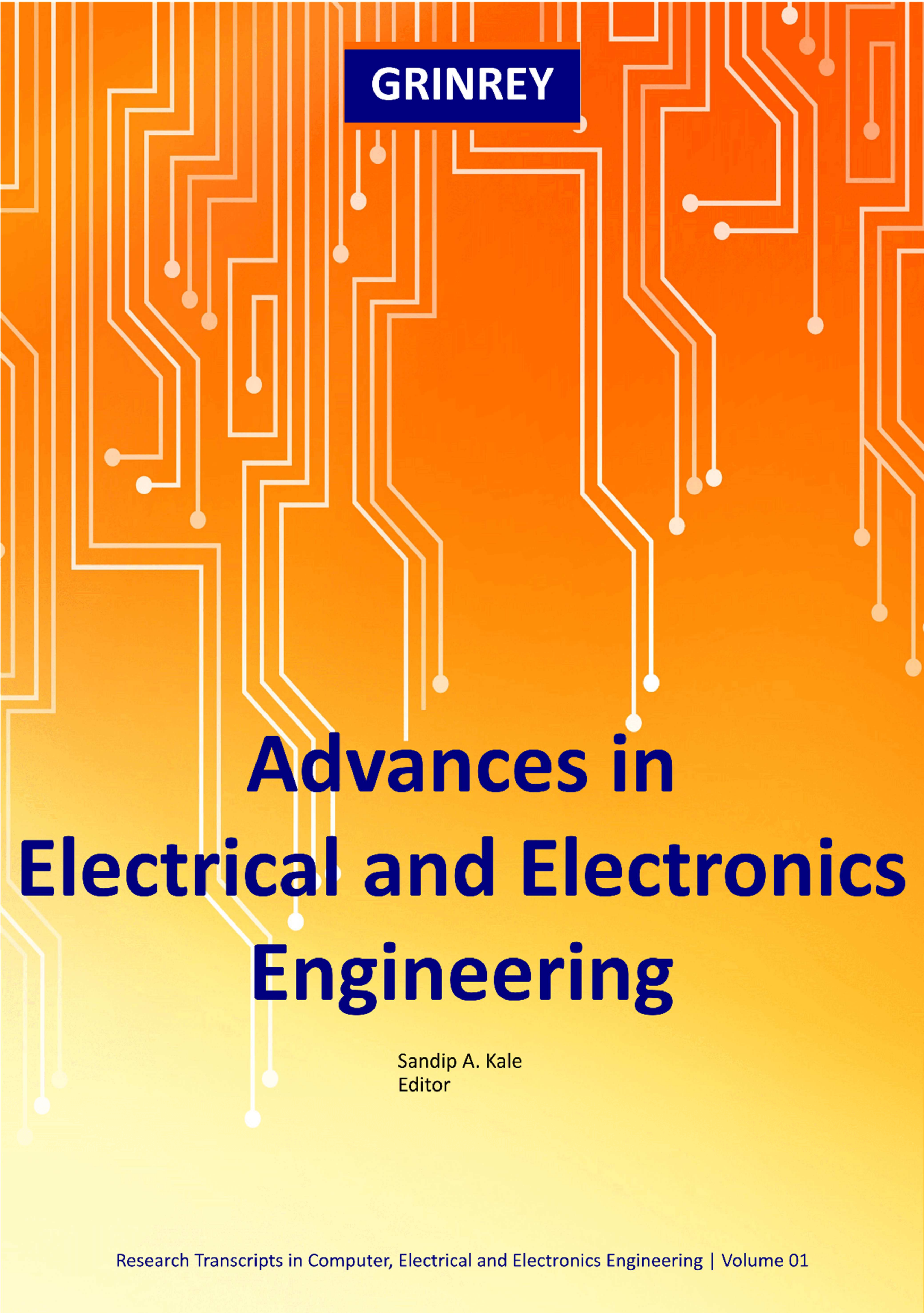

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6

Energy Generation From Corn Starch Effluent Using Microbial Fuel Cell Using Lead Electrodes

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ABSTRACT

Microbial Fuel Cell (MFC) is a promising alternative energy sources from organic wastes. MFC technology converts energy stored in organic compounds to electricity. This work investigated the viability of corn starch effluent as substrate (fuel) for bio-energy generation using MFC with the aid of Soldering Lead as electrodes. A dual chamber MFC was developed. Two plastic containers were used to house the anode and cathode solutions with PVC pipe serving as the Proton Exchange Membrane (PEM) casing. The anodic chamber was charged with corn starch effluent mixed with a buffer solution while the cathode chamber contained Potassium ferry cyanide ($K_3Fe(CN)_6$) solution, a conductive material. The output currents and voltages were measured using digital multi-meter (DT 9205D). The maximum current and voltage achieved is 0.11 mA and 0.78 V. The highest power density and current density was 10.64 mW/cm^2 and 14.00 mA/cm^2 respectively. The results (current, voltage, current and voltage density) were found to be relatively improved as compared to previous studies. Conclusively, household and agricultural organic wastes materials could possibly find usefulness as a clean source of energy for powering portable electrical appliances subject to erratic electricity supply and in off-grid environs.

Keywords: Bio-energy, Environment, Microbial Fuel Cell, Renewable energy, Wastes materials.

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1. INTRODUCTION

Growing difficulties with the use of petroleum-derived energy resources and its associated challenges of pollution, global warming and climate change are a major drive for the development of renewable energy resource. Emission from burnt fossil fuels causes adverse effects to man and his environment [1-3]. Alternative energy generation, storage and use are key focus in the research circle with increasing global interest and importance in areas like biomass [4,5], geothermal [6], hydrogen [7-9], solar [10-12], tidal [13-15], wind [16]. Presently, no one alternative energy resource possesses the capacity to completely replace and rival the conventional fossil-fuel based energy resource in term of generation and use. However, a hybrid of sustainable energy sources could be explored like, solar-wind hybrids, solar-biomass hybrids or solar-hydrogen fuel cells [17-19].

An emerging sustainable energy resource is Microbial Fuel Cells (MFCs), which is similar to the traditional fuel cells. MFCs utilises the biocatalytic potential of viable micro-organism by transforming the energy stored in the chemical bonds of biodegradable substrates, to produce bio-energy [20-22]. Literature abounds on viable substrates like sewage sludge [23], Ethanol [24], Glucose [25,26], Cellulose [27], domestic sludge [28,29], swine wastewater [30], etc. Potter first presented the concept of MFC in 1911 [22,31]. This was affirmed by Cohen around 1931, when a voltage of 35 V when was generated at a current of 0.2mA from a stacked bacterial fuel cell setup [22,32]. In 1963, National Aeronautics and Space Administration (NASA) also attempted the possibility of recycling and converting human waste to energy during space flights [33–35]. Hence the investigation of the feasibility of bio-energy generation from starch effluent.

2. METHODOLOGY

The material used for this pilot study is corn effluent, sourced from a local producer of corn starch at Ibogun Fashina, Ifo local Government of Ogun State, Nigeria. A two-chambered fuel cell was constructed using two plastic containers with diameter 100.5 mm and height of 120 mm for cathode and anode (Figure 1). One hole of diameter 25 mm at 50.4 mm height from the top of each container was drilled for the inclusion of salt bridge. In the setup for the anode, 1000 ml of the anodic inoculation was applied and container cap was closed air-proof. In the cathodic chamber, 1000 ml potassium dichromate solution was applied.

Fig. 1. A pilot system for a double chamber microbial fuel cell (MFC)

2.1 Electrode Preparation

A soldering lead was adopted as electrode for both anode and cathode. The anodic chamber was maintained under anaerobic conditions containing the substrate and biocatalyst microorganisms. The cathodic chamber was kept under aerobic conditions with the salt bridge forming a link between cathodic and anodic chambers, thus facilitating the movement of ions. A digital multi-meter (DT-9205A) was used for measuring the output current voltages (OCVs). The electrodes were used to convene electrons in anode and cathode sides with copper wire nectwork. The electrodes were locally sourced, hence comparatively inexpensive and available. Electrodes were pre-treated in pure ethanol for about 30 minutes and thereafter cleaned in 1M HCl, and recleaned in in a 1M sodium hydroxide solution for 1 hour to deactivate and get rid of inorganic contaminants. Thereafter, stored in distilled water preceding usage. The choice of electrode material affects the performance of MFCs.

2.2 Substrate Preparation

85.0g of wet starch was diluted in 75.0 cm^3 of distilled water and heated to a temperature range of 80 °C -100°C for 30 minutes under continued stirring. Dried sodium chloride of 5g was then added to the mixture, with continued stirring for another 5 minutes to allow for even mixture. Sodium chloride added was to improve the electrical conductivity of the wet starch. The prepared hot gel was instantly poured into a PVC pipe of 25 mm diameter and 15 cm long, and thereafter allowed to air-cool and set. So the PEM was ready for usage in the MFC setup.

2.3 Anolyte Preparation

177.42g of the substance was measured and mixed with 1000 ml of buffer solution and made airtight. The solution was carefully stirred to produce a homogeneous mixture, controlled at a fixed pH of 7.2 and a concentration of

177.4 gdm^{-3} buffer solutions. The buffer solution had a blend of 4.6 gdm^{-3} di-potassium hydrogen photo-phosphate (K_2HPO_4) solution (base) and 2.70 gdm^{-3} of potassium di-hydrogen photo-phosphate (KH_2PO_4) solution (acid), 1000 cm^3 each and 1000 ml of distilled water. The anode chamber was covered and made airtight to disallow atmospheric oxygen coming into the chamber, allowing the bacteria function in an absolute anaerobic condition.

2.4 Catholyte Preparation

The solution contains 32.93 g/dm^3 of potassium ferry cyanide ($K_3Fe(CN)_6$), which is a conductive material, which was charged into a compeletely aerated cathodic chamber. Otherwise, the cathode can accomodate air, with oxygen as the oxidant.

2.5 Experimental Procedure

The set-up was monitored for 14 days, such that the open circuit voltages (OCV) (potentials) was daily measured on 12 hours interval readings. Current and voltage readings was taken with a digital multi-meter (DT-9205A). Current densities, power densities and columbic efficiencies were derived applying the experimental readings equations 1 and 2. Tests (pH, chemical oxygen demand (COD) and biological oxygen demand (BOD) were carried out on substrate used for this work before and after setting up and running the MFC.

2.6 Calculations

The readings of currents and voltages was converted to power density (mW/m^2) using Eq. 1 [36],

$$P = \frac{\text{Current (mA)} \times \text{Volts (v)}}{\text{Surface area of the projected anode } (m^2)} \tag{1}$$

Current density C (mA/m^2) was estimated thus [37],

$$C = \frac{\text{Current produced (mA)}}{\text{Surface area of the projected anode } (m^2)} \tag{2}$$

3. RESULT AND DISCUSSION

3.1 Characterization of Substrate

The substrate, corn wastewater was characterized using standard methods. The characterization of the corn wastewater prior to its use as substrate gave a pH of 7.09, BOD of 228.60 mg/l and COD of 475.30 mg/l. The pH value of corn wastewater indicated the relatively neutral (basic) nature of this wastewater. The

BOD and COD values determined for corn wastewater were slightly lower than the values of 290 mg/l (BOD) and 654 mg/l (COD) reported for domestic wastewater [38]. The pH is also slightly lower compared to pH of 8.00 obtained for Tapioca wastewater produced using pure starch [39] and slightly lower than pH of 8.3 recorded for paper industry wastewater [40]. The difference in the pH values may be due to the chemical composition of both wastewaters.

The daily average current output is presented in Figure 2. The daily average output current was 0.03 ± 5.18 x 10^{-3} mA with SD of 2.74x 10^{-2} mA. The maximum current obtained was 0.11 mA, which is slightly lower than the highest current of 0.15 mA reported using animal-based waste [41]. Similarly, the voltage observed was also lower to that achieved using animal-based waste [41].

The daily average of voltage output obtained during the experiment for the 14 days is presented in Figure 3. A maximum voltage of 0.78V and minimum voltage of 0.42 V was achieved. For the 14-day study, average voltage of 0.67 ± 0.02 V was achieved. The maximum voltage attained in this work is slightly lower than the maximum voltage of 1.1 V recorded for animal-based (poultry droppings) waste [41]. The plot of voltage against time in Figure 3 showed cycles of voltage from the initial value of 0.74 V in day 1 to a steady decrease in voltage from 0.75 V in the second part of day 11 to 0.42 V in the second part of day 14. The instability in readings recorded largely depended on the cell's internal stability and steady microbial activities.

The current and power densities of were evaluated by dividing the values of current and power with the area of projected anode. These values are presented in Figure 4. For the experimental set-up, the maximum values of current and power densities calculated were 14.00 mA/cm^2 and 10.46mW/cm^2 respectively. The values for both current and power densities recorded in this study were found to be higher than the current and power densities values of 0.015 mA/cm^2 and 0.005mW/cm^2, respectively, reported using oil refinery wastewater [42]. The power density attained in this work is considerably higher than the range of 3.2 – 5.5 mW/m^2 achieved using fish market wastewater as substrate [43]. The plot of current density and power density against time shows a similar sinusoidal pattern with intermittent increase and decrease in the values for both parameters.

3.2 Statistical Analysis of Data

The ANOVA test was carried out on the measured data from the experiment and presented as Table 1. It is observed that the value of $F_{critical}$ (2.4387) is far less than the value of $F_{observed}$ (28.6507) which implies that the variances of the data on current and voltage are not the same, that is, they are statistically independent of each other. This is further substantiated by the P-value <<0.05 at 95% confidence limit, which indicates the significance of the result, which shows that the data obtained in this work are statistically not the same. The correlation between the current and voltage was 0.5717, which implies that a positive and moderately strong relationship exists between voltage and current.

Table 1. Analysis of Variance (ANOVA)

Source of Variation	**SS**	**df**	**MS**	**$F_{observe}$**	**P-value**	**$F_{critical}$**
Between Groups	443.74	4	110.934	28.6507	3.078E-17	2.4387
Within Groups	522.71	135	3.8719			
Total	966.45	139				

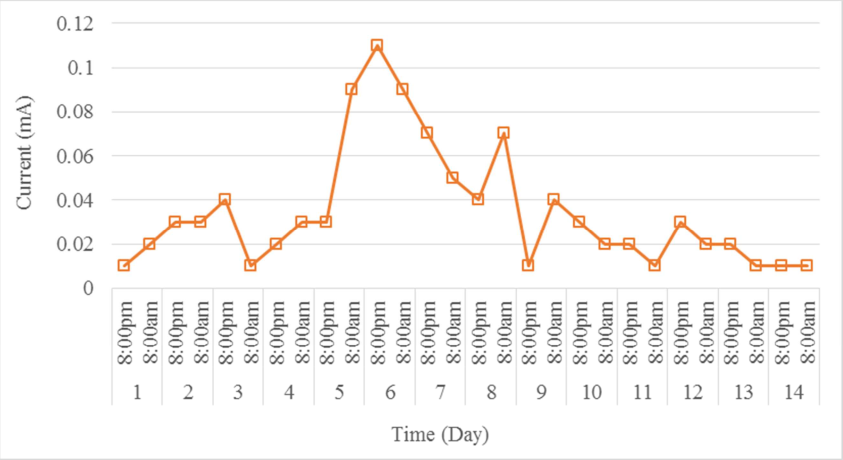

Fig. 2. Plot of Current Against Time

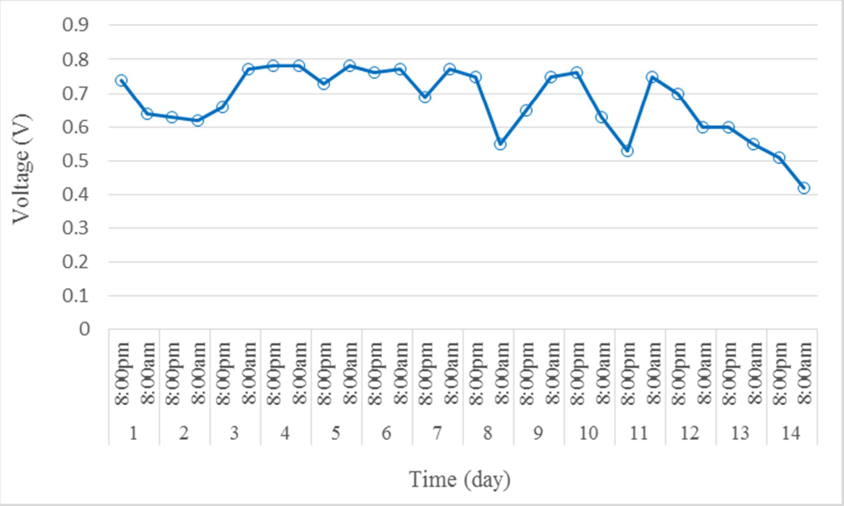

Fig. 3. Plot of Voltage Against Time

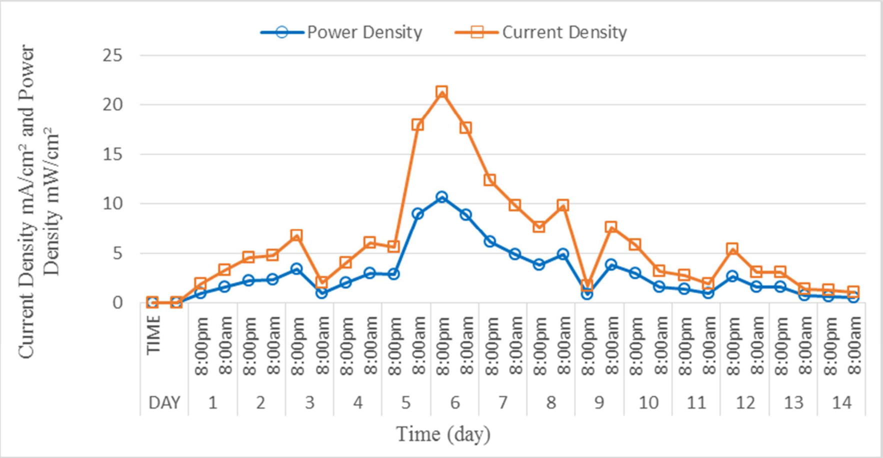

Fig. 4. Plot of Current Density and Power Density Against Time

4. CONCLUSION

This study investigated the viability of corn wastewater effluent as substrate in MFC solution for generation of off-grid energy using lead electrodes. A modified starch was used as PEM in the double chamber MFCs with the anode chamber totally maintained in an anaerobic condition whilst the cathode was fully aerated. The lead electrode showed a considerable potential of high voltage of about 0.78 V with a very low current potential ranging from 0.01-0.11mA. It was observed that the principle guiding MFC for the removal of toxicity is the availability of biodegradable compounds present in the effluent sample. The study proved a great potential as another source of sustainable energy. Its ability to generate bioenergy alongside treating wastewater makes it more attractive in this modern time when efforts are geared towards reducing pollution and its attendant problems.

NOMENCLATURE

BOD	:	Biological Oxygen Demand
COD	:	Chemical Oxygen Demand
I	:	Current
MFC	:	Microbial Fuel Cell
PEM	:	Proton Exchange Membrane
OCV	:	Output Current Voltages
V	:	Voltage
Ts	:	Temperature of surface

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