Electricity production from dual chambers microbial fuel cell fed with chicken manure-wastewater

PhD. Ali J. Jaeel
Department of Civil Engineering, Wasit University, Wasit, Iraq
Email address: alijwied@hotmail.com; alijwied@gmail.com

Msc. Salah Lafta Farhan
Department of Civil Engineering, Wasit University, Wasit, Iraq

1. Abstract

Chicken manure wastewaters are increasingly being considered a valuable resource of organic compounds. Screened chicken manure was evaluated as a representative solid organic waste. In this study, electricity generation from livestock wastewater (chicken manure) was investigated in a continuous mediator-less horizontal flow microbial fuel cell with graphite electrodes and a selective type of membrane separating the anodic and cathodic compartments of MFC from each other. The performance of MFC was evaluated to livestock wastewater using aged anaerobic sludge. Results revealed that COD and BOD removal efficiencies were up to 88% and 82%, respectively. At an external resistance value of 150 Ω, a maximum power and current densities of 278 m.W/m^2 and 683 mA/m^2, respectively were obtained, hence MFC utilizing livestock wastewater would be a sustainable and reliable source of bio-energy generation .

Keywords: MFC, anaerobic sludge, electricity generation, livestock wastewater

انتاج الطاقة الكهربائية من خلية وقود بايلوجية مغذاة بمياه صرف تحتوي على دَمْن الدجاج

الخلاصة

تعتبر مياه الصرف الممزوجة بدَمْن الدجاج مصدرا قيما للمركبات العضوية. دَمْن الدجاج المغربل تم تقييمه كمصدر للنفايات الصلبة العضوية وتم استخدامه كمصدر لإنتاج الطاقة الكهربائية في خلية وقود بايلوجية تعمل بنظام الجريان الافقي وتحتوي على قطبي كاربون (موجب وسالب) يفصلهما غشاء انتقائي. تم تقييم أداء خلية الوقود البايلوجية في معالجتها لمياه صرف تحتوي على دَمْن الدجاج من خلال استخدام حمأة لا هوائية. نتائج الدراسة أظهرت نسب إزالة الاوكسجين الكيمياوي المستهلك والاوكسجين البايلوجي المستهلك بمقدار 88% و 82% على التوالي. بعد ربط حمل خارجي ثابت مقداره 150 اوم، كان مقدار كثافة القدرة القصوى 278 ملي واط لكل متر مربع وكثافة التيار القصوى 683 ملي امبير لكل متر مربع. وبالتالي فان مياه الصرف الصحي الحاوية على روث او دَمْن الدجاج ستكون مصدر مستدام وموثوق بها لتوليد الطاقة الحيوية في خلية الوقود البايلوجية.

كلمات البحث: خلية الوقود البايلوجية، الحمأة اللاهوائية، وتوليد الكهرباء، مياه الصرف الحاوية على روث المواشي والدجاج

2. Introduction

Microbial fuel cells (MFCs) technology represents a promising approach for generating electricity from biomass using bacteria. A MFC is a bioreactor that converts the energy stored in the chemical bonds of organic compounds directly into electric energy through electro-catalytic reactions of microorganisms under anaerobic conditions [1]. A typical MFC consists of the anode and cathode chambers, physically separated by a proton exchange membrane (PEM). Microorganisms in the anode oxidize the organic substrates and produce electrons and protons. Protons are conducted to the cathode chamber through the PEM, and electrons through the external circuit. Protons and electrons are consumed in the cathode chamber with parallel reduction of oxygen to water [2], which is the cathode reaction usually encountered in MFCs. In a MFC system the electron transfer from the bacteria to the anodic electrode can proceed in a direct way from their membrane to the anode surface (mediator-less MFCs) [3] or indirectly, by means of a mediator (mediator MFCs) [4]. Mediator-less MFCs show significant potential for harvesting energy from waste organic matter [5] since this technology is more economically viable, without requiring exogenous chemicals to accomplish electron transfer. In such type of MFCs, microorganisms act as catalysts for the transfer of electrons from the substrate to the anodic electrode and for this reason the selection of a highly performing microbial consortium (either pure or mixed culture) is of crucial importance [6]. MFCs operating using mixed cultures can utilize more complex carbon sources due to the much wider substrate acceptability, because of the presence of different bacterial species [7]. In the anaerobic chamber, the substrate is oxidized by bacteria and the electrons transferred to the anode either by an exogenous electron carrier, or mediator, such as potassium ferric cyanide, or neutral red [8, 9], or directly from the bacterial respiratory enzyme to the electrode. In the latter case, the MFC is known as a mediator-less MFC [10, 11]. The main objective of this work was to evaluate the performance a horizontal flow microbial fuel cell (MFC) inoculated with aged anaerobic sludge and fed with livestock wastewater. The performance of the MFC was considered with respect to COD removal and power generation.

3. Materials methodology

3.1 Culture and medium

Chicken manure was tested as a representative of livestock organic solid waste. Manure samples were collected from nearby chicken breeding farms, the samples dried, crushed and after that screened using a very fine sieve (0.5mm opening), and then the dry manure samples were added to a clean water to form a wastewater of a manure to liquid ratio of 100 g/l. The average measured characteristics of livestock wastewater used in this study are listed in Table 1. The anodic chamber of the MFC was inoculated with anaerobic sludge collected from septic tank bottom. The inoculum sludge was sieved through 1mm opening sieve and heated at 100 °C for 15min to suppress the methanogens, cooled at room temperature, and 1.0-liter volume of sludge was added to the anode compartment.

3.2 Microbial Fuel cell

The horizontal flow MFC consisted of a dual rectangular chambers as shown in Fig.1 made of transparent Plexiglas parallelepiped having dimensions of 15 x 15 x 8 cm. One side of each chambers (15cm x 8cm) was perforated with 20 pores of diameter 5mm. A cation exchange membrane (CEM) type CMI-7000, was supplied by membrane international INC., NJ. The CEM sheet of dimensions 15 x 8 cm was placed between two perforated glass sheets, so that the net surface area of the membrane was $393mm^2$. The anode and cathode chambers contained graphite plain electrodes (4 x 4 x 0.5 cm) without any coating; each had a surface area of 56 cm^2. The graphite electrodes were abraded by sand paper to enhance bacterial attachment. The electrodes were soaked in deionized water over-night before usage. CMI-7000 was pretreated by boiling in each of the following solutions for 1 hour; distilled water, 3% hydrogen peroxide, 0.5 M sulfuric acid, distilled water three times and then stored in water until use. Copper wire was clamped with electrode to a 10000-ohm resistor. The cathode compartment was filled with 1.0 liter of phosphate buffered saline (PBS), and continuously sparged with air. Voltage readings were taken with a voltmeter once a day. The MFC was placed at room temperature. After 7 days, 6.6 ml of 3M sodium acetate (pH=5.2) was added to 1.0 liter of present wastewater. This was added as a nutrient for the microorganisms and a source of electrons due to oxidation of carbon source by microorganisms **.**

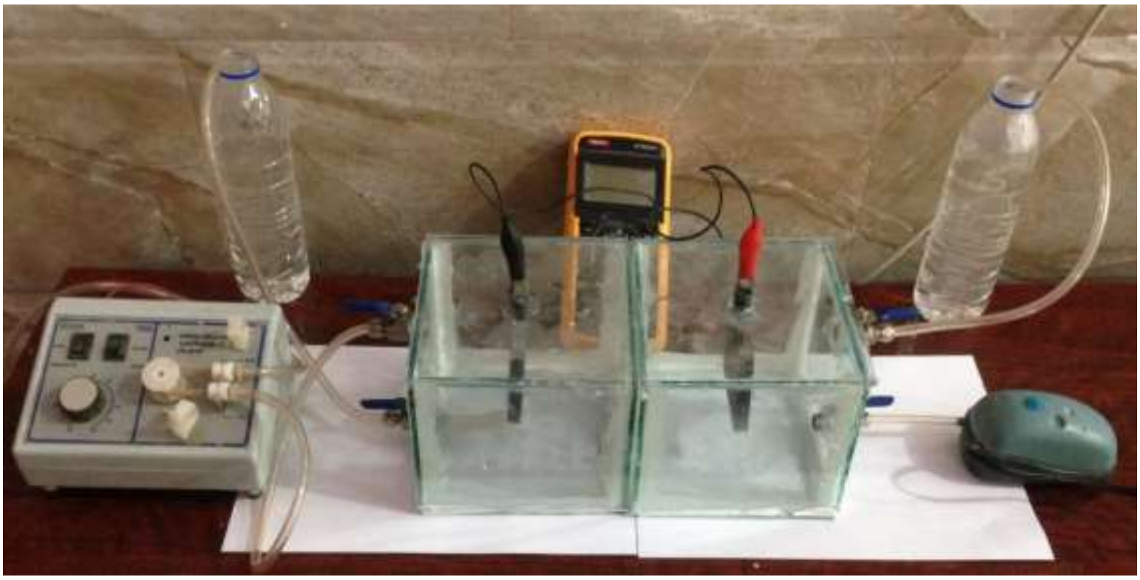

Fig.1A Isometric detail for two chambers MFC

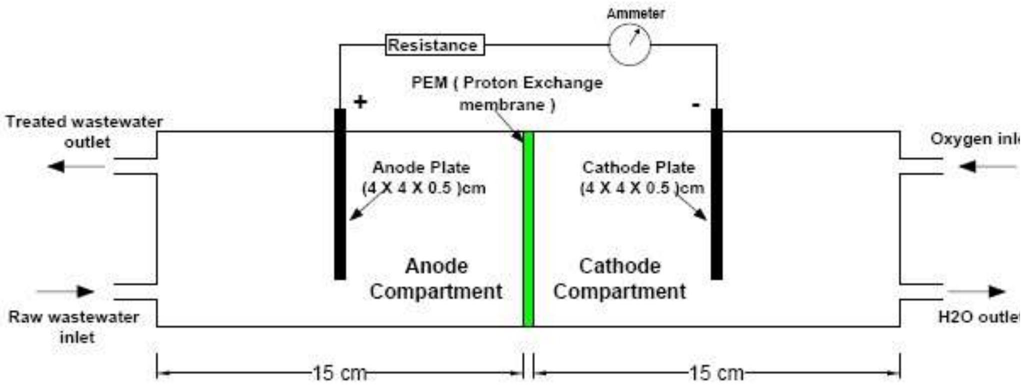

Fig. 1B MFC - Side View

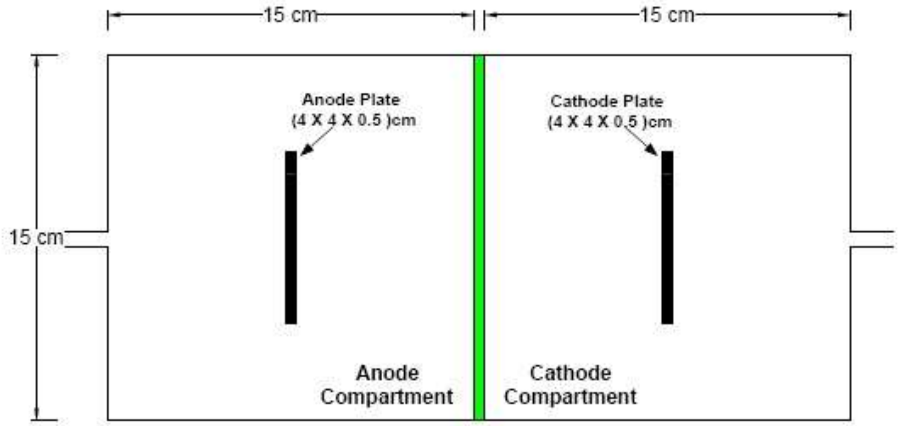

Fig. 1C MFC - Top View

Fig.1 Two chambers MFC separated by cation exchange membrane

3.3 Operating conditions

The bioreactor was operated at room temperature, approximately 30 ˚C and continuously fed with livestock wastewater at a rate 1 mL/min until stable power output. Wastewater fed to the bio-electro reactor had a pH ranging from 7.1 to 7.3 and average settled concentrations of COD and BOD of 2100 and 1720 mg/L, respectively. Table 1 presents the quality of the livestock wastewater. Granular aged anaerobic sludge which was collected from the bottom of a local septic tank was used to inoculate the MFC.

Table 1 Characteristics of the livestock wastewater used for this study

Properties	Raw wastewater	Settled wastewater (6hr)
COD (mg/l)	2500	2100
BOD5(mg/l)	2000	1720
TSS (mg/l)	1200	590
Cond. (µs/cm)	7500	7420
pH	7.3	7.1

3.4 Analysis

The concentrations of chemical oxygen demand (COD) and biological oxygen demand (BOD) were determined according to the procedures described in the *Standard Methods* [8]. Voltage was continuously measured by a multimeter with a data acquisition system and converted to power according to P=IV, where P = power, I = current, and V= voltage. The power was normalized by the surface area of the anode.

4. Results and discussion

4.1. Startup of MFCs

Voltage was produced over time when livestock wastewater was pumped into the anode chamber. Voltage values were recorded using the Easy Log USB Voltage Data Logger. The voltage logger was directly connected to a personal computer, providing an online download data. Generated electrical current was measured using multimeter device type Best DT9205A. A resistance box (ranging from 1 Ω to 10000 Ω) was used to control the external applied resistance. With the increase of time, a steady increase in open-circuit voltage was observed and registered a maximum of 0.75 volt. Along with the voltage increase, biofilm growth on the anode was observed. Thereafter, external resistance (150Ω) was connected to the circuit, current density of 683 mA/m^2 was achieved which indicated that the startup of MFCs had finished. The experimental data demonstrated the feasibility of bioelectricity from livestock wastewater using MFC.

4.2 COD and BOD removal efficiencies

After the anode chamber in the MFC was inoculated with anaerobic mixed consortia, the MFC was operated with livestock wastewater as the feed to support the formation of biomass and subsequent adaptation to the new microenvironment. Constant substrate (COD) removal efficiency and voltage output were considered as indicators to assess the stable performance of the MFC. The microbial fuel cells was operated continuously for 50 days. Approximately, after 27days, a steady state condition was achieved for the MFC. Maximum COD removal up to 88% was obtained, for settled wastewater having an average initial COD concentration of 2100 mg/L as given in Fig.2. Maximum BOD removal up to 82% was obtained, for the settled wastewater having an average initial BOD concentration of 1720 mg/L as given in Fig.3. The efficiency of COD removal was in a very good agreement with the maximum reported efficiency 91% (Elakkiya and Matheswaran, 2013) and 82% (Mathuriya and Sharma, 2010).

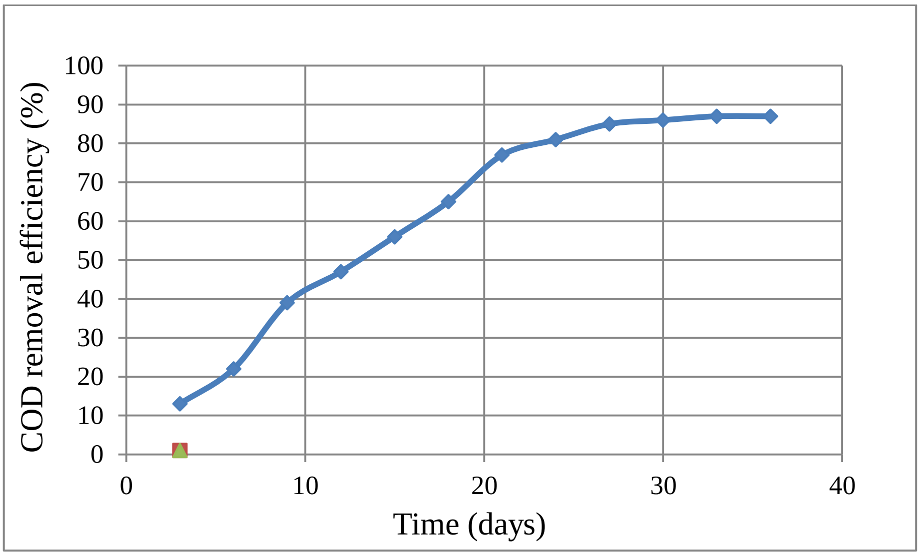

Fig.2. COD removal efficiency

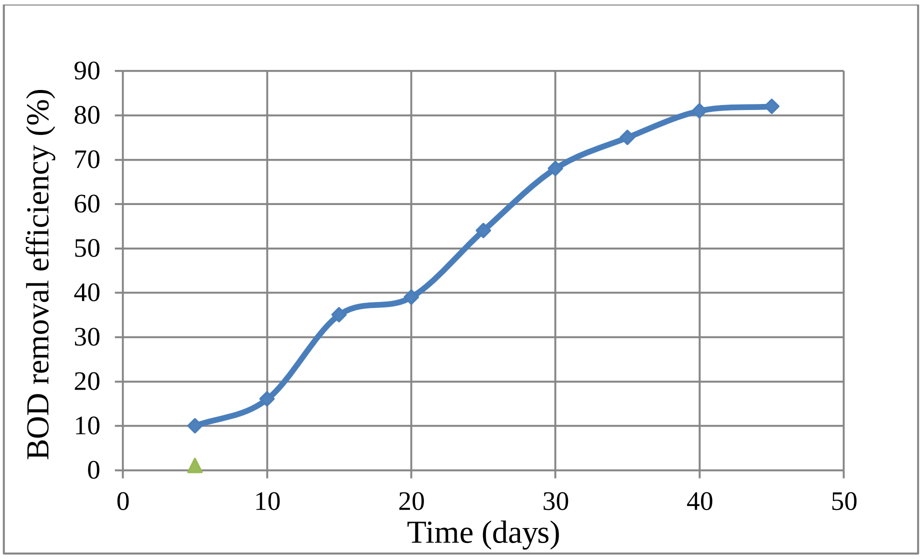

Fig.3. BOD removal efficiencies

4.3 Polarization Curves.

A polarization curve describes voltage as a function of current and is a powerful tool for the analysis and characterization of MFC. A maximum power can be produced when the internal and external resistances are equal [14]. In this study, for MFCs inoculated with mixed cultures, the relationships between the cell voltage and power densities as a function of the cell current densities are given in Fig. 4.The plots present the power output from the MFC as a function of circuit load, using a periodical increase in the external variable resistor. A maximum power density of 278 mW/m^2 at external resistance of 150Ω was achieved in MFC inoculated with aged septic tank sludge

(mixed cultures). Fig. 5 shows the variation of current density with time, the current density of 683 mA/m^2 becomes stable after 45 days of continuous MFC operation.

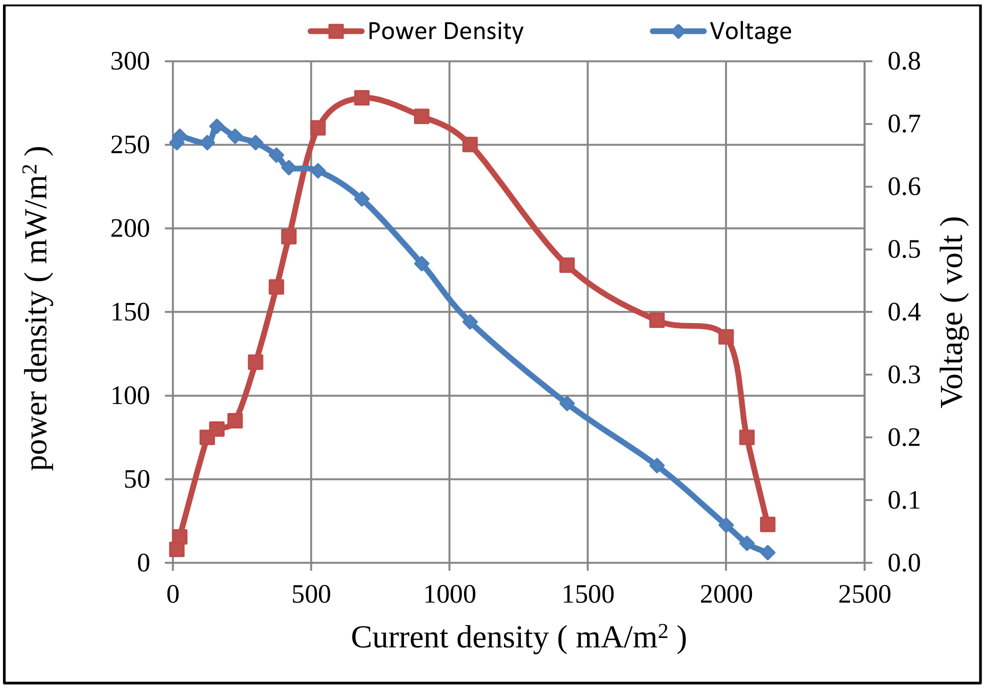

Fig.4. Polarization curve for MFC

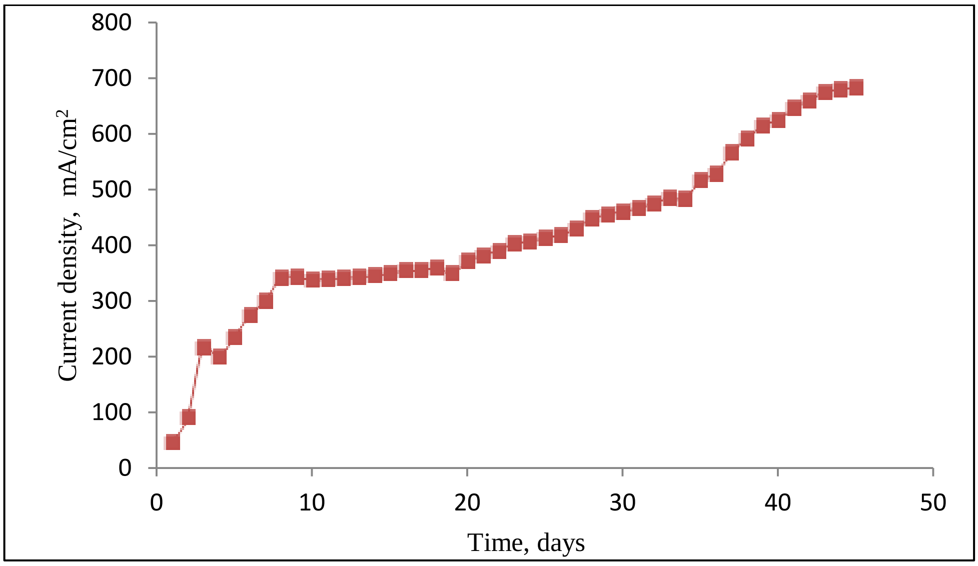

Fig.5. Variation of current density with time

4.4. Voltage at different external resistance

Variation of voltage was observed across the variable external resistance. The maximum voltage of 745mV was observed for MFC at external resistance of 750 Ω.

4.5. Effect of the external resistance on power production

The power production for the MFC was evaluated. Fig.6. shows the power production observed at variable external resistance. Maximum power density of 278 mW/m^2 was observed at external resistance of 150Ω as shown in the Fig. 6. Decrease in power density was observed with the increase in resistance beyond 150Ω, indicating importance of the external load for controlling power production. These results suggest that, at high external resistance the electron transfer through the external circuit to the cathode might be the limiting factor.

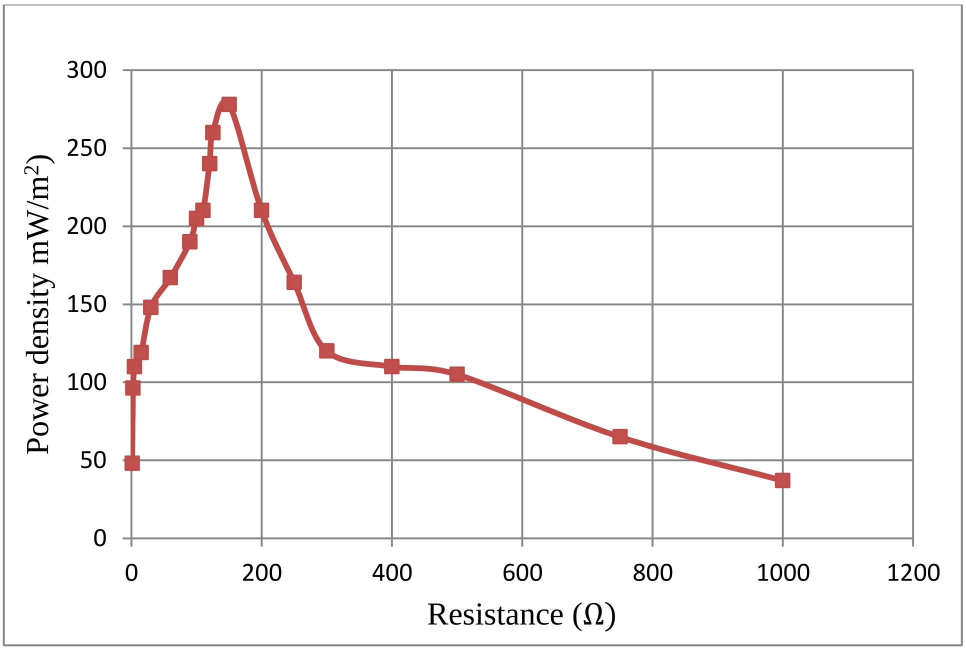

Fig.6. the power density observed under variable resistances

5. Conclusions

During this study, electricity was successfully generated with waste (as COD) removal from livestock (chicken manure) wastewaters using Microbial Fuel Cell technology. This study demonstrates that livestock wastewater containing high concentrations of degradable organics can make MFC operation more reliable and sustainable. This study evaluated the feasibility of bioelectricity production from particulate manure via horizontal microbial fuel cell. Results from the proposed MFC configurations demonstrated that chicken manure has the potential as a renewable feedstock to produce electricity at a rate of 278 mW/m^2 as a power density and 683 mA/m^2 as a current density. Differences in the external resistance in MFCs affected current generation, anode potential, bacterial diversity as well as intermediate metabolism. Lower circuit loads increased the electrochemical performance and were

associated with changes in the diversity of anode attached bacteria. Results revealed that COD and BOD removal efficiencies were up to 88% and 82%, respectively so this study recommends the further tuning of the technology for the better usage of the waste towards the commercial utilization for the generation of alternate energy to sustain the demand of future.

6. References

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