M silver nanoparticles from the dairy industry wastewater in MFC. The maximum output was achieved after 6 hours from the commencement of the experiments (Drisya and Manjunath, 2017b). The maximum voltage of 713 mV was obtained from 8 L wastewater of secondary clarifier using double chambered MFC with 1M NaCl with 5 % agar salt bridge and graphite electrode (Ali, *et al.*, 2018). The theoretical power equation was formulated using an artificial neural network approach and compared with the experimental results (Ali, *et al.*, 2018). The maximum voltage predicted from the model was fitted well with the experimental data of 0.999 (R^2). The optimum length of 260 mm and area of 506.7 mm^2 of 1M NaCl with 10 % agar salt bridge obtained from the Taguchi method in MFC produced the output current of 4.75 mA, voltage of 22.325 mV, power of 0.1061 mW, current density of 19.79 mA/m^2 and power density of 0.4419 mW/m^2 (Sarma, *et al.*, 2019). The decrease in length and increase in the area produced more current, voltage, and power using 1M NaCl with a 10 % agar salt bridge in MFC (Sarma, *et al.*, 2019). The inference (Sarma, *et al.*, 2019) was correlated with the results of other studies (Logan, *et al.*, 2006; and Liu and Cheng, 2014). The application of the Taguchi method was studied for H_2 production and substrate degradation with the optimum value of process parameters (Venkata Mohan, *et al.*, 2009b). After implementing the Taguchi optimization results, the H_2 production improved by three-fold (Venkata Mohan, *et al.*, 2009b). The maximum power density was found to be 9956 mW/m^3 from the food waste leachate in two chambered MFC. The MFC was operated against NaCl as a substrate in the anode chamber, external resistance of 1000 Ω and pH of 9, and with cation exchange membrane (Li, *et al.*, 2013). The maximum power density of 8.09 ± 1.52 mW/m^2 was obtained from the dairy industry wastewater flow rate of 0.05 L/h in double chambered MFC using *Lactobacillus pentosus* as a catalyst (Boas, *et al.*, 2015). The efficiency of continuous flow type

MFC was monitored for electrical power generation from the dairy industry wastewater (Drisya and Manjunath, 2017a). MFC was designed with two chambered MFC, Agar-NaCl salt bridge as proton exchange membrane, cow dung as inoculum in the anode chamber. The maximum power and electrical energy generation of 0.0287 mW and 0.0677 Wsec respectively were obtained for the duration of 7 h and at neutral pH (Drisya and Manjunath, 2017a). The voltage and current generation in MFC were found to be 355 mV and 0.081 mA respectively (Drisya and Manjunath, 2017a). The MFC was evaluated for treating dairy industry wastewater and power generation using cow dung as inoculum, copper and zinc electrode, and NaCl-agar salt bridge of 10 cm length (Sahana and Manjunath, 2018). The maximum power and electrical energy observed after 7 days period to be 0.0229 mW and 0.0412272 Wsec respectively for zinc electrode, and 0.0552 mW and 0.0992124 Wsec respectively for copper electrode (Sahana and Manjunath, 2018). The maximum power density of 58.19 mW/m^2 and the COD reduction of 94.8 % was achieved through RSM approach against the degree of sulphonation 68 %, aeration of 121.62 mL/min. and Pt load of 0.42 mg/cm^2 (Sedighi, *et al.*, 2018). The double chambered MFC was constructed with carbon cloth coated with Pt as electrodes and proton exchange membrane as proton exchanger between anode and cathode chamber for achieving maximum power and COD reduction (Sedighi, *et al.*, 2018). The peaks of selected chemicals were identified using the neural network approach in MFC (Feng, *et al.*, 2013). The cation exchange membrane produced the maximum current of 1.8 mA for the 1 Ω resistance and 80 % of COD was removed from the seawater. The anion exchange membrane yields a maximum current of 1.8 mA but the COD reduction was achieved 77 % at the 1 Ω resistance after 5 days of MFC operation (Jafary, *et al.*, 2017). The maximum removal of COD, oil, and grease, BOD, EC, and TDS are 93.98, 83.82, 90.63, 73.06, and 72.66 % respectively from the dairy industry wastewater (Drisya and Manjunath, 2017a). Similarly, the maximum removal of COD, BOD, EC, TDS and oil and grease were found to be 87.12, 76.97, 82.84, 81.94, and 76.98 % respectively for the zinc electrodes used in both anode and cathode chamber of MFC (Sahana and Manjunath, 2018). But, the maximum removal of COD, BOD, EC, TDS and oil and grease of 71.74, 67.60, 49.73, 43.78 and 68.87 % respectively using copper electrodes in both anode and cathode chamber of MFC from dairy industry wastewater (Sahana and Manjunath, 2018).

Mathematical model

As per Taguchi L_9 orthogonal array, a total of 9 experimental Runs were performed in DCSB-MFC. The parameters chosen for this study to get maximum power and pollutants reduction in DCSB-MFC from dairy industry wastewater are ferrite electrode, the ferrite electrode surface area of 0.0132 m^2, the dilatation ratio of “0”, the operating temperature of 28 °C, no mediator, no additional electron transfer microorganisms, an oxygen flow rate of 10 m^3/h, 1M $K_3Fe(CN)_6$ electron acceptor, NaCl molar concentration, agar concentration and salt bridge length. The regression equation is used to fit experimental data from the best-optimized process parameters for getting the maximum output in DCSB-MFC. In this study, Minitab 18 (version 18.1) was used to find the regression coefficients of the proposed model equation. The multi regression equation for the maximum reduction of COD (Y_{COD}) and maximum power output (Y_{Power}) is expressed by Eq. 6.

$$Y_{COD} \text{ (or) } Y_{Power} = A_0 + A_1X_1 + A_2X_2 + A_3X_3 + A_{11}X_1X_1 + A_{22}X_2X_2 + A_{33}X_3X_3 + A_{12}X_1X_2 + A_{23}X_2X_3 + A_{31}X_3X_1 + A_{123}X_1X_2X_3 \quad (6)$$

in which, A_0 is the interception coefficient, A_1, A_2 and A_3 are the linear coefficients, A_{11}, A_{22} and A_{33} are the one way interaction coefficient, A_{12}, A_{23} and A_{31} are the two way interaction coefficient, and A_{123} is the three interaction coefficient, and X_1, X_2 and X_3 are the independent variables viz., NaCl molar concentration, agar concentration, and salt bridge length.

Validation test

In this study, the response (maximum COD reduction and power production) and process parameters were fitted by multiple regression equations. In order to validate the proposed model with experimental data, the coefficient of determination (R^2) was evaluated from the regression equation (Sivakumar, 2016). The multiple regression equation between the response and process parameters for obtaining the maximum COD reduction and power production in DCSB-MFC using dairy industry wastewater is presented in Eqs. 7 and 8 respectively.

Table 10: Experimental and model results for COD reduction and power production

Experimental runs	X_1 (A)	X_2 (B)	X_3 (C)	COD reduction percentage		Power production	
				Observed	Predicted	Observed	Predicted
1	1	5	0.05	78.31	78.35	8.45	8.45
2	1	10	0.10	82.33	82.54	10.57	10.58
3	1	15	0.15	76.31	76.86	7.36	7.38
4	2	5	0.15	59.23	59.42	6.25	6.25
5	2	10	0.05	80.24	80.33	9.75	9.75
6	2	15	0.10	65.45	65.83	5.36	5.36
7	3	5	0.10	56.26	56.36	5.15	5.14
8	3	10	0.15	72.17	72.61	6.94	6.92
9	3	15	0.05	74.39	74.54	7.08	7.07

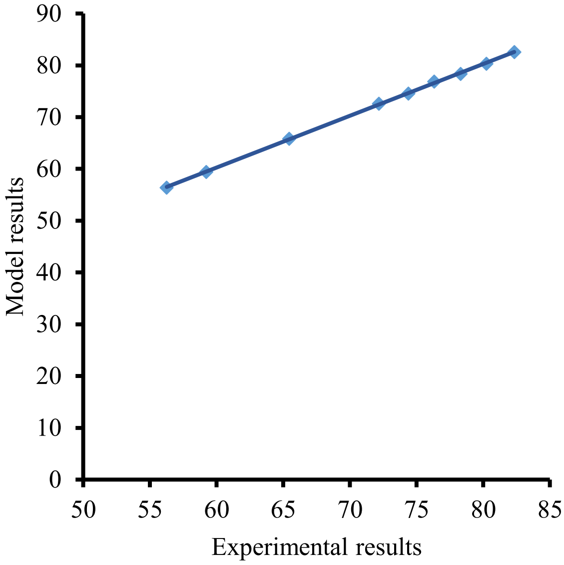

Fig.11: Relationship between experimental and model results of COD reduction

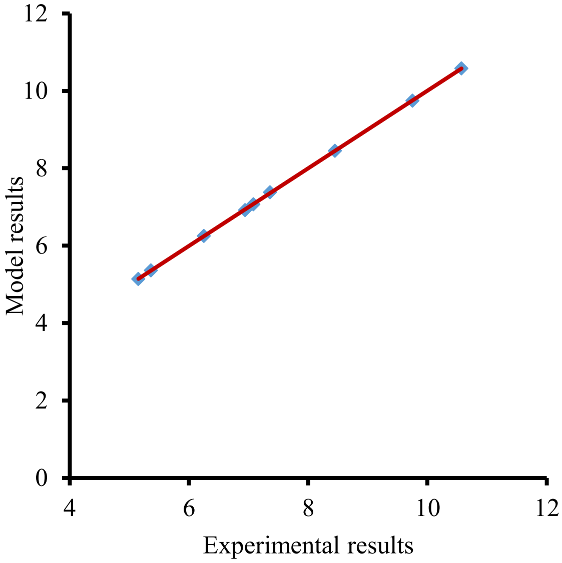

Fig.12: Relationship between experimental and model results of power production

$$Y_{COD} = 87.03 - 21.72\ X_1 + 8.263\ X_2 - 467.0\ X_3 + 4.983\ X_1X_1 - 0.3967\ X_2X_2 + 1967.2\ X_3X_3 + 0.2067\ X_1X_2 - 0.0000002\ X_3X_1 \quad (7)$$

$$Y_{Power} = 2.610 - 2.082\ X_1 + 2.077\ X_2 + 4.633\ X_3 + 0.4717\ X_1X_1 - 0.1201\ X_2X_2 + 135.3\ X_3X_3 + 0.1093\ X_1X_2 - 21.0\ X_3X_1 \quad (8)$$

The maximum COD removal percentage and maximum power production from dairy industry wastewater using DCSB-MFC from Eq. 7 and Eq. 8 are presented in Table 10. The relationship between the experimental observed data and model calculated data on COD removal percentage and power production from dairy industry wastewater using DCSB-MFC is shown in Fig. 11 and Fig. 12 respectively.

From Figs. 11 and 12, it could be seen that most of the experimental data values were much closer to the straight line of predicted values from the model. The R^2 value found between the experimental and model was 0.996 and 0.993 for the COD removal percentage and power production respectively. Furthermore, the results of R^2 indicated that the model was highly significant to reproduce the experimental data for obtaining the maximum power production from the dairy industry wastewater against the optimized parameters using DCSB-MFC.

The linear, quadratic and interaction of NaCl molar concentration, agar concentration and salt bridge length contributed to obtain maximum COD reduction (Eq. 7) and power production (Eq. 8) except the interaction between agar concentration with salt bridge length (the term X_2X_3) and combined interaction of NaCl molar concentration, agar concentration and salt bridge length (the term $X_1X_2X_3$) from dairy industry wastewater using DCSB-MFC. Thus, NaCl molar concentration of 1M, agar concentration of 10 % and length salt bridge of 0.05 m from the Taguchi approach is the best value for reducing the concentration of the maximum pollutant and producing power using DCSB-MFC from dairy industry wastewater.

This study observed that DCSB-MFC can do the three-unit operations namely wastewater treatment, electrolyte dissociation and electrochemical oxidation such that DCSB-MFC can perform the simultaneous treatment and power production from wastewater (Venkata Mohan, *et al.,* 2009a). The integrated treatment approach of DCSB-MFC and non-requirement of supply of external power, it can be implemented in the wastewater treatment plant to enhance the treatment efficiency and possibly renewable energy generation. From the experimental and model studies, this study concluded that DCSB-MFC can be performed well for maximum pollutants reduction and simultaneous power production for the appropriate process parameters value from dairy industrial wastewater.

CONCLUSION

In this study, the Taguchi L9 Orthogonal array can facilitate the selection of an optimum value from the process parameters to achieve the maximum reduction of pollutants and maximum production of power from dairy industry wastewater. The maximum reduction of COD, current, voltage, power, current density and power density in DCSB-MFC from dairy industry wastewater was found to be 86.30 %, 16.10 mA, 886.34 mV, 14.27 mW, 1219.69 mA/m^2 and 1081.06 mW/m^2 respectively for the value of the optimized parameter of 1M NaCl concentration, 10 % agar concentration and 0.05 m salt bridge (confirmation test). The use of ferrite electrode in DCSB-MFC enhanced the bioelectricity from dairy industry wastewater. The maximum influencing parameter for the production of electricity and reduction of pollutants from dairy industry wastewater using DCSB-MFC was found in this study are agarose concentration followed by NaCl molar concentration and salt bridge length (ANOVA). DCSB-MFC is also reducing the other pollutants to the maximum level for the best-optimized value of process parameters as similar to COD reduction and power production from dairy industry wastewater (verification test). The regression model was developed in this study can be used to predict the best combination of process parameters against the required output power and reduction of various pollutants (validation test). In this study, DCSB-MFC used microorganisms available in the substrate and without a catalyst for producing electricity, whereas, in the conventional cell, the electricity was produced with a suitable catalyst. The microorganisms used in DCSB-MFC can assimilate the toxic content available in the wastewater if it exists, so DCSB-MFC can be an attractive alternative technology to meet the future energy demand through the simultaneous production of bioelectricity along with treatment of wastewater. This study may be extended using different electrodes size, spacing and catholyte at different operating conditions. Furthermore, the effect of microbes at various pH conditions for the production of bioelectricity will be conducted in the future.

AUTHOR CONTRIBUTIONS

Author has performed the main conceptual ideas and the proof outline, carried out the experimental investigations, investigated the findings of experimental results, designed the model and analysed the data and wrote the manuscript with input from the experimental and model results.

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ABBREVIATIONS

%	Percentage
'I'	Current
'L'	Litre
'M'	Molar
'm'	meter

'n'	Number of observations
'P'	Power
'V'	Volt
'W'	Watt
'Y'	Response corresponding to the selected process parameters
°C	Degree centigrade
µA	micro-amps
µW	micro-watt
A	Amps
A/m^2	amps per square meter
ANN	artificial neural network
ANOVA	analysis of variance
APHA	American Public Health Association
BOD	Biochemical oxygen demand
CD	Current density
C_f	Final concentration
C_i	Initial concentration
COD	Chemical oxygen demand
DCSB-MFC	Double chambered salt bridge microbial fuel cell
EC	Electrical conductivity
Eq.	Equation
Eqs.	Equations
$K_3Fe(CN)_6$	Potassium ferricyanide
$KgCOD/m^3$	Kilogram COD per cubic meter
m^2	Square meter
m^3/h	Cubic meter per hour
mA	milli-amps
mA/m^2	milli-amps per square meter
MFC	Microbial fuel cell
MFCs	Microbial fuel cells
mg/cm^2	milligram per square centimeter
mg/L	milligram per litre
mM	milli-mole
mV	milli-volts
mW	milli-watts
mW/m^2	milli- watts per square meter
NaCl	Sodium chloride
NN	neural network
PD	Power density
PVC	Polyvinyl chloride
R^2	Coefficient of regression
RSM	response surface methodology
S/N ratio	signal to noise ratio
TDS	Total dissolved solids
TSS	Total suspended solids
W/m^2	watts per square meter
Wsec	watt-second
Ω	ohm

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