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Evaluating the Effectiveness of Cassava Wastewater Treatment in a Low Cost Microbial Fuel Cell

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Authors' contributions

This work was carried out in collaboration between all authors. Author ORA designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Authors ITA and OSA performed the laboratory analysis and managed the analyses of the study. Author AOD managed the literature searches and final analysis of the study. All authors read and approved the final manuscript

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ABSTRACT

The performance of two-chambered low-cost microbial fuel cell (MFC) with cassava wastewater was evaluated for the effective treatment of polluting content. Two 30 L plastic containers were used to serve as anode and cathode chamber. The electrodes were made from readily available carbon papers sew together with naked copper wire while the salt bridge was made of inverted 'U' shaped PVC pipes. Results revealed that the removal efficiency for magnesium and cyanide were low while the 5-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) removal were 65% and 53%, respectively. Increase in the voltage and power was observed at the beginning of the degradation which later gradually decreased with time. The maximum current generation (0.76 mA) was observed at an external load of 1000 Ω with a maximum voltage of 0.75 V while power obtained was 5.63×10^{-4} Watt. The coefficient of determination (R^2) obtained was 0.9875, 0.9878 and 0.9926, for voltage, current and power, respectively. Plots indicated a best fitted model with the obtained data. It was revealed from the study that MFC can provide a

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sustainable and cheap means of treating cassava wastewater in developing countries with dual advantage of power production. The treatment technique would reduce environmental pollution from the usual indiscriminate disposal on land and water.

Keywords: Cassava wastewater; wastewater treatment; microbial fuel cell; energy generation.

1. INTRODUCTION

Amidst various agricultural products processing, cassava generates a lots of wastewater. Volume of water consumed and wastewater generated depend on the quantity of cassava tubers been processed and mass of the end product [1]. Cassava wastewater constitutes a major environmental concern especially in Africa due to indiscriminate disposal, not only the volume of wastewater generated but the contents of the wastewater and offensive odour generated from its unplanned disposal over time. Most of the medium and small scale cassava processing industries dispose the cassava peels and wastewater indiscriminately.

Globally, more than 268 million tons of cassava is produced annually. African countries produce over 103 million tons per annum while Nigeria account for about 35 million metric tons from the total amount with possible increase to 40 million tons as the call to embrace indigenous agricultural farming increases [2]. Recently, production figures ranked Nigeria as the leading producer of cassava in the world. By implication, the quantity and quality of cassava wastewater generation in Nigeria is high.

The deleterious effects and adverse impact of indiscriminate disposal of cassava wastewater is not limited to public health but also has negative impact on crops and plants, soil, surface and groundwater resources, property values, ecological impact and social life of a community [3,4]. Recent research works [5] highlighted the negative impact on receiving water body and aquatic life while other studies [6] emphasized the effect of cassava effluent on Okada environment in North East Local Government Area of Edo State, Nigeria. The study revealed a negative impact on selected animals and impairment to plant growth in addition to air pollution. Cassava wastewater should be treated to produce effluent water of moderate quality that can be disposed to the natural water surface or land with little or no adverse impact on human health or the surrounding environment [3,4].

Cassava (*Manihot esculenta* 'crantz') is a very significant food crops in Nigeria and most of the tropical regions. It provides about 40% daily calorie in Sub Saharan Africa and about 70% of the daily Calorie intake of over 50 million Nigerians [7]. Cassava is used to produce a wide range of industrial products such as ethanol, glue, glucose syrup extensively used by pharmaceutical and confectionary industries, for starch production and consumables like bread as well as for African delicacies like fufu and gari production. Cassava wastewater often becomes putrid with main pollutant as cyanide, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved and suspended matters amidst others. The disposal of cassava wastewater is a great concern in developing countries [5,6] where adequate legislation policy and standards are not strictly adhered to, and where they are followed, there are limited space for land based treatment and disposal.

Primary treatment methods for treating wastewater involves screening, grit chamber and sedimentation, while secondary treatments utilizes activated sludge or trickling filters or lagoons to convert the non-settle-able solids to settle-able solids. In the last century, activated sludge process has been the major technique for the treatment of wastewater but the method is expensive and energy consuming, instead of energy producing. Typical treatment method for starchy wastewater like cassava wastewater is the aerobic biological treatment. But recently, the microbial fuel cell (MFC) has proven to be a promising and sustainable technology for the treatment of wastewater by removing or treating the pollutants in wastewater before discharge into the environment accomplish by energy generation to meet increasing energy needs [8,9,10]. Other advantages of MFC includes reduction of the operational cost of treating wastewater [11], as it is a clean and safe technology with low emissions, permits the reuse of wastewater and easy to operate.

The MFC cell makes use of the bacterium already present in wastewater as catalysts to generate electricity while simultaneously treating the wastewater [12,13,14]. In MFC, microorganisms in the wastewater oxidizes the organic matter in anode chamber (through anaerobic conditions) producing electrons and protons. Electrons transfer via external circuit to the cathode chamber where electrons, protons and electron acceptor (mainly oxygen) combine to produce water [15]. In a two-chamber set up, the anode and cathode compartments are separated by an ion-selective membrane, allowing proton transfer from anode to cathode and preventing oxygen diffusion to the anode chamber. Although MFCs generate a lower amount of energy than hydrogen fuel cells, a combination of both electricity production and wastewater treatment would reduce the cost of treating primary effluent wastewater. Cassava mill wastewater in a single celled MFC inoculated with mixed culture sludge was analyzed to generate energy [16]. However, in this study, the effectiveness of treating cassava wastewater was determined in a double chambered MFC made with locally available materials. The materials were selected so that both the local and industrial cassava processors would find it economical, easy and safe to use while processing on-site instead of usual indiscriminate discharge on land and water. The outcome of this work is also significantly important for public health workers, environmentalists, water resources analyst and engineers.

2. MATERIALS AND METHODS

2.1 Building the Anode and Cathode Chamber

Two medium-sized plastic containers were taken to serve as anode and cathode chamber. Connection openings were made at 13 cm to the top and 5 cm to the bottom of each of the two chambers as passage to link the chambers. Nuts were fixed to the interior and exterior opening of the tank and tightened. 9 cm PVC pipes were connected to the exterior nuts with the means of adaptor and another 9 cm PVC pipe was fixed to the other edge of the adaptor for further connection to the ball gauge.

Salt bridge made of elbow PVC pipes in an inverted "U" shape was connected to the ball gauge to reduce the rate of flow of the solution into the opposite chamber.

The ball gauge and salt bridge were connected together with union connector to allow for disconnection when needed. Lids of the chambers were perforated to obtain tiny openings at the top of the two chambers to serve as openings for copper wires connecting the electrodes in the anode and cathode chambers while the openings to the cathode chamber also allowed passage of air in and out of the chamber [Fig. 1(a - d)].

2.2 Making the Electrodes

The electrodes were made from readily available carbon paper. A total of 100 pieces of carbon papers were collated together in the regular rectangular shape of 30 cm by 20 cm (≈ 25 cm^2). Flexible copper wire was taken, one end of the flexible copper wire was prepared by stripping off the insulator around it by using wire stripper. The stripped or naked copper wire was carefully wounded and sewed round the collated carbon papers in and out of each layer while the unstrapped end was left for connection to the external circuit, this formed the electrode for the anode chamber. The protocols were repeated for making the electrode for the cathode chamber [Fig. 1 (e and f)].

2.3 Making the Salt Bridge Solution

One end of the inverted 'U' shaped PVC pipe was already prepared and securely sealed with aluminum foil to prevent leakage, and kept in a secured petridish. Agar powder (60 g) was added to 300 ml of clean water and stirred with glass rod for proper dissolution before adding 12 g of table salt. The solution in the flask was mixed thoroughly and placed in an autoclave to boil for one hour. The warm solution was carefully poured into the open end of the inverted 'U' shape PVC pipe over the petridish and observed for any leakages (where leakages was observed, aluminum foil was used to tube opening and refilled). In the absence of any leakage, the tubes over the petridish were kept into refrigerator for cooling. After cooling, aluminum foils were removed from the bridge and salt bridges were used immediately to prevent drying out of the solution in the tubes [Fig. 1(g)].

2.4 The Fuel Cell Assemblage

The entire experiment was performed at room temperature. The two chambers were coupled together with salt bridge in between. The cathode chamber was filled with conductive salt solution (2500 g of salt dissolved in 25 L of clean water). The anode chamber was carefully filled with 25 L of cassava wastewater with all safety precaution.

The prepared electrodes (made of collated carbon paper with copper wires) were tied to the lid opening of each chamber and submerged into the anode and cathode solution. The experimental set-up is shown in Fig. 1(h). The hydraulic retention time (HRT) was 24 - 48 h. Voltage of the cell were monitored and measured by using a precision multimeter.

2.5 Cassava Wastewater Collection and Characterization

Fresh cassava wastewater was obtained from residues at the processing yard. The composition of the wastewater such as pH, Turbidity, Total suspended solids (TSS),Total dissolved solids (TDS), Hardness, Conductivity, Iron , Magnesium, Lead, Cyanide, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were determined using standard protocol of APHA [17] before and after retention in the cell chamber.

The pH, conductivity and turbidity were determined by using pH meter, conductivity meter and turbidity meter, respectively. TSS, TDS, hardness were determined spectro-photometrically by using UV absorption spectrophotometer.

The potential was measured using a digital multimeter and converted to power (P) using equation 1.

$$P = I\,V \tag{1}$$

Where I= Current (A) and V = Voltage (V)

The treatment efficiency (E_T %) representing the fraction of the original concentration that was removed in the process was calculated as shown in equation 2. Where C_i represents the initial concentration of the wastewater and C_f represents the final concentration of the wastewater.

$$E_T\,\% = 100.\ \frac{C_i - C_f}{C_i} \tag{2}$$

3. RESULTS AND DISCUSSION

3.1 Wastewater Characterization

The initial and final concentrations of the cassava wastewater are shown in Table 1. The initial average concentration (before treatment) was denoted as A while the final average concentration (after degradation) was denoted as B against the permissible limit for effluent discharge.

The initial hydrogen ion concentration (pH) of cassava wastewater was strongly acidic, which slightly reduced after retention in the cell but not within the recommended discharge value of 6.0-9.0. Mean turbidity value of wastewater was initially 212 NTU but reduced to 68 NTU after degradation in the cell. Final concentration was recorded higher than the recommended value for discharge which. should be less than 10 NTU.

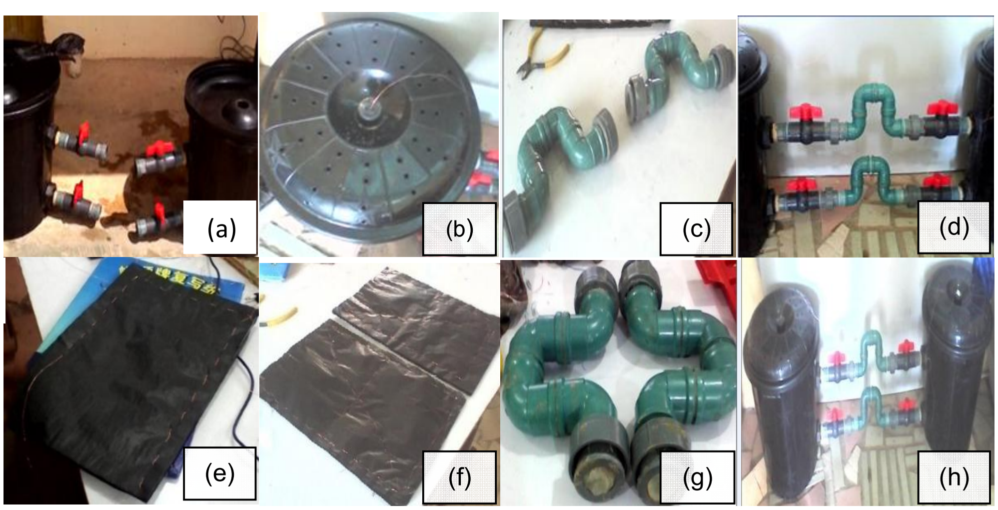

Fig. 1. (a) Chambers with adaptor, ball gauge and union connection (b) Perforated lid (c) Salt bridge connections (d) Inverted "U" shape double salt bridge connection (e) Sewed electrode (f) Anode and cathode electrode (g) Salt bridge (h) MFC set up

Cassava wastewater contains high turbidity due to presence of large amount of cassava peel particles, starch residue and organic matter generated during processing of effluent. The initial values for TSS and TDS were also higher than the allowable threshold limit due to high level of starch dissolution of cassava roots in water. The continuous fermentation of carbohydrate rich starchy wastewater within the cell also resulted to high concentration of TSS and TDS compared to the recommended level for discharge even after degradation. The wastewater hardness was slightly reduced in the degradation process, from an initial value of 95.5 mg/l to the final values of 97.3 mg/l. The conductivity of wastewater was slightly reduced from an average value of 1921 to 1129 µ S/cm.

The concentration of iron at the influent was at a low level of 0.03 mg/l and increased to 1.0 mg/l after continuous retention in the cell. Magnesium (as dissolved inorganic substance) was slightly reduced from an average value of 217.5 mg/l to 210.5 mg/l. Variation in concentration of other heavy metals like lead (Pb) and cyanide (Cn) were insignificant.

The BOD test measures the oxygen demand of biodegradable pollutants whereas the COD test measures the oxygen demand of oxidizable pollutants. The BOD_5 and COD as a measure of the relative oxygen-depletion effect of the waste contaminant were degraded from 495 mg/l and 985 mg/l to 173 and 462 mg/l, respectively. Both have been widely adopted as a measure of pollution effect. Both BOD and COD were significantly reduced in microbial cell but not within the permissible threshold limit for disposal. BOD_5 and COD removal efficiency has been reported between 62–91% [18,19] from cassava wastewater under different conditions of experimental set-up.

3.2 Treatment Efficiency

The removal efficiency of the parameters tested is presented in Fig. 2. The pH content of the wastewater was slightly increased while remained acidic. Maximum removal of turbidity, TSS, TDS was recorded 68%, 80% and 46%, respectively. The removal efficiency for magnesium and cyanide were minimum while BOD and COD were 65% and 53%, respectively.

3.3 Energy Generation

The MFC inoculated with cassava wastewater was operated in a continuous mode at external load of 1000Ω. The variations of voltage, current and power generation with time were recorded and are shown in Fig. 3.

Within the first minutes of operating the cell, the potential was low. The initial output was 0.35 V which gradually increased to 0.65 V after 60 minutes. The experiment remained stable between 150 – 250 minutes of operation giving rise to an output of 0.74 V. Between this time interval, voltage readings increased from 0.70 to 0.74 volts at 120 and 180 minutes, respectively, yielding a maximum output of 0.75V between 260 and 270 minutes of operation after which gradual decrease began at approximately in ~280 minutes. The drop in voltage generated continued till 1380 minutes which became negative through the second day of operating the MFC

Table 1. Performance of the MFC for cassava wastewater treatment

Parameter	Initial concentration A	Final concentration B	*Discharge standard
pH	3.80 ± 0.4	5.15 ± 0.01	6.0 -9.0
Turbidity (NTU)	212.55 ± 0.2	68.44 ± 0.1	10 NTU
TSS (mg/l)	1401 ± 0.2	122.50 ± 0.05	50 – 100
TDS (mg/l)	1842 ± 0.01	978.8 ± 0.01	500
Hardness (mg/l)	95.0 ± 0.4	97.5 ± 0.35	-
Conductivity (µ S/cm)	1921.05 ± 0.01	1129.5 ± 0.01	-
Iron (mg/l)	0.03	1.0	0.3/ 1.0
Mg(mg/l)	217.5 ± 0.02	210.5 ± 0.01	
Lead (mg/l)	0.05 ± 0.01	0.08 ± 0.15	0.05 / 0.1
Cyanide (mg/l)	33 ± 0.4	32± 0.85	0.05 / 0.1
BOD_5 (mg/l)	494.88 ± 0.01	173.0 ± 0.2	50
COD (mg/l)	984.0 ± 1	462.0 ± 0.65	100

**Malaysian Environmental quality (industrial effluent) regulation, 2009. Applicable to discharge into waters with in catchment area*

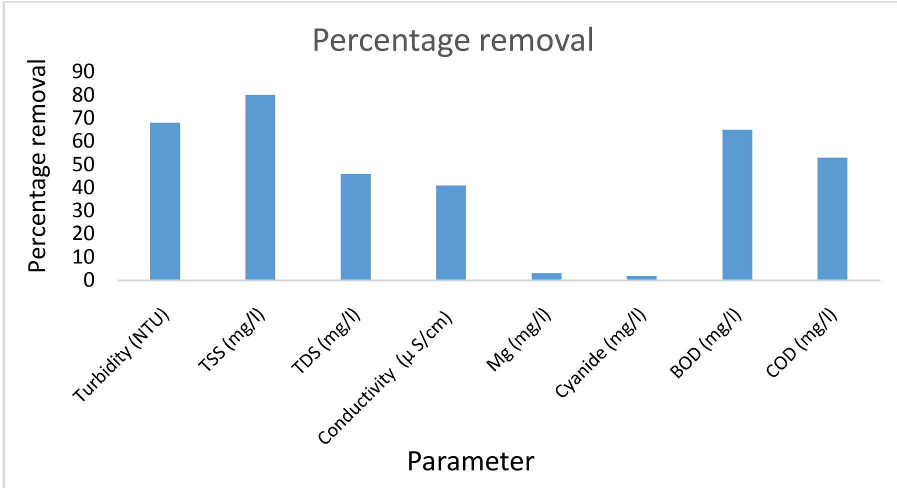

Fig. 2. Percentage removal for selected parameters

The corresponding initial electric current (10^{-4}A) production was also low, at 3.5 to 5.40 x 10^{-4}A in 10 minutes. Gradual increase of the current (5.80, 6.10, 6.30, 6.50 to 7.6 x10^{-4} A) were observed up to 270 minutes. Maximum current generated (0.76 mA) was observed at 272 minutes. Thereafter, the generated current began to decrease (7.6, 7.3, 7.2, 7.1, 7.0, 6.9, 6.8 to 0.1 x10^{-4} A) at 1360 minutes to the starting time. Negative current of -0.1, -0.2, -0.3, -0.2 was recorded at 1370 minutes up to the second day.

As the molecules in the nutrient of the wastewater are broken down and electrons are released, it facilitates the rise in voltage, current and power generation, while these are used up the output decreases.

This decrease might be attributed to the growth of methanogens (microorganism that produces methane as a metabolic byproduct in anoxic condition) in the anode chamber, reducing the availability of electron and proton, hence reducing current. The higher the nutrient concentration in the cassava wastewater the more is the effective performance of self-produced bacteria which in turn affect the performance of MFC in producing energy. Hence, variation in enrichment of bacteria affected the generation of voltage, current and power. In this present study, high external resistance could also be attributed to low energy production because it is widely reported that larger current production at lower external resistance is usually envisaged. The production of current decreased with increase in resistance at same concentration of wastewater. Hence, a low current was recorded in this experimental set-up. Power generated was 2.92 x 10^{-4} W within the first 10minutes, and increased to a maximum value of 5.63 x 10^{-4} W at a retention time of 270 minutes before a gradual decrease to 0.009 x10^{-4}W at 1440 minutes.

A maximum voltage output of 275 mV and a corresponding current output of 2.75 mA within 240 min (4 h) were recorded from a cassava mill effluent operated in a two cell chamber, with anode chamber inoculated with artificial wastewater containing glucose of different concentration as carbon source [20]. A maximum voltage output and power density of 450 ± 20 mV and 29 mW/m^3 was obtained from a single chamber MFC with cassava peel and extract with anode consisting of carbon graphite brushes, while the cathode was a membrane electrode assembly (MEA), consisting of a gas diffusion layer coated with 60% PtC at 0.5 mg/cm^2 [10]. A maximum voltage of 687 mV was later obtained from aqueous filtrates of microbial hydrolyzed cassava peels operated at different pre-treatment methods [3].

A linear relationship between voltage generated and time was observed in a MFC inoculated with rice washing water also rich in starch with higher voltage in micro-volt recorded in the first day of the operation which decreases to the fifth day irrespective of adding slurry or vermicompost [21]. In contrast, maximum voltage of 490.8 mV was obtained from a starch processing wastewater of 4900 mg/l COD [11].

Ghangrekar and Shinde [22] obtained a voltage of 0.116 volts in the first fifteen days of operating a membrane-less microbial fuel cell inoculated with septic tank sludge, the voltage increased to 0.188, 0.175 and 0.151 V between 35,55 and 78 days of operation with corresponding current generation of 0.175,0.148 and 0.121mA. Here, the maximum current and voltage obtained were 0.175 mA and 0.19 V, respectively at external load of 10 Ω while higher voltage were generated by using mixed cultures.

As shown in Fig. 2, A-B was the initial stage which is called the exponential stage. At this stage, the set-up was in operation and the microbes started decomposing the complex waste nutrient to liberate electron at the anode chamber which later found their way through the external circuit to the cathode, thereby voltage was generated.

B-C was the stationary stage where the microbes had been able to decompose all the substrate and therefore maximum and stable voltage was noted. At this stage the microbes performed up to their maximum efficiency because of the availability of food.

C-D displayed the lagging stage where the substrate was almost exhausted by the microbes gradually and it showed the fall in voltage, current and power generation. At this stage the microbe in anode chamber was more than the substrate available in the waste water therefore there was reduction in the performance of MFC.

E was the death stage at which all the substrate had been exhausted therefore it led to death of some microbe which could not survive the current condition of the substrate.

3.3 Mathematical Modeling for the Outputs

The best fitted curve of voltage generated is a polynomial equation of the fifth-order. The mathematical model for voltage is given in equation 3. The best fitted curves for the current and power generation are also polynomial equations of the sixth and fifth-order, respectively while the mathematical equations obtained are given in equation 4 and 5, respectively. This reflects that the voltage, current and power generated with respect to time did not follow a linear order. The decrease in voltage and power is not only dependent on time alone but also on many other parameters involved in this process (type of bio-waste or substrate, type of inoculum, concentration, type of chamber, cell volume, anode and cathode material, cell type, electrode material etc.).

The coefficient of determination (R^2) as a regression analysis that describes the relationship between the variables employed for the evaluation of degradation process within the cassava wastewater gave the respective values of (R^2) as 0.9875, 0.9878 and 0.9926 for

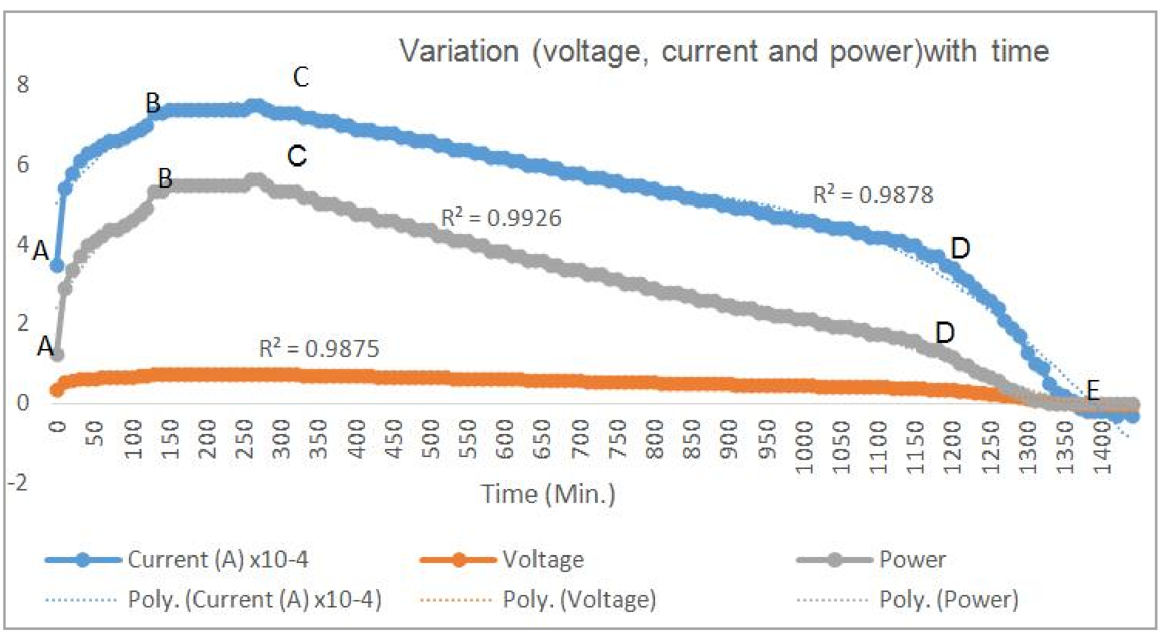

Fig. 3. Variation of voltage, current and power with time

voltage, current and power, respectively which indicate a good fit to the recorded data.

Voltage (V) = $2E\text{-}10x^5 - 9E\text{-}08x^4 + 1E\text{-}05x^3 - 0.0011x^2 + 0.0304x + 0.4621$ (3)

Current (A) = $1E\text{-}11x^6 - 4E\text{-}09x^5 + 2E\text{-}08x^4 + 8E\text{-}05x^3 - 0.008x^2 + 0.2646x + 4.7691$ (4)

Power (W) = $3E\text{-}09x^5 - 1E\text{-}06x^4 + 0.0002x^3 - 0.0132x^2 + 0.3725x + 2.0458$ (5)

The terms of the equations, voltage with time, current with time and power generation with time indicates that a retention time significantly influenced the removal efficiencies of organic and inorganic matter in the wastewater. Significant terms are kept in the representative to be used in mathematical model equations.

4. CONCLUSION AND RECOMMENDATION

The present study revealed that organic, inorganic and heavy metals might be degraded from cassava wastewater in a MFC system. The removal efficiency for magnesium and cyanide were low while BOD_5 and COD removal were 65% and 53%, respectively. Increase in voltage and power was observed at the beginning of the experiment which later decreased with time. The maximum current generation of 0.76 mA was recorded at external load of 1000 Ω with maximum voltage of 0.75 V while power obtained was 5.63×10^{-4} Watt. MFC is a sustainable and cheap means of treating cassava wastewater in developing countries with dual advantage of power production. The treatment technique when put in place would reduce environmental pollution instead of the usual indiscriminate disposal of wastewater on land and water. Consortium of bacteria and isolation of potent microorganism could be used to improve electron transfer and power density respectively during degradation process.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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