POTENTIAL OF AGRO-BASED INDUSTRIAL WASTEWATER AS AN ALTERNATIVE SUBSTRATE FOR BIOELECTRICITY

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ABSTRACT

The potentials of agro-based industrial wastewater as an alternative substrate for bioelectricity were investigated. Piggery and poultry wastewater as well as 0.1 M potassium permanganate were collected, prepared and served as substrates in the anodic and cathodic chambers of the Microbial Fuel Cell (MFC) set up. Standard analytical procedures were adopted in the physicochemical determination, while the generation of electricity was evaluated using current densities (mA/cm^2) and power densities (mW/m^2) respectively. The results revealed that the power density of the piggery wastewater reached a peak value on the 288th hour with a value of 151.98 mW/m^2 with a BOD, COD, TDS and TSS values were 65.52, 52.22, 11.40 and 57.39% respectively, while the poultry wastewater reached a peak power density of 120.24 mW/m^2 on the 240th hour with a BOD, COD, TDS and TSS values of 21.74, 40.06, 2.34 and 52.87% respectively. On the other hand, results on the current densities (mA/cm^2) and power densities (mW/m^2) showed that the poultry wastewater MFC had peak values of 50.52 mA/cm^2 and 151.98 mW/m^2 on the 10th day, while the piggery powered MFC peaked on the 12th day with peak values of 69.47 mA/cm^2 and 234.48 mW/m^2 respectively. Statistically, the power and current densities of piggery wastewater were significantly greater ($p<0.05$) than that of the poultry wastewater. There were significant positive ($p<0.05$) relationship between physicochemical parameters and power density with time. Thus, the excellent transformation of these liquid wastes using MFC for energy generation could be exploited as benign and environmentally friendly approach.

Keywords: Alternative energy source, Bioelectricity, Microbial fuel cell, Piggery wastewater, Poultry wastewater

INTRODUCTION

Energy has been the major aspects in the evolution of civilization, as fossil fuels have taken care of industrial revolution part. The energy needs cannot be sustained by fossil fuels only at the end of 21st century as they are not substantial enough because of their limited availability. Over two million people in Nigeria are still living off the grid and are living in environments where there is no access to good and portable water due to pollution of their water bodies via wastewater discharge. So, the need for renewable alternative source of energy generation is need of the day (ENVIS, 2014).

Recently, bioelectricity production is the production of electricity by organisms on account of production of electrons resulting due to their metabolism. These electrons produced can be captured so as to maintain a stable or continuous source of energy production. Bacterial cells when provided a suitable substrate can metabolize the components producing electrons which can be harvested and utilized by connecting them through a circuit. These components can be packed into an assembly called a 'microbial fuel cell' (MFC) proving to be a source of energy (Moqsud *et al.*, 2013). Thus, the MFC is a promising technology for efficient wastewater treatment and recovering energy as direct electricity for onsite applications (Duteanu *et al.*, 2010).

There is abundant potential energy of approximately 17 GW of power (1.5 91011 kWh) contained in domestic, industrial and animal wastewater together. Thus, capturing part of this energy would provide a new source of electrical power and would also compensate the consumption of energy for wastewater treatment (Feng *et al.*, 2015). In the treatment of biodegradable organic matters in MFCs, removal efficiencies comparable with established treatment methods can be obtained. Even some of the bio-refractory compounds can be effectively removed in MFCs (Duteanu *et al.*, 2010). In a study conducted by Min *et al.* (2005) on treating swine wastewater in a dual chambered MFC, 86% removal of chemical oxygen demand (COD) and 83% removal of NH^{+4}–N were achieved with the maximum power density of 45 mW/m^2. A meat packing wastewater, diluted to COD of 1,420 mg/L, produced 80 mW/m^2 power density and biochemical oxygen demand (BOD) removal efficiency greater than 86% (Heilmann and Logan, 2006). Power was increased by 33% by addition of salt (300 mg/L sodium chloride) due to increase in solution conductivity. The study on MFC technology was conducted as it is believed to be cheaper, easy to manage and have the capacity to produce energy simultaneously as it treats wastewater. The technology promises the availability of electricity if it is harnessed so that the large out-of-energy-grid population in Nigeria can be reached with this cheap power source. The effluent from this technology is also safe for discharge to the environment. The study was aimed at investigating the potential of agro-based industrial wastewater as an alternative substrate for bioelectricity.

MATERIALS AND METHODS

Sample Collection and Preparation: The sampling site was located at Bvisoug Limited (Farm Division), Umuagwo in Ohaji Egbema Local Government Area of Imo State, Nigeria. Wastewater effluent samples were collected from poultry and piggery farms of this site in the early morning hours during the routine clean-up of the farm. The samples were adequately labelled. Each sample was collected in sterile a 10 litre gallon and homogenized by vigorous agitation and thereafter transported to the Anthony Van Leeuwenhoek Research Laboratory, Owerri, Imo State, Nigeria for further analysis.

Physicochemical Characteristics of the Raw Wastewater: The standard procedures of American Public Health Association (APHA, 1998) manual and AOAC (2010) were adopted for the physicochemical analysis. The tests carried out in this study include: biological oxygen demand (BOD), chemical oxygen demand (COD), pH, phosphate, conductivity, total dissolved solid (TDS), total nitrogen and total suspended solid (TSS).

Component and Construction of the Microbial Fuel Cell: Microbial fuel cells were constructed in line with the H-type design of Adeleye and Okorondu (2015). In this method, the salt bridge was made a day before the set-up was coupled. The samples were collected the same day the MFC was to be coupled. The set-up was coupled by joining the two chambers using the salt bridge with the aid of the adopter inch and Abro sealant. Thereafter, 900 mL wastewater was placed in the anode as the anolyte and the catholyte which was 900 mL of 0.1 M potassium permanganate was introduced into the cathode. A multimeter was connected to the cathode and the anode with the aid of the low resistance copper wire before they were inserted into the chambers. Next, the multimeter was set at 2000 m for measuring DC current in millivolts. The initial reading was taken at time 00 and allowed to acclimatize for 1 hour before subsequent readings were taken. The triplicate set ups were left for 18 days at room temperature (Adeleye and Okorondu, 2015). A complete set up of the MFC used in this study is shown in Figure 1.

Figure 1: Microbial fuel cell after addition of wastewater

Physicochemical Analysis of Wastewater during the Bioelectricity Generation: In the course of treatment, the physicochemical parameters of the wastewater were also assessed. The physicochemical analyses were done according to standard procedures of APHA (1998) and AOAC (2010) as previously described above.

Power Density Determination: The power density (P_{An}, W/m^2) was calculated on the basis of the area of the anode (A_{An}) (Logan *et al.,* 2006) as:

$$P_{An} = \frac{E_{cell}^2}{A_{An}R_{ext}} - - - - - - - - - - Equation\ 1$$

Where: P_{An} = power density, A_{An} = area of the anode, R_{ext} = external resistor and E_{cell} = cell voltage (potential difference). More so, recalling that power is also calculated as:

$$P_{An} = IE_{cell} - - - - - - - - - - Equation\ 2$$

The power density can be calculated from the open circuit voltage using the relation:

$$P_{An} = \frac{IE_{cell}}{A_{An}} - - - - - - - - - - Equation\ 3$$

Where: I = current.

Statistical Analysis: The data obtained in this study were subjected to analysis of variance (ANOVA). The regression and coefficient of determination were also conducted on the data to model the power densities, current densities and power dependence on the substrate used and time. The t-test statistics were conducted to test whether the current and power densities of piggery wastewater do significantly differ from that of the poultry wastewater. The results obtained were expressed as mean ± S.D. The probability level of significance was set at $p<0.05$. SPSS version 20 was used for all analyses.

RESULTS AND DISCUSSION

Electricity Generation by the Microbial Fuel Cell: The power density and current density of the MFC powered by poultry wastewater recorded a starting current density and power density of 33.68 mA/cm^2 and 51.41mW/m^2 respectively (Figure 2).

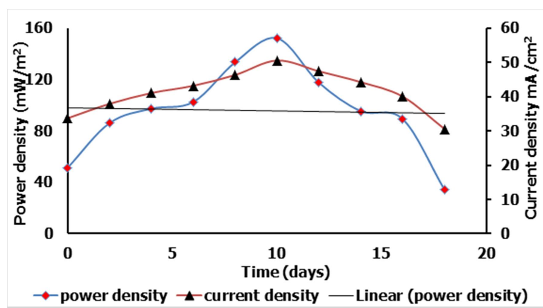

Figure 2: Power density and current density of the microbial fuel cell treating poultry waste waster

These values peaked on the 10th day with peak values of 50.52 mA/cm^2 and 151.98 mW/m^2 respectively and declined to 30.52 mA/cm^2 and 34.10 mW/m^2 respectively on the 18th day. On the other hand, in Figure 3, the MFC powered by piggery wastewater recorded a starting current density and power density of 45.26 mA/cm^2 and 120.24 mW/m^2 respectively. These values peaked on the 12th day with peak values of 69.47 mA/cm^2 and 234.48 mW/m^2 respectively and declined to 24.21 mA/cm^2 and 12.50 mW/m^2 respectively on the 18th day. The coefficient of determination of time and power densities were 0.002 and 0.111 for poultry and piggery wastewaters respectively.

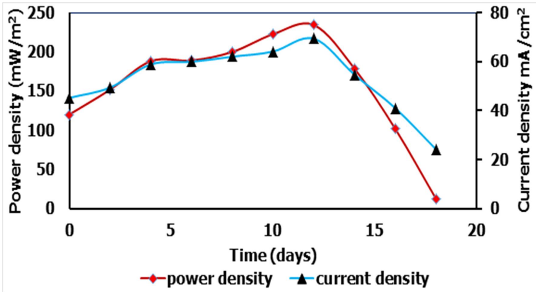

Figure 3: Power density and current density of the microbial fuel cell treating piggery wastewater

The result in Table 1 revealed the coefficient of determination of time and current densities were 0.003 and 0.107 for poultry and piggery wastewaters respectively.

Table 1: Best fitted straight line equation for power density and current density of the microbial fuel cell of the wastewaters overtime

Wastewaters	Equation (Y = a + bt)	Coefficient of Determination (R^2)	Value of t-statistic for the regression Coefficient
Power density (Poultry)	Y= 98.058 – 0.244t	0.002	-0.120
Current density (Poultry)	Y = 40.953 + 0.057t	0.003	0.878
Power density (Piggery)	Y = 193.024 – 3.669t	0.111	-1.002
Current density (Piggery)	Y = 59.458 – 0.724t	0.107	-0.981

Power and current densities in piggery wastewater recorded negative relationship with time. A unit increase in the number of days of treatment of piggery wastewater results to reduction in the power and current densities by 3.669 and 0.724 respectively. Power density in poultry wastewater recorded a negative relationship with time, while current density recorded a positive relationship with time. A unit increase in the number of days of treatment of poultry wastewater results to reduction in the power density by 0.244 day. A unit increase in the number of days of treatment of poultry wastewater results to increase in the current density by 0.057 day. Statistically, there was significant differences ($\alpha = 0.01$; $p<0.05$) detected in the power and current densities of the wastewaters. This implied that the power and current densities of piggery wastewater is significantly greater than that of the poultry wastewater as can be deduced from their averages. These data indicated better performance than results obtained by Ghoreyshi *et al.* (2011) who recorded maximum power 53.7031 mWm^{-2} and current density 110.86 mAm^{-2} using date syrup or any waste of date as substrate for bioelectricity.

Dependency of the Power Density on the Physicochemical Parameter: The dependence of the power density on the physicochemical parameters was also monitored. Dependence was measured as a response of the percentage BOD, COD, TDS and TSS respectively. The power density of the piggery wastewater reached a peak value on the 288th hour with a value of 151.98 mW/m^2 with a BOD, COD, TDS and TSS values were 65.52, 52.22, 11.40 and 57.39% respectively (Figure 4) while the poultry wastewater reached a peak power density of 120.24 mW/m^2 on the 240th hour with a BOD, COD, TDS and TSS values of 21.74, 40.06, 2.34 and 52.87% respectively (Figure 5). It was noted that the power produced depended on the physicochemical parameters because when a reasonable percentage of the parameters were removed, there was a rapid decline in the value of the power density.

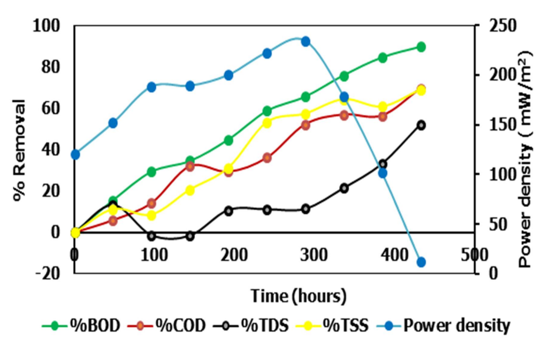

Figure 4: Dependency of power density on physicochemical parameters of piggery wastewater

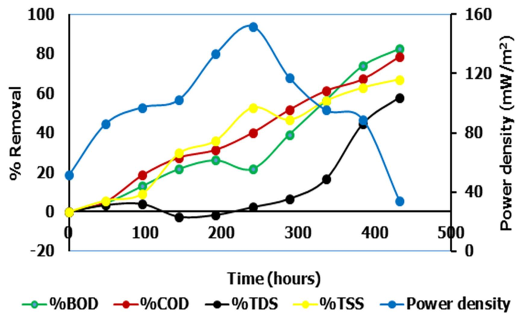

Figure 5: Dependency of power density on physicochemical parameters of poultry wastewater

The result in Table 2 showed the multiple regression estimates of the dependency of power density on physicochemical parameters of piggery wastewater. The coefficient of determination (R^2) was found to be 0.941 (94.1%).

Table 2: Multiple regression estimates of the dependency of power density on physicochemical parameters of piggery wastewater

Variable	Regression coefficient	t-ratio	Level of significance
Constant	134.998	5.414	0.006
BOD	6.877	1.565	0.193
COD	0.053	0.018	0.986
TDS	-4.254	-2.668	0.056
TSS	3.183	2.211	0.092
Time	-1.679	-1.313	0.260
R^2	0.941		

This means that 94.1% of the relationship between the physicochemical parameters of piggery wastewater and the observed values of power density generated could be mathematically determinable, leaving only the rest 5.9% to errors. In other words, the mathematical model concerned has been found to be very good. BOD showed a positive coefficient (6.877) with power density of piggery wastewater. This indicated that as BOD removed increases the power density increases too and vice versa. This implied that a unit increase in BOD removed will lead to a 6.877 corresponding increase in power density of piggery wastewater. COD showed a positive coefficient (0.053) with power density of piggery wastewater. This indicated that as COD removed increases the power density increases too and vice versa. This implied that a unit increase in COD removed will lead to a 0.053 corresponding increase in power density of piggery wastewater. TDS showed a negative coefficient (-4.254) with power density of piggery wastewater. This indicated that as TDS removed increases the power density decreases and vice versa. This implied that a unit increase in TDS removed will lead to a 4.254 decrease in power density of piggery wastewater. TSS showed a positive coefficient (3.183) with power density of piggery wastewater. This indicated that as TSS removed increases the power density increases too and vice versa. This implied that a unit increase in TSS removed will lead to a 3.183 corresponding increase in power density of piggery wastewater. Time showed a negative coefficient (-1.679) with power density of piggery wastewater. This indicated that as the number of hours increases the power density decreases and vice versa. This implied that a unit increase in the number of hours will lead to a 1.679 decrease in power density of piggery wastewater.

On the other hand, the result in Table 3 showed the multiple regression estimates of the dependency of power density on physicochemical parameters of poultry wastewater.

Table 3: Multiple regression estimates of the dependency of power density on physicochemical parameters of poultry wastewater

Variables	Regression coefficients	t-ratio	Level of significance
Constant	65.709	4.979	0.008
BOD	-0.896	-0.557	0.607
COD	-5.317	-1.451	0.220
TDS	-1.774	-1.948	0.123
TSS	0.026	0.016	0.988
Time	1.270	1.676	0.169
R^2	0.879		

The coefficient of determination (R^2) was found to be 0.879 (87.9%). This means that 87.9% of the relationship between the physicochemical parameters of poultry wastewater and the observed values of power density generated could be mathematically determinable, leaving only the rest 12.1% to errors. In other words, the mathematical model concerned has been found to be very good. BOD showed a negative coefficient (-0.896) with power density of poultry wastewater. This indicated that as the BOD removed decreases the power density increases and vice versa. This implied that a unit increase in BOD removed will lead to a 0.896 decrease in power density of poultry wastewater. COD showed a negative coefficient (-5.317) with power density of poultry wastewater. This indicated that as the COD removed increases the power density decreases and vice versa. This implied that a unit increase in COD removed will lead to a 5.317 decrease in power density of poultry wastewater. TDS showed a negative coefficient (-1.774) with power density of poultry wastewater. This indicated that as TDS removed increases the power density decreases and vice versa. This implied that a unit increase in TDS removed will lead to a 1.774 decrease in power density of poultry wastewater. TSS showed a positive coefficient (0.026) with power density of poultry wastewater. This indicated that as TSS removed increases the power density increases too and vice versa. This implied that a unit increase in TSS removed will lead to a 0.026 corresponding increase in power density of poultry wastewater. Time showed a positive coefficient (1.270) with power density of poultry wastewater. This indicated that as the number of hours increases the power density increases too and vice versa. This implied that a unit increase in the number of hours will lead to a 1.270 corresponding increase in power density of poultry wastewater. It is evident that the power generation is dependent on the wastewater parameters since the parameters were proportional to the organic content of the wastewater. Jung *et al*. (2008) reported that the treatment of swine wastewater in the single chamber MFC had 84% COD removal with maximum power density of 228 mW/m^2. Adeleye and Okorondu (2015) reported that the power generated by the MFC followed the pattern of a growth curve which was likely to be dependent on the organic components of the wastewater and similar observation was recorded in this study, the power generated was a function of the percentage BOD_5, COD, TDS and TSS in the wastewater.

Conclusion: The whole study revealed that the MFC (MFC) performed better treatment of piggery wastewater than poultry wastewater as indicated in their respective wastewater treatment efficiencies. Also, the power and current generation was significantly dependent on the physicochemical parameters and time. The MFC technology as a bioremediation strategy when applied to agro - liquid wastewaters could be exploited both as an alternative source of bioelectricity and wastewater treatment.

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