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Evaluation of the Electricity Generation Potential of Bacteria with Microbial Fuel Cell Technology using Abattoir Effluent as a Substrate

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ABSTRACT
The concerns about global warming are gradually causing sensitive debate globally therefore its pertinent at this period to intensify the quest for alternative sources of energy. The potential of abattoir effluent to generate electricity at room temperature via microbial fuel cell technology has been demonstrated. Microbial fuel cell is a bio electrochemical system which utilizes bacteria to generate electricity. This study was conducted to evaluate the potential of bacteria to generate electricity through microbial fuel cells with abattoir effluent serving as a substrate. The study was carried out using a dual chambered microbial fuel cell. And the set up was monitored for a period of seven days. Readings were taken at intervals of two hours all through the experiment. The highest voltage generated was 0.58V on the first day and the lowest voltage recorded was 0.05V on the seventh day. The results from this study indicate that bacteria in microbial fuel cells can utilize abattoir effluent converting chemical energy to electrical energy. The low voltage generated makes microbial fuel cells less efficient than traditional energy generation methods. There is still much to be learned about complex interactions between micro organisms and electrode materials in microbial fuel cells. Hence, further research is needed to develop more efficient, durable and cost effective materials for microbial fuel cells.

Keywords:
Microbial Fuel Cell,
Bacteria,
Abattoir,
Effluent Voltage.

INTRODUCTION

Abattoirs are facilities designed for slaughtering of animals for the consumption of meat. The vital role played by these abattoirs in the supply of processed meat cannot be overemphasized.. Although abattoirs have also been implicated in environmental pollution there has also been reports of numerous benefits from abattoirs aside from the provision of meat (Idu et al., 2023). Electricity is one of the most important sources of energy for daily life. The present-day energy (electricity) scenario in Nigeria and around the world is precarious, thus driving to the search of alternative to fossil fuels (Pant, 2020). The current energy production methods are not sustainable, and concerns about climate change and global warming require developing new technologies of energy production using renewable and carbon-neutral sources.

Microbial fuel cells (MFC) are regarded as a sustainable technique for energy generation and wastewater treatment. Agriculture and anaerobic digestion are complementary biological processes used to produce biofuel. It refers to any fuel that obtains its energy through biological carbon fixation (Hall *et al*., 2021). This technique has the ability to convert chemical energy stored in organic matter into direct current (DC) in a single step. In addition to generating power, this technique offers the ability to treat wastewater using microorganisms found in the waste water (Logan and Regan 2020).

Although this technology appears to be promising, microbial fuel cells nevertheless have their own set of obstacles. The high internal resistance of microbial fuel cells has had an impact on their power production. However, in an effort to enhance power density in MFCs, electron acceptors other than oxygen have been intensively (You *et al*., 2019). These authors used ferricyanide and permanganate solutions to increase power density by lowering internal resistance or increasing open circuit voltage (OCV). You *et al.* (2019) have observed a maximum open circuit voltage of 1.532 volts using permanganate solution. Increasing human activity leads to increased consumption of natural nonrenewable energy sources, which results in a quicker pace of fossil fuel depletion. As a result, energy derived from fossil fuels may not be able to solve the energy issue because the source depletes and causes environmental damage through the production of greenhouse gases, which causes climate change and global warming (Adeleye and Okorondu, 2018). The current energy (power) scenario in Nigeria and around the world is fragile, prompting the hunt for alternatives to fossil fuels. The current energy production methods are unsustainable, and worries about climate change and global warming need the development of alternative energy production technologies based on renewable and carbon-neutral sources.

MATERIALS AND METHODS

Study area

The area from which the samples were collected at abattoirs located at Plot 653A, Bangaie area and Plot N537 New market area both in Bida local government area of Niger state, Nigeria. The discharge point into the river is situated at Latitude 13026.047‟ N, Longitude 8423.356‟ E and elevation 703.4m above sea level. The global position system (GPS) was used to determine the coordinates and elevation.

Samples Collection

Samples and sediments from the abattoir's 2,000 mL of effluent was collected in a plastic container. In order to prevent anthropogenic activities from influencing the sample, samples were taken in the morning by using a shovel to scoop the abattoir effluent and sediment into a bowl. Sample will be transported immediately to Microbiology Laboratory of The Federal Polytechnic Bida, Niger State.

Physicochemical analysis

The analysis of some physicochemical parameters was carried out in accordance with the technique illustrated by American Public Health Association (2001). This includes: dissolved oxygen (DO), electrical conductivity (EC), biological oxygen demand (BOD), Total Dissolved Solids (TDS), Temperature, pH and color, were analysed on the abattoir effluent.

Construction of Microbial Fuel Cell

The construction of MFC would follow Cheng *et al.*, (2019) description. The proton pump and external circuit are coupled to two containers that make up the MFC assembly. Apparatus to be used includes the following; 1000 mL plastic containers, Copper wires with a diameter 1.40 mm, proton pumps**,** digital multimeter ALDA DT-830D

MFC set up:

The MFC was configured using a modified technique presented by Faluyi *et al*. (2021; Eke *et al*., 2020; Biffinger *et al.*, 2018). The abattoir effluent was utilized to construct microbial fuel cells, and the voltage of electricity produced was determined for 21 days. Microorganisms in abattoir effluent was measured and identified using the pour plate method. Agar-agar salt bridges was used to create dual chambers for a microbial fuel cell. Each catholyte included abattoir effluent, and the anolytes was potassium ferricyanide with a double copper-copper electrode and potassium permanganate with a single copper-copper electrode. The setup was monitored for 7 days.

The MFC was set up as follows;

i. Two plastic containers was required for the setup. One of the containers was serving as an anaerobic jar constructed with a tightly sealed cover. This was labeled as the anode while the second container was constructed as an aerobic jar allowing air supply to the cathode.

ii. Using a cotton wick in salt water the proton exchange bridge was constructed. The cotton soaked wick was placed inside the plastic pipe serving as a passage for ions to move from the anode to the cathode.

iii. The bridge for proton exchange was connected to the two plastic containers by boring a hole by the side of the containers, the proton exchange bridge was fixed to the bored hole tightly to avoid any leakage.

iv. Inside each plastic container was copper wires coiled up with a point at the top to allow for external connection.

v. The two plastic containers which now has copper wires at the top was connected to external circuit and connected to a digital multimeter.

vi. The anaerobic chamber was filled with sludge containing the microorganisms and glucose and then sealed. For increased conductivity water was added and a pinch of salt to the aerobic chamber

vii. The Voltage current was measured and results recorded at intervals of two hours.

Electricity measurement.

The amount of voltage generated each day was measured using a digital multimeter to calculate the bioelectricity produced; voltage was expressed in volts

RESULTS AND DISCUSSION

Results

Table 1: Mean physicochemical parameters of selected abattoir waste water

Parameters	Unit	NMKT WP	BNG WP	NMKT BP	BNG BP	Control	Standard (FEPA 1991)
Colour		Light brown	Light brown	Dark brown	Dark brown	Colorless	NS
Odour		Offensive	Offensive	Offensive	Offensive	-	NS
Temp.	ºC	27.15±0.07a*	27.16±0.08a	26.65±0.64a	26.65±0.64a	28.4	Ambient
pH		7.60±0.13a	7.54±0.20a	7.44±0.19a	7.44±0.19a	6.9	6 – 9
Conductivity	µS/cm	737.00±4.24a	735.00±7.07a	870.00±42.43b	865.00±41.43b		100 -300
Total dissolve solid	mg/L	73.33±4.20a	73.26±4.31a	81.33±6.94b	83.33±9.94b	50.6	500 -2000
Dissolved0 Oxygen	mg/L	5.80±0.85a	5.85±0.92a	5.30±0.14a	5.40±0.11a	4.68	NS
Biological oxygen demand	mg/L	73.55±3.75a	76.10±6.08a	84.30±2.69b	87.30±2.11b	14.69	30 - 50
Chemical oxygen demand	mg/L	235.50±16.26a	262.50±9.19ab	837.00±4.24b	844.00±8.29b	98.7	100
Total suspended solid	mg/L	1000.00±141.42a	1015.00±49.50a	1240.00±56.57b	1255.00±66.57b	360	500 -1500
Nitrate	mg/L	7.10±1.22a	7.04±0.14a	7.75±0.27a	7.94±0.77a	5	20 - 50
Phosphate	mg/L	13.97±0.47a	13.05±3.89a	18.47±0.24b	21.44±0.22b	10.05	20 -100

*Mean values with similar subscript alphabets along the same row are not significantly different at P > 0.05
NMKT WP = New market washing point, BNG WP = Bangaie washing point, NMKT BP = New market butchering point, BNG BP = Bangaie butchering point, NS= Not specified

Table 2: Mean Voltage Generated Daily at Temperature of 28ºc

Day	28ºC
One	0.58 ± 0.01^{f}
Two	0.55 ± 0.01^{ef}
Three	0.52 ± 0.01^{e}
Four	0.42 ± 0.06^{d}
Five	0.28 ± 0.04^{c}
Six	0.18 ± 0.02^{b}
Seven	0.05 ± 0.07^{a}

Note: values with different superscripts are significantly different (P >0.05)

Discussion

Table 1 highlighted results on mean physicochemical parameters of selected abattoir waste water in Bida Metropolis Niger State. There was no significant difference (P >0.05) between the Temperature (^{0}C) pH, Dissolved Oxygen (mg/l) and Nitrate (mg/l) of waste water sample collected from both the washing point as well as the butchering point of new market and Bangaie abattoir respectively. However conductivity was significantly higher in waste water collected from butchering point (870.00±42.43 and 865.0±41.43 µS/cm) and significantly lower at waste collected from washing point (734±4.24 and 735±7.07 µS/cm) for new market and bangaie abattoir respectively. This conductivity value was greatly higher than the standard recommended conductivity by federal environmental protection agency (FEPA) 1991 of 100 – 300 µS/cm. The chemical oxygen demand was significantly lower at new market washing point (235.5±16.26 mg/l), this lowest value of COD was greatly higher than the standard recommended by FEPA 1991 of 100 mg/l. The biological oxygen demand was significantly lower at washing point of the two abattoir (73.55±3.75 and 76.10±6.08 mg/l) for new market and bangaie washing point respectively, though these concentrations were greatly higher than the standard recommended limit by FEPA 1991 of 30-50mg/l.

The results from the physicochemical analysis of abattoir effluent displayed high levels of indicators of pollutants in the effluent being discharged by the abattoir in Bangaie and New market areas of Bida, Niger state. The result also indicated that the pollutants were discharged above permitted limits. The temperature of the effluent was 27.3ºC which was within the permitted limit (ambient temperature (FEPA 1991). This is similar to the work carried out by Faluyi *et al.,* 2021 and Agarry *et al.,* 2022 who recorded 27ºC and 27.5ºC respectively but different from the research conducted by Egbadon *et al.,* 2016 on abattoir effluent. Temperature fluctuations in water bodies especially when it short term may cause fishes and some aquatic organisms to die. The eggs of fishes would also not hatch resulting in a population decline. For aquatic life to thrive the temperature should not be above 25 to 28ºC (Karthikeyan, 2023).

The pH of 7.5 (Table.1) for the abattoir effluent was within acceptable limit, this is similar to the work conducted by Ikekwem, 2019 and Kim et al., 2022. These researchers reported a pH of 7.1 and 7.3 respectively. The growth of aquatic macrophytes is inhibited by a high pH this is due to the fact tht there is an impairment of iron(Fe) and phosphorus (P) uptake (Argo, 2019) and a pH of above 8.5 causes a reduction in fish production (Edmund, 2020). The total suspended solids in the abattoir effluent were high (Table 4.1), this is similar to the work of Walter, 2021, Ikekwem, 2019 and Li *et al.*, 2023 who had values of 1840 mg/mL, 1715 mg/mL, and 1780 mg/mL respectively. Light penetration is reduced when the volume of suspended sediment is high thus impairing the activities of photosynthetic phytoplanktons, macrophytes and algae. The rate of photosynthesis by green aquatic algae, macrophytes reduces drastically when there is reduced light penetration and this affects cells which serve as food sources to a lot of invertebrates residing in the aquatic environment (Water quality, 2018).

The total dissolved solids (TDS) and electrical conductivity (E.C) in the abattoir effluent sample was low and high respectively (Table 1). According to FEPA standard the TDs in abattoir effluent should be between 500-2000 mg/mL and electrical conductivity should be between the range of 100-300 (Umar, 2021). The low level of total dissolved solids could be as a result of the amount of salts in the abattoir effluent. A high salt concentration decreases osmotic pressure causing water to flow out of plants in a bid to achieve equilibrium. The resultant effect of this is stunted growth in plants and hence reduced crop yields (Saha, 2022). There was a high biological oxygen demand (BOD) and chemical oxygen demand (COD). Similar results were obtained by Min et al., 2023, Logan, 2019 and Jung et al., 2018. Dissolved oxygen (DO) values were found to be 5.5 mg/ml. according to FEPA standard, the dissolved oxygen value should be 2.0 mg/mL (WHO, 2012). The abattoir industry releases a large amount of biochemical oxygen demanding wastes. A high BOD and COD values implies a very high level or rate of pollution. This can be attributed to the rate of microbial activities within the effluent. There is a symbiotic relationship existing in the aquatic environment between bacteria and algae which helps to increase microbial activities. The aerobic bacteria utilizes the oxygen produced by the algae to decompose the organic matter in the abattoir effluent forming carbondioxide, water and new bacterial cells. The carbondioxide produced on the other hand is utilized by the algae in the presence of sunlight for energy synthesis and new algal cells formation. Thus the bacteria feeding on the organic matter increases their rate of growth and also multiplies leading to a reduction in BOD. The anaerobic bacteria in the aquatic environment also decompose organic matter leading to the production of methane and water forming new offspring of cells. It is important to note that adequate mixing hinders or reduces the activities of bacteria that are anaerobic (Umar, 2021).

Voltage generation using Microbial fuel cells and abattoir effluent as substrate

The experiment was set up using a double chambered MFC operated with abattoir effluent sample set at varying condition as feed to enhance biomass formation and subsequent electricity generation. As at when the MFC was inoculated with the abattoir effluent, a 24hr lag phase existed which was accompanied by an increase in voltage. The presence of components in the abattoir effluent which are easily utilized by the mixed culture of micro organisms could be attributed to the initial current increase. After the exhaustion of these degradable substrate there was a decrease in the current output.

The ability of the isolated bacteria to act as a catalyst in the microbial fuel cell to generate electricity using abattoir effluent as a substrate was determined. The microbial fuel cell generated some electricity after a period of seven days and the results are displayed in table 2 above. There was a steady increase in the amount of electricity generated from day one up to day seven. This result confirms the study of Nimje et al. 2019 who also proved that micro organisms in microbial fuel cells had the ability to produce high electric voltage. Abattoir effluent has a high level of electrical conductivity and this is due to the presence of charged particles of various sizes substances (Allison et al., 2020). This study also agrees with the work done by Malvankar et al 2022 who also proved that electricity could be generated from mixed species of micro organisms that are found in waste water sludge. The result of this study also agrees with Collins *et al.*, 2021 who also generated electricity from swine waste water. Voltage generated from the microbial fuel cells with the aid of the bacteria is passed through the proton pump to the anode. Abattoir effluent has a lot of microbes that are endogenous and this enables it to generate a high amount of electricity. In this study, a maximum output voltage of 0.58V was obtained in a period of seven days from the abattoir effluent.

A maximum current of 0.85V and 0.94V was reported by Siva *et al.,* (2019) for waste water from sugar and diary industries. Agarry and Aremu also reported a voltage output of 2.28V, 1.06V, 0.97V, 0.89V and 0.73V for sugar, brewery, abattoir, dairy and pineapple juice waste waters as fuel in MFC respectively. Furthermore, Sharma and Mathuriya reported maximum current output of 8.40V and 12.40V on day 5 for sugar and Dairy industry waste water in their MFC. This high current reported by Sharma and Mathuriya might be due to the nature of the portion exchange membrane made up of Nafion 117 which has been reported as the best portion exchange membrane for experimenting microbial fuel cell. It has a higher hydraulic time retention of about ten days. Min *et al.*,(2015) and Fatemi *et al.,* (2022) who recorded a power output of 1.0V and 2.8V in their MFC produced by *Geobacter metallireducen* and *Saccharomyces cerevisiae* as pure culture and a salt bridge between the anode and cathode chambers. The high voltage of electricity (3.99V) generated in this study could be as a result of the activities of a consortioum of bacteria in the microbial fuel cells. This result is similar to Fatemi *et al.,* and Mathuriya *et al.,* who recorded a voltage of 2.8V and suggested that using a consortium of micro organisms more power would be produced synergistically as compared to a single pure culture. These observations also indicate that the performance of MFC as regards generation of electricity depends on the availability of different types of micro-organisms found in effluent of biological wastes. More electrons are released in presence of wider substrate utilized by complex mixed cultures. This probably may be responsible for higher voltage generation in our MFC using abattoir effluent (Boon *et al.,* 2023).

Plate 1. Live Picture of the Microbial Fuel set up

CONCLUSION

This study concludes that electricity can be generated from abattoir effluent using microbial fuel cell technology. The maximum voltage generated was 0.58 volts. In addition, the presence of the isolated microorganisms in the abattoir effluent which led to the degradation of substrate for electricity generation from renewable and carbon neutral source which are environmentally friendly and do not emit any form of greenhouse gases. The low voltage recorded in this study could be as a result of the sensitivity of the microbial fuel cells to environmental changes like temperature and pH which could affect their performance. Further research is needed to develop more efficient, durable and cost effective materials for microbial fuel cells.

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