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Bioelectricity Generation of Dual Chamber Microbial Fuel Cell (MFC) Using Cow and Carabao Wastewater

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Abstract

The microbial fuel cell (MFC) is a system that can efficiently and directly transform several non-purified organic substrates and various waste classes into electrical energy from the activity of bacteria. The performance of the dual chamber MFC system using cow and carabao wastewater were compared under identical conditions. Each set-up comprised anode and cathode with 25L wastewater (cow or carabao), microbial inoculant derived from effective microorganisms and molasses, stainless-steel electrodes, and salt bridge as proton exchange membrane (PEM). In these conditions, the MFC was operated for twenty (20) days and three (3) replications. Maximum power densities per surface area generated were 29.19 mW/m2 for cow wastewater and 10.88 mW/m2 for carabao wastewater. Meanwhile, peak power densities per volume were recorded at 583.87 mW/m3 and 217.51 mW/m3 for cow and carabao wastewater, respectively. Deductively, cow wastewater shows significantly higher results in bioelectricity generation than carabao wastewater. Furthermore, in terms of wastewater treatment, cow wastewater provided a greater TDS reduction efficiency of 41.23% than carabao wastewater, with only 28.59%.

Keywords: *bioelectricity; carabao wastewater; cow wastewater; microbial fuel cell*

Introduction

The energy consumption of the Philippines is continuously increasing along with its large population and growing economy. As an easy solution to meet the growing demand, the country heavily depends on coal for power generation (Taniguchi, 2019). The transition to a clean energy system is being viewed in the Philippines. According to DOE Energy Secretary Alfredo Cusi, a clean energy scenario was planned to reduce greenhouse gas emissions and develop renewable energy utilization.

One of the emerging developments in renewable energy technology is the microbial fuel cell (MFC) which generates electricity from the activity of bacteria (Daisog et al., 2011). Microbial fuel cells can create chemical energy from a variety of waste classes and have the ability to efficiently and directly convert several non-purified organic substrates into electrical energy (Choudhury et al., 2020).

Animal wastewater, however, is commonly treated as waste instead of a resource, which can lead to environmental issues (Calub, Salude, & Tabing, 2016). Since wastewater involves bacterial activities, which has the potential for energy generation, this sparks an interest.

With the continuous study to improve the performance of microbial fuel cells, this study aimed to evaluate cow and carabao manure in dual chamber MFC for bioelectricity generation.

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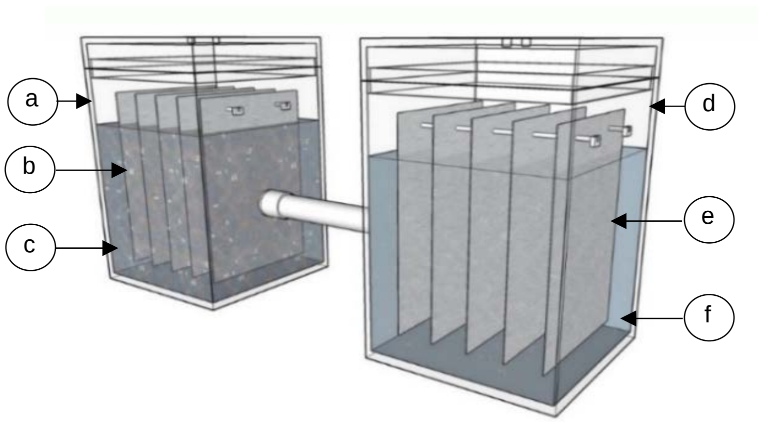
Materials and Methods

MFC Set-up

This study used an H-shaped two-chamber MFC system. Figure 1 shows the system components which are: anaerobic anode; aerobic cathode; electrode; proton exchange membrane or PEM; and Bluetooth data-logging multimeter. Two (2) 36L fabricated glass containers were used as the anode and cathode chamber and were separated by salt bridge as proton exchange membrane. To prevent leakage in the anaerobic anode chamber, sealant was applied. Stainless steel plates were used as anode and cathode.

Figure 1.

Microbial fuel cell set-up; (a) anaerobic chamber; (b) anodes; (c) wastewater; (d) aerobic chamber; (e) cathodes; (f) unchlorinated water with KMnO4 solution



Microbial Inoculant Preparation

Figure 2a shows the inoculants comprised of the mixture of molasses and effective microorganisms (EM) and were used to boost the microbial activity of the system. Before adding it to the carabao and cow wastewater, it was stored for seven days in an area without exposure to sunlight. The inoculants are ready to use when bubbles are present in the mixture as shown in Figure 2b.

Figure 2.

Microbial inoculant preparation; (a) before and (b) after 7 days

(a) (b)

Substrate Preparation

Carabao wastewater was collected from the Bulacan Agricultural State College (BASC) College of Agriculture, and cow wastewater was collected from San Juan, San Ildefonso, Bulacan, wherein both animals were given forage as their diet (Figure 3a). The wastewater was filtered using #35 mesh (0.5 mm) and measured using a weighing scale (Figure 3b). The wastewater was mixed thoroughly before adding it to the anode chamber (Figure 3c). The retention time for the carabao slurry is 20 – 30 days, according to Philippine Agricultural Engineering Standards (PAES) 413:2001.

Figure 3.

Substrate preparation; (a) collection, (b) filtering, and (c) loading

(a) (b)

(c)

MFC Set-up Procedure

1. Prepare all the materials.
2. Build the salt bridge. Put 100 g/L of agar in hot water to dissolve it. While the agar solution is still hot, add salt to it. The end of a plastic pipe should be sealed so that it may be used to form

the salt bridge. Pour the agar-salt mixture into the plastic pipe. The agar-salt mixture should be allowed to cool and harden.

3. Connect the electrodes. Connect the copper wire to every electrode component. Use epoxy to secure the wire to the plates and prevent corrosion. Then, test the electrodes with a multimeter.
4. Assemble the MFC setup by connecting the salt bridge between the two containers. Seal all sides using epoxy to prevent leakage.

MFC Operation Set-up

The MFC system was operated in a closed room for three batches. The prepared cow and carabao wastewater and microbial inoculant with 90:10 ratio were placed in the anaerobic anode chamber. With 25 L capacity, the set-up was fed with 22.5 L of wastewater and 2.5 L of microbial inoculant. The stainless-steel electrodes were inserted into the anode and cathode chamber. A 158g $KMnO_4$ dissolved to 800 ml distilled water solution was fed into the cathode chamber every day. The external circuit was connected through a 100k ohm resistor and started measuring the electrical properties via bluetooth data-logging multimeter.

Post Set-up Operation

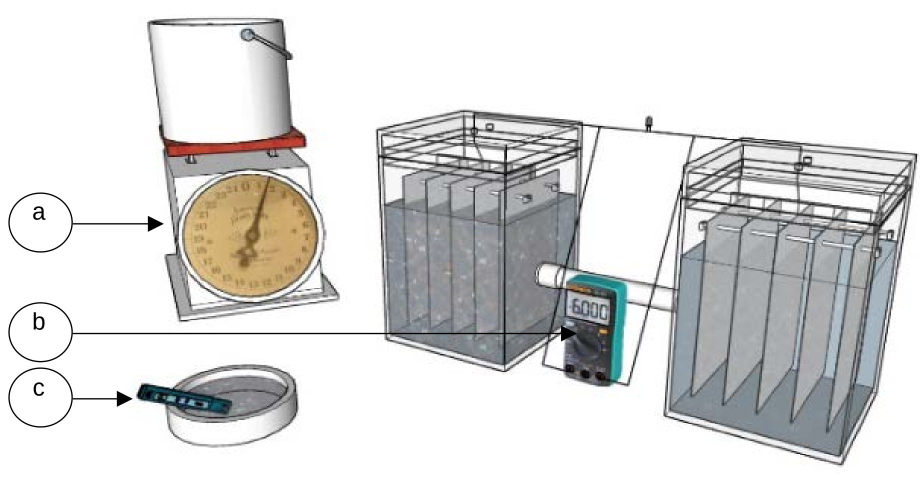
The MFC set-up was disassembled by removing the electrodes and membrane. The wastewater was unloaded from the system. To avoid contaminating the anode and cathode chambers, the proton exchange membrane (PEM) was changed correspondingly in every batch of operation. The set-up was regularly cleaned after each operation and stored properly when not in use.

Instrumentation Set-up

Figure 4 presents the location where the test instruments were positioned. The bluetooth data-logging multimeter was connected to the MFC set-up; the water quality meter was placed in a container with wastewater, and the weighing scale was placed with a bucket.

Figure 4.

Test Instruments Set-up; (a) weighing scale, (b) Bluetooth data-logging multimeter, (c) water quality meter



Data Collection

Water Quality Parameters

The wastewater was tested before and after the MFC operation. Temperature, pH level, total dissolved solids (TDS), and electrical conductivity (EC) were measured using a water quality meter.

Bioelectricity Generation

The MFC system was operated and monitored every hour for 20 days duration per batch. Bluetooth data-logging multimeter was connected to the system to monitor the electricity generation and record the voltage data. Other data was computed using the equations below:

$$P = I \cdot V = V^2/R \qquad (1)$$

where: I = current (A); V = voltage (V); R = electric resistance (Ω); and P = power (W).

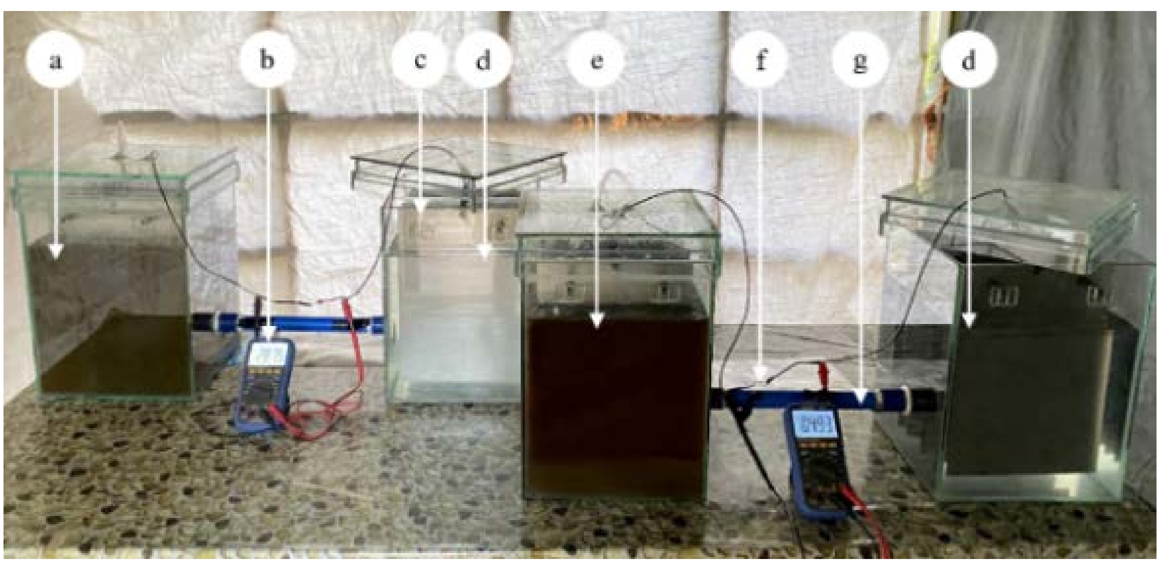
Moreover, power density in terms of the surface area of electrode (mW/m^2), and in terms of volume (mW/m^3) was also computed.

Results and Discussion

Two (2) identical MFC set-ups shown in Figure 5 were fabricated for the two (2) treatments, which are the cow and carabao wastewater. The set-up was composed of an anaerobic anode chamber, aerobic cathode chamber, electrode, proton exchange membrane or PEM, resistor, gas bag, and Bluetooth data-logging multimeter.

Figure 5.

Microbial fuel cell set-up: (a) wastewater A; (b) Bluetooth data-logging multimeter; (c) electrodes; (d) unchlorinated water; (e) wastewater B; (f) resistor; (g) salt bridge



Electricity Generation

The electricity generation was recorded and computed in terms of voltage generation, power generation, and power density.

Voltage Generation

MFC operation for cow and carabao wastewater at the 1-hour interval was observed over 20 days, resulting in the closed-circuit voltages (CCV) shown in Figure 6. The highest voltages from the cow and carabao wastewater were obtained with values of 1206 mV and 709.33 mV, respectively. It was observed that both the wastewater from cow and carabao peaked on the sixth day of MFC operation due to the highest temperature recorded on the sixth day (Figure 7), indicating that the microbial activity was more active at that time. According to Li et al. (2017), the operation temperature greatly influences the power generation of MFC.

Figure 6.

Voltage generation of cow and carabao wastewater

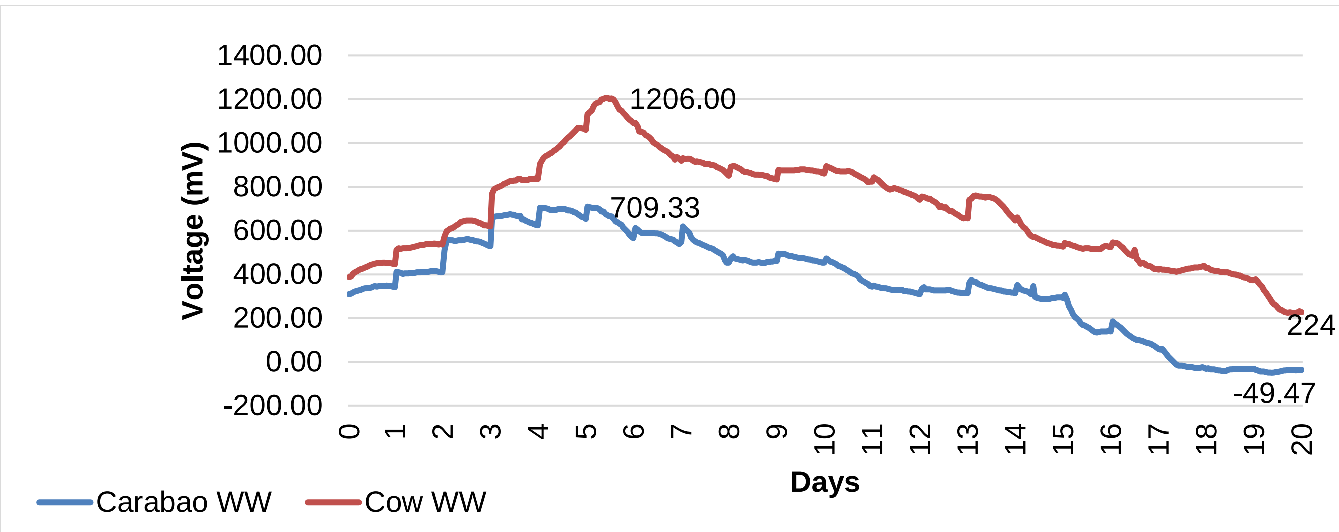
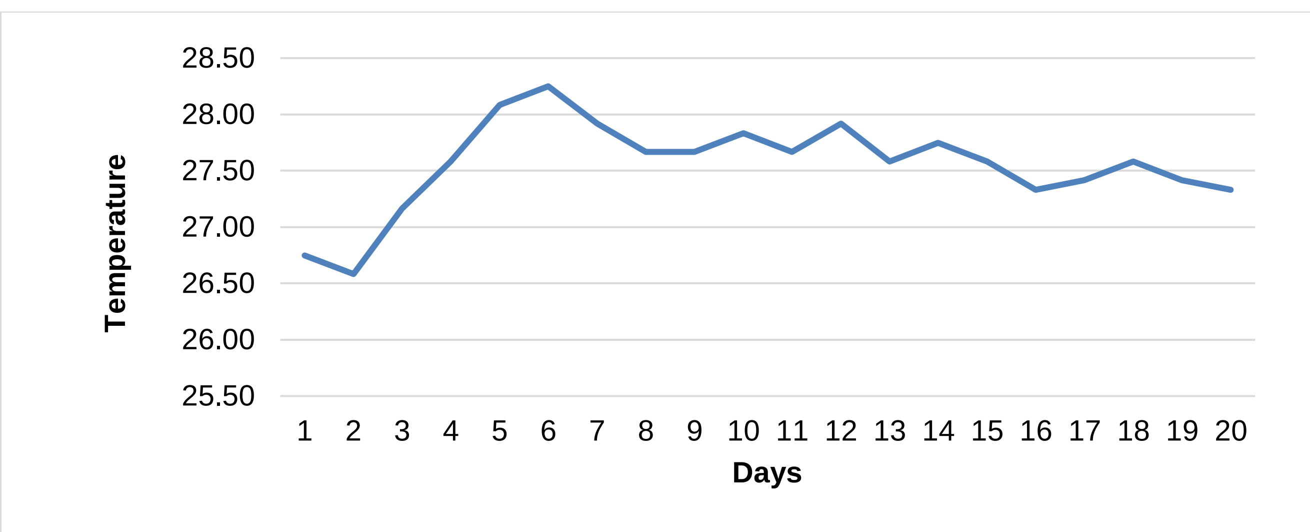


Figure 7.

Mean temperature of three (3) batches



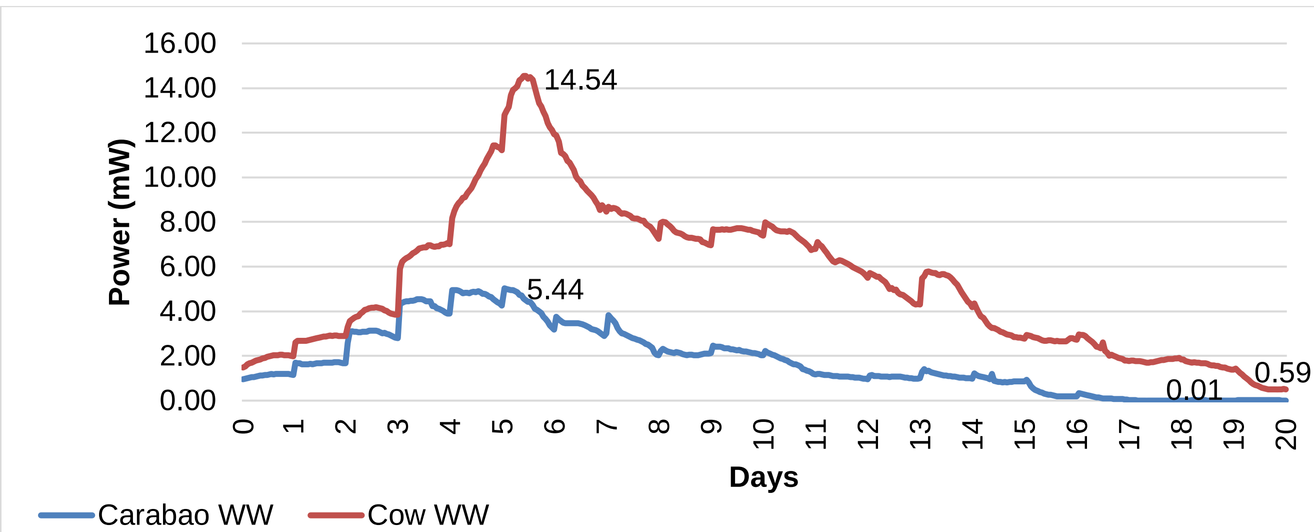
It was also observed that there is an increase in voltage every time that potassium permanganate ($KMnO_4$) solution was added to the system. Since there is no air pump in the system that provides oxidation, $KMnO_4$ increases the voltage generation because it is actually an oxidant. According to Liu (2019), potassium permanganate was used as oxidant for MFC due to its high oxidation ability.

Power Generation

The power generation was computed using the voltage values of cow and carabao wastewater obtained at 1-hour intervals for 20 days. The sixth day of both treatments yielded the highest power values from the cow and carabao wastewater, measuring 14.54 mW and 5.44 mW, respectively. The lowest power generated by cow and carabao wastewater was measured with values of 0.59 mW and 0.01 mW on the 20th and 18th day, respectively. Since power is related to the voltage by P = VI, the trend of the curve is also similar (Figure 8).

Figure 8.

Power generation of cow and carabao wastewater



Power Density per Unit Area

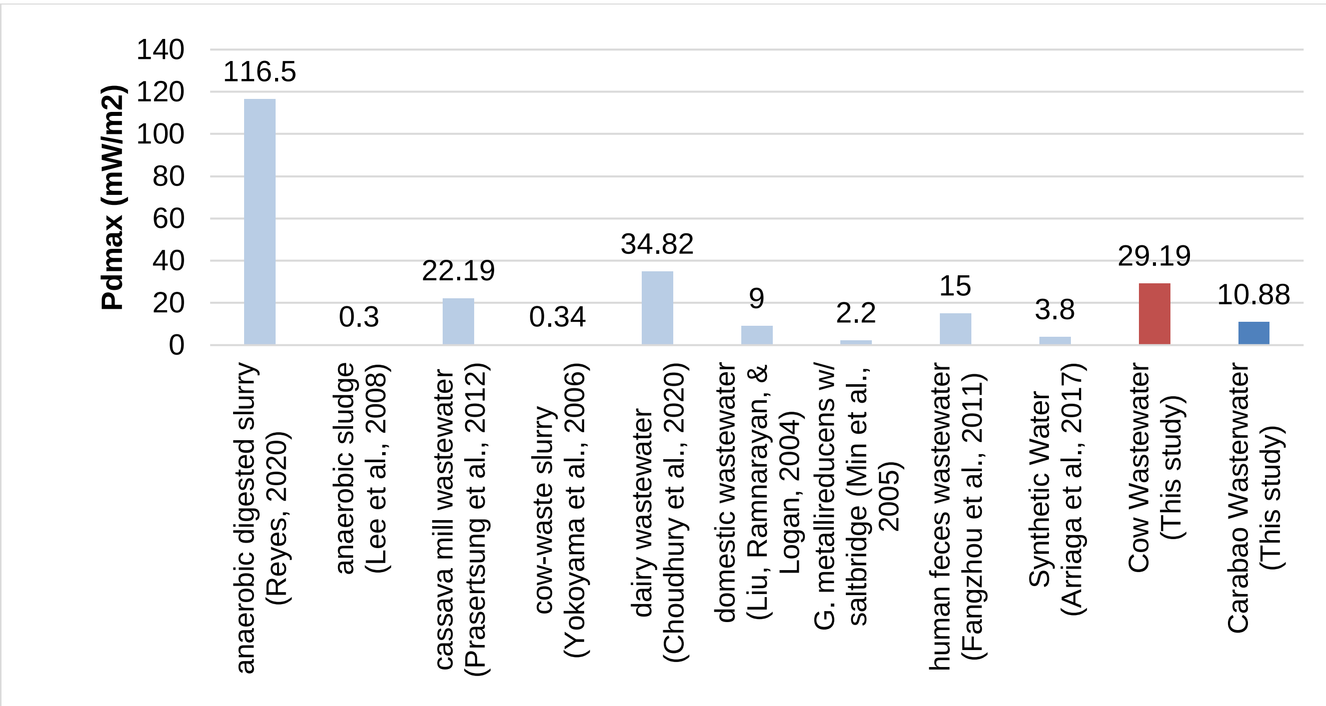
The power density was calculated using the power produced by cow and carabao wastewater as well as the surface area of the electrodes that were employed. The sixth day of both operations exhibited the highest values of the cow and carabao wastewater power densities in terms of surface area, measuring at 29.19 mW/m^2 and 10.88 mW/m^2, respectively. The least power densities per surface area for cow and carabao wastewater were observed on the 20th and 18th days, respectively, with values of 1.19 mW/m^2 and 0.02 mW/m^2.

Figure 9 shows the power density per surface area of cow and carabao wastewater with different MFC substrates from other studies for comparison. Anaerobic digested swine slurry measured a peak power density of 116.5 mW/m^2 at the treatment with the highest microbial inoculant ratio (1:3) derived from fermented soybean and effective microorganism solution using stainless steel electrodes and continuously aerated by an air pump (Reyes, 2020). Dairy wastewater obtained a power density of 34.82

mW/m^2, which was operated in dual chamber MFC with Nafion-117 PEM, and the electrodes are carbon cloth and platinum (Choudhury et al., 2020). Domestic wastewater was placed on a Plexiglas tube with Nafion-117 as a proton exchange membrane, and graphite electrodes produced 9 mW/m^2 of power density (Liu, Ramnarayan, & Logan, 2004). Human feces wastewater with 15 mW/m^2 was operated with dual chamber MFC separated by Nafion-117 PEM with carbon paper and platinum electrodes and constantly aerated (Fangzhou et al., 2011). On the other hand, this study uses cow and carabao wastewater inoculated with effective microorganisms and molasses, operated in dual chamber MFC with salt bridge PEM and stainless steel electrodes without added oxygen generated peak power density per surface area of 29.19 mW/m^2 and 10.88 mW/m^2, respectively.

Figure 9.

Maximum power density per surface area of different wastewater



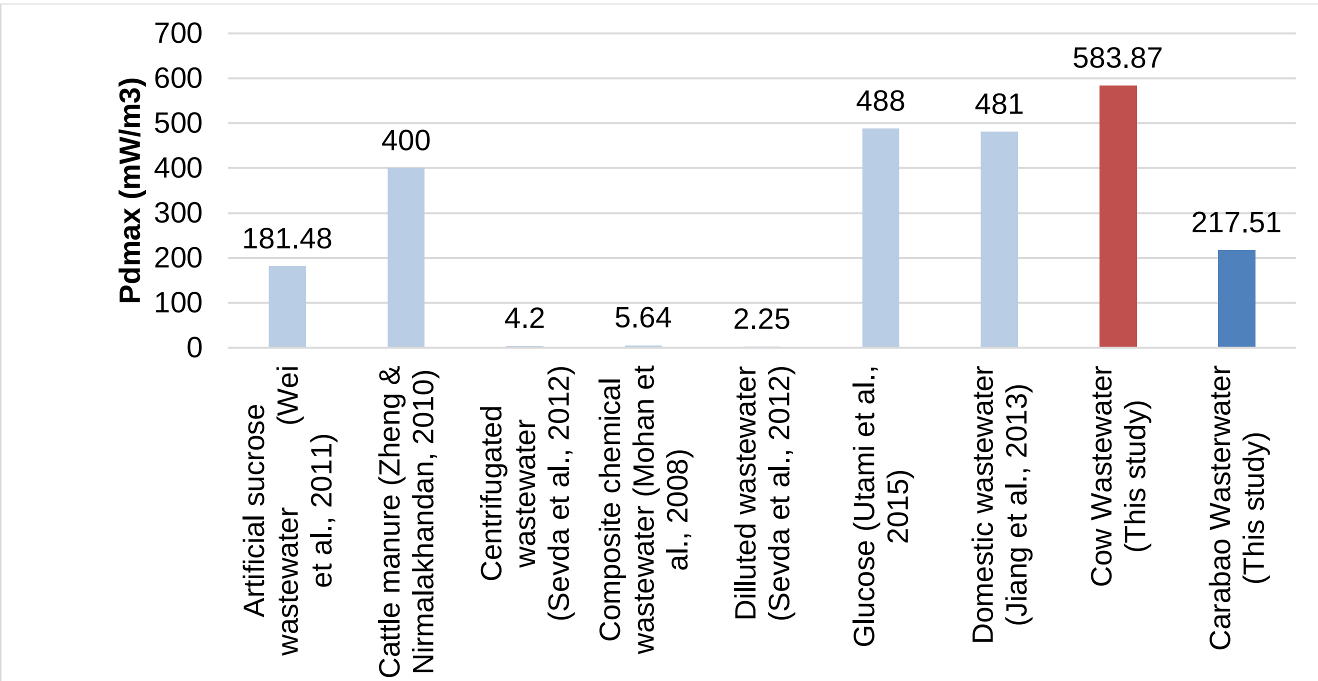
Power Density per Unit Volume

Power density in terms of volume was calculated using the volume of wastewater and the power generated by cow and carabao wastewater. The maximum power densities per volume of the cow and carabao wastewater were found on the sixth day of both operations, measured at 583.87 mW/m^3 and 217.51 mW/m^3, respectively. The 20th and 18th days, respectively, had the lowest power densities (volume) for cow and carabao wastewater, with values of 23.74 mW/m^3 and 0.38 mW/m^3, respectively.

Figure 10 shows the power density per volume of cow and carabao wastewater with different MFC substrates from other studies. Centrifugated and diluted wastewater obtained power density of 4.2 mW/m^3 and 2.25 mW/m^3, respectively, which was operated with silver, platinum, and titanium electrodes under dual chamber MFC with Zirfon PEM (Sevda et al., 2012). Domestic wastewater was subjected to polymethylmethacrylate (PMMA) plastic cylinder MFC with carbon fiber brush as electrodes and was able to have a power density of 481 mW/m³ (Jiang et al., 2013). On the other hand, this study employs cow and carabao wastewater in dual chamber MFC with salt bridge PEM and stainless steel electrodes without added oxygen generated peak power density per volume of 583.87 mW/m³ and 217.51 mW/m³, respectively.

Figure 10.

Maximum power density per volume of different wastewater



Water Quality Analysis

Before and after the MFC operation, the water quality of cow and carabao wastewater were measured in terms of temperature, pH, EC, and TDS using a water quality tester. TDS was analyzed in terms of reduction efficiency. The physical and chemical characteristics of cow and carabao wastewater in three trials are shown in Table 1.

Since the set up was in a location in which the temperature is not constantly stable, the temperature of the wastewater was considerably affected by the temperature of the environment surrounding it. There is a decrease in the temperature of cow and carabao wastewater from the initial and final readings, as there is also a decrease in external temperature, as shown in Figure 7. Since exoelectrogens perform best at temperatures between 25 and 30 ºC (Ren, Jian, & Chae (2017), temperature readings from cow and carabao wastewater are all considered normal.

There is also a decrease in electrical conductivity (EC) of both wastewaters since the MFC has used the dissolved substances for electricity generation for 20 days. The higher the EC means, the higher number of pollutants and contaminants from wastewater. The cow wastewater had a reduction rate of 43.25%, while 38.83% from the carabao wastewater. The contaminants and impurities were reduced over time using MFC, which is suitable for water treatment.

After the MFC operation, the pH of cow and carabao wastewater rises, causing it to become less acidic gradually. pH readings are considered normal because exoelectrogens have been found to be effective and active at pH values between 6.0 and 7.0, according to Guang et al. (2020).

Table 1.

Physico-chemical properties of cow and carabao wastewater

PARAMETERS	Initial	Final	Reduction Rate
Cow WW			
Temperature (ºC)	29.53	26.03	
TDS (ppm)	3403	2000	41.23%
EC (µS/cm)	7467	4237	43.25%
pH	6.40	6.63	
Color	Dark Brown		
Carabao WW			
Temperature (ºC)	29.33	25.97	
TDS (ppm)	2343	1673	28.59%
EC (µS/cm)	4687	2867	38.83%
pH	6.39	6.53	
Color	Dark Brown		

The Total Dissolved Solids (TDS) decreases from initial to final readings because the wastewater from the anode chamber was mixed with the unchlorinated water from the cathode chamber; hence, the mixture became more diluted. TDS reduction rate of cow wastewater was higher than the reduction rate of carabao wastewater. Cow wastewater reduced 41.23% of TDS from 3403 ppm to 2000 ppm after the operation. Carabao wastewater only reduced 28.59% of TDS after the operation. Higher reduction efficiency is desirable since lower TDS equals purer and clearer water.

Figure 11.

Total Dissolved Solids (TDS) removal efficiency of different wastewater

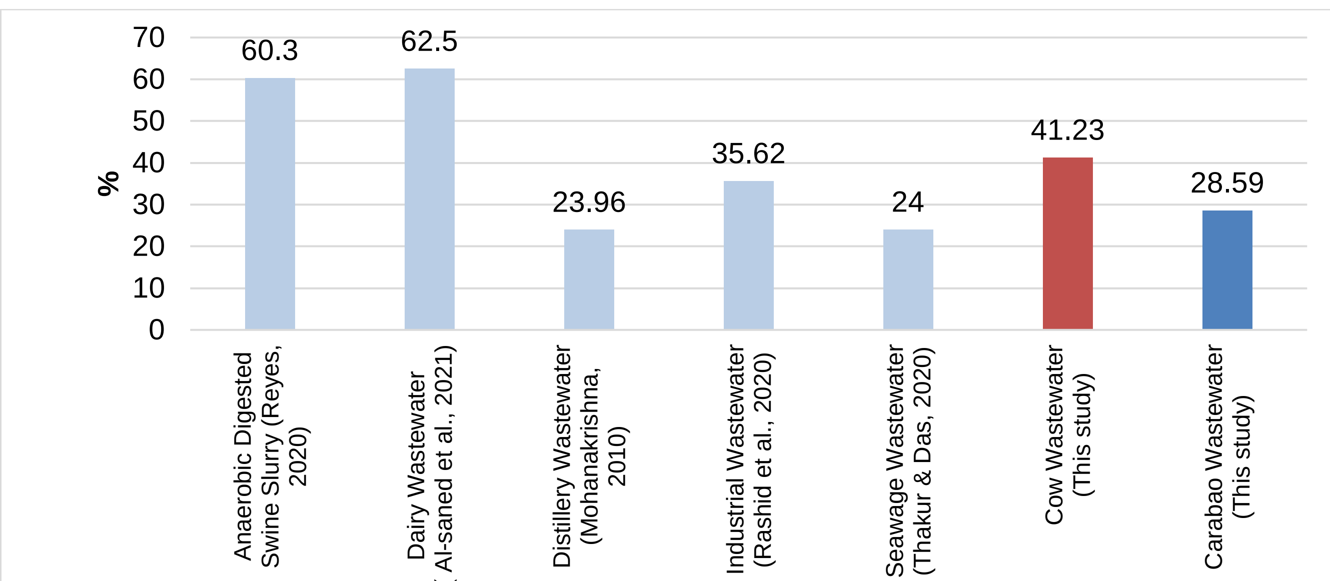


Figure 11 shows the TDS removal efficiency of cow and carabao wastewater with different MFC substrates from other studies. Anaerobic digested swine slurry achieved a removal efficiency of 60.3% TDS at 1:3 microbial inoculant ratio utilized by an MFC system with stainless steel electrodes and constantly aerated by an air pump (Reyes, 2020). Dairy, distillery, industrial, and sewage wastewaters under MFC set up with graphite plate electrodes, Nafion PEM, and constantly aerated by oxygen were able to reduce the TDS with 62.5%, 23.96%, 35.62%, and 24%, respectively. On the other hand, this study employs cow and carabao wastewater in dual chamber MFC with salt bridge PEM and stainless steel electrodes without added oxygen, obtaining TDS removal efficiency of 41.23% and 28.59%, respectively.

Biogas Production

The biogas produced was collected using a gas bag with a 3L capacity. The gas bag was changed every day or once the biogas had occupied the capacity of the gas bag. The biogas collected from cow and carabao wastewater and the flare testing of the biogas were shown in Figure 12 and 13, respectively.

Figure 12.

Biogas collected from cow and carabao wastewater for one day

Figure 13.

Testing of biogas collected

Conclusion

Based on the findings of the study, the following conclusions were made:

1. The anode chamber must be maintained anaerobic, while the cathode chamber must be aerobic.

2. MFC system with cow wastewater had significantly higher voltage generated than carabao wastewater. Peak voltages of cow and carabao wastewater were 1206 mV and 709.33 mV, respectively.

3. Significantly more power was produced by the MFC system using cow wastewater than by the carabao wastewater. With a value of 14.54 mW, cow wastewater demonstrated greater power generation than carabao wastewater.

4. The power density per surface area and per volume of the MFC system using cow wastewater was much greater compared to the power density of the carabao wastewater. The peak power density per surface area of cow wastewater was 29.19 mW/m2, whereas the highest power density of cow wastewater was 10.88 mW/m2. Maximum power density per volume of cow and carabao wastewater were 583.87 mW/m3 and 217.51 mW/m3, respectively.

5. Cow wastewater was better in wastewater treatment than carabao wastewater. Carabao wastewater only obtained 28.59% TDS removal efficiency, compared to 41.23% for cow wastewater.

Recommendations

To further improve the results of this study and for future adaptation, the following are recommended:

1. Since some of the electrodes were rusted after several MFC operation, it is recommended to use other electrode materials that are less corrosive and less expensive but highly conductive.

2. Maximize the size of electrodes to increase the surface area and improve electricity generation.

3. Continuous measurement of temperatures not just the initial and final values is recommended to have a measurement of it throughout the experiment.

4. Perform other wastewater treatment parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), and other important parameters to improve the water quality analysis.

5. Since biogas is simultaneously generated, it is also recommended to consider at the amount of biogas generated per day, in relation to the voltage generated per day.

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