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BIOELECTRICITY GENERATION POTENTIALS OF SOME NIGERIAN INDUSTRIAL WASTEWATER THROUGH MICROBIAL FUEL CELL (MFC) TECHNOLOGY

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ABSTRACT

A Microbial Fuel Cell (MFC) is a biochemical-catalyzed system which generates electricity by oxidizing biodegradable organic matter in the presence of either fermentative bacteria or enzymes. Microbial fuel cell technology is a new type of renewable and sustainable technology for electricity generation since it recovers energy from renewable materials that can constitute environmental pollution if disposed of without proper treatment, such as organic wastes and wastewaters. This work therefore investigates the possibility of electric current generation from different Nigerian industrial wastewaters using MFC.

The experiment was performed using wastewater samples from five different sources; Abattoir, Brewery, Sugar mill, Pineapple juice production company and Dairy/milk production company. All samples were found to generate current with wastewater from sugar mill generating the maximum of 1.28 mA; followed by brewery wastewater 1.06mA; abattoir wastewater, 0.96 mA; pineapple juice wastewater, 0.79 mA; and dairy wastewater 0.71mA. The current generation was found to increase when agitated and sample from sugar mill reached 1.56 mA with others following similar trend.

The current generation was also found to increase with an increase in temperature from 25^0C to 35^0C with sample from sugar mill reaching a maximum of 1.58 mA with others following similar trend.

Keywords: Bioelectricity, Current Generation, Microbial Fuel Cell, Industrial Wastewater

INTRODUCTION

Current prediction for the global energy needs has led to a search for alternate and sustainable energy resources. It is evident that mankind is increasingly dependent on energy with the advancement of science and technology (Mathuriya and Sharma, 2009). Increased economic growth and social development are leading to a large gap between energy demands and energy availability. The non renewable resources of energy is depleting at a faster rate since increasing human activities are consuming the natural energy sources leading to depletion of fossil fuels. Hence, there is the need for high efficient energy transformations and ways to utilize the alternate renewable energy sources.

An alternative way of producing energy is by bioelectricity generation from wastewater. Bioelectricity is an electric current that is generated by a variety of biological processes and generally range from one to few hundred milli-volts. Bio-hydrogen production by anaerobic fermentation and bioelectricity generation through microbial fuel cells (MFC) using a variety of substrates including wastewater have been studied quite extensively (Kim *et al.*, 2000; Huang *et al.*, 2004; Logan 2004; Ginkel *et al.*, 2005; Logan and Regan 2006). Trapping renewable energy from waste organic sources has facilitated energy production and at the same time accomplishes wastewater treatment (Logan 2004; Liu *et al.*, 2004).

Microbial fuel cells (MFCs) are electrochemical device that convert the chemical energy contained in organic matter into electricity by means of the catalytic (metabolic) activity of living microorganisms (Mathuriya and Sharma 2009). MFC consists of anode and cathode separated by a cation specific membrane. In the anode compartment of MFC, microorganisms oxidize waste (substrate) thus generating electrons and protons. Electrons are transferred through an external circuit while the protons diffuse through the solution to the cathode, where electrons combine with protons and oxygen to form water (Jae *et al.*, 2003). Mediators are required because most of the bacteria species used in MFC are inactive for transport of electron.

Wastewater sources that have been used in MFC tests includes domestic wastewater (Liu *et al.*, 2004), swine wastewater (Min *et al.*, 2005), meat packing wastewater (Heilmann and Logan 2006), hydrogen fermentation reactor effluent (Oh and Logan 2005), paper industry wastewater (Mathuriya and Sharma 2009) and corn stover hydrolytes (liquidities corn Stover; Zuo *et al.*, 2006). Thus, the high organic load in wastewaters is no longer seen as waste, but instead as a valuable energy resource. Ways of exploiting these biological substrates degradation for the generation of electricity is the driving force for the development of microbial fuel cell (MFC). Although the concept of electricity production from bacteria was conceived nearly a century ago by Potter (Potter, 1910), only recently the technology has been sufficiently improved to make it useful as a method for energy generation. MFC have operational and functional advantages over the technologies currently been used for energy generation from organic matter. Firstly, the direct conversion of substrate energy to electricity enables high conversion efficiency. Secondly, MFC operate efficiently at ambient temperature. Third, MFC does not require gas treatment because the off-gases of MFC are enriched in carbon dioxide and normally have no useful energy content. Fourth, MFC do not need energy input for aeration provided the cathode is passively aerated (Liu *et al.*, 2004). Fifth, MFC have potential for widespread application existing in electrical infrastructures and can also operate with diverse fuels to satisfy our energy requirements. Therefore, this study investigates the possibility of bio-electricity generation from some Nigerian Industrial wastewaters.

MATERIALS AND METHODS

Material

The following materials were used for this research work; Different industrial wastewater samples and Microbial fuel cell (MFC).

Wastewater Sample collection

The wastewater samples used for this research work were collected from different sites and industries, located in Nigeria. Abbatoir wastewater was collected from an abattoir at Oke-Aanu area of Ogbomoso, Nigeria. Raw wastewater samples were collected from the wastewater treatment section of the following industries; a sugar mill, pineapple juice producing industry, Dairy/ milk production industry and a brewery, all located in Southwestern Nigeria.

Physico-chemical characterization of wastewater samples

The wastewater samples were characterized for their physico-chemical properties according to the standard methods (APHA, 1998) and their microbial constituents isolated.

Construction of Microbial Fuel Cell (MFC)

Two MFCs were constructed separately to assess and compare the relative efficiencies of ferricyanide (MFC_{FC}) and aerated catholytes (MFC_{AC}) in bioelectricity generation. MFCs were designed and fabricated using Plexiglass material in our laboratory. The fuel cells consisted of two equal volume (0.75 L) chambers for anode and cathode separated by proton exchange membrane (PEM) (Naflon 117, sigma-Aldrich). Naflon 117 sheets was arch punched to 50mm size and pretreated by boiling sequentially in 30% H_2O_2 de-ionized water (pH 7.0), 0.5M H_2S0_4 and de-ionize water each consecutively for one hour to increase the porosity prior to use. Arch punched PEM was fixed between washers and clamped in the hollow tube (50mm diameter) attaching both chambers. Graphite plates (4x5cm; 10mm thickness) without any coating were used as electrodes for both anode and cathode. Prior to use electrodes were soaked in de-ionized water for a period of 24hours. Anode was perforated by providing nine uniform size holes of 0.1 cm diameter to increase the surface area. Electrodes were positioned at a distance of 6cm on either side of PEM. Copper wire was used as contact for the electrodes after carefully sealing the contact with ‘epoxy’ material. Each chamber was provided with sample port, wire point input (top), inlet and outlet ports and anode chamber was sealed with washers to ensure anaerobic microenvironment.

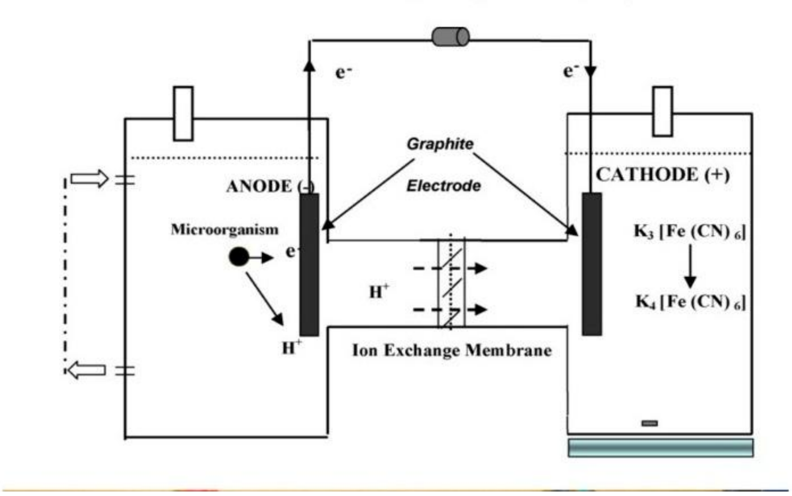

Figure1. Diagram of a microbial fuel cell

Experimental Design

The cathode chamber of MFC was filled with potassium ferricyanide [50mM $K_3Fe(CN)_6$] as an electron acceptor and phosphate buffer [50mM K_2HPO_4] as catholyte mediator. Catholyte solution was continuously stirred at 50 rpm using magnetic beads to ensure effective contact between proton, electron and mediator. The catholyte was continuously sparged with air using air pump attached with sparger network. Under these conditions the dissolved oxygen (DO) concentrations in the cathode chamber of MFC was observed to be between 4 and 5mg/L. The pH of the catholytes was maintained at 7.5. Anode chamber of the fuel cell was observed to resemble anaerobic suspended contact bioreactor normally used for wastewater treatment. The anode chamber was initially inoculated with artificial wastewater containing glucose as carbon source. The composition of the artificial wastewater was 1.0g glucose, 450.0mg $NaHC0_3$, 100mg NH_4Cl, 10.5mg K_2HPO_4, 6.0mg KH_2PO_4, 64.3mg $CaCl_2.2H_2O$, 18.9mg $MgSO_4.7H_2O$, 10.0mg $FeSO_4.7H_2O$, 0.65mg $CuSO_4.5H_2O$, 6.0mg $MnSO_4$, 0.5mg $ZnSO_4.7H_2O$, 20mg $CoCl_2.6H_2O$ and 0.65mg $CuSO_4.5H_2O$ (gL^{-1}). After two cycles, feed solution containing 50% artificial wastewater and 50% different wastewater samples were separately inoculated into the MFC to test-run the MFC. After another two cycles, feed solution was switched to 100% various wastewater samples. The pH of the anode was maintained at 6.0 (±0.1) throughout the experiment to sustain the survival of acidogenic bacteria. The performance of microbial fuel cell was evaluated under room (mesophilic) temperature (25°C ±2 °C) and ambient pressure except during the study of effect of increase in temperature. The anode chamber was sparged with oxygen free N_2 gas for a period of 4 minutes to maintain anaerobic microenvironment after each feeding cycle. Feeding, decanting, and recirculation operations was performed using peristaltic pumps controlled by electronic timer.

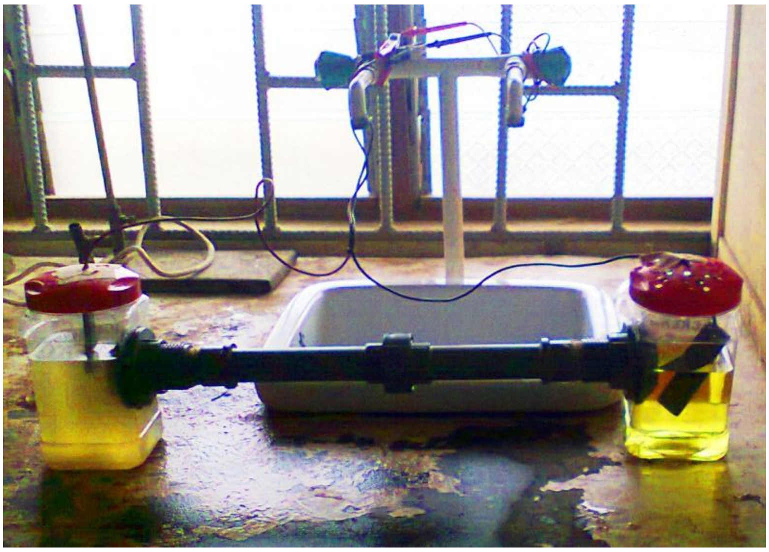

Figure 2. The experimental set-up

Analytical Procedure

Current (*I*) and potential (*V*) measurements were recorded at 30 minutes interval of operation using auto-range digital Multimeter (made by Kusam, model DT-830D) by connecting to 10Ω external circuit. For polarization curve preparation, current generation was monitored at various external resistances (30Ω–100Ω). The readings were recorded after connecting the resistance for few minutes on obtaining stable voltage readings.

RESULTS AND DISCUSSION

Wastewater Characterization and Microbial Isolation

The results of wastewater characterization and isolation of microbial constituents of the wastewaters are given in the tables below

Table 1. Characteristic of different wastewaters

Parameters	**Abbatoir wastewater**	**Sugar wastewater**	**Pineapple juice wastewater**	**Dairy Wastewater**	**Beer Brewery wastewater**
Colour	Dark-brown	Brownish	Greyish-white	Whitish-grey	Dark brown
Temperature (^{o}C)	27	30	26	28	27
pH	6.6±0.1	6.3±0.1	6.9±0.1	8.0±0.1	6.5±0.2
COD(mg/L)	1426.26	350.13	527.61	1233.55	1820.39
BOD(mg/L)	719.18	108.96	284.05	768.20	1348.39
TSS(mg/L)	746.73	116.24	123.17	311.11	514.99

Table 2. Microorganisms Isolation

Wastewater sample	**Microorganisms isolated**
Abattoir wastewater	*Staphylococcus aureus, Escherichia coli, Proteus morganii, Serratia marscencens, Pseudomonas aeruginosa, Bacillus macerans*
Sugar wastewater	*Serratia marscencens, Bacillus licheniformis, Micrococcus acidiophilus, Pseudomonas aeruginosa, Saccharomyces cerevisiae*
Pineapple juice wastewater	*Staphylococcus aureus, Bacillus cereus, Pseudomonas fluorescens, Bacillus macerans, Escherichia coli, Saccharomyces cerevisiae*
Dairy wastewater	*Escherichia coli, Proteus vulgaricus, Streptococcus faecalis, Staphylococcus aureus, Micrococcus acidophilus, Bacillus cereus, Pseudomonas aeruginosa, Bacillus licheniformis*
Brewery wastewater	*Bacillus cereus, Micrococcus luteus, Pseudomonas aeruginosa, Escherichia coli, Pseudomonas nigrificans, Saccharomyces cerevisiae*

Current Generation

After setting the experiment, the MFC's were operated with the different wastewater samples each as feed to support the formation of biomass and subsequent generation of electricity. After MFC's were inoculated with different wastewater samples each, a lag phase of about 24-hr was noticed before production and readings of current commences.

The experimental cycle lasted for 300 minutes (5hr) for 100% concentration of wastewater each and current readings were observed and recorded at 30 minutes interval. It was observed that the current generation followed similar trend for all wastewater samples. The current generated increases steadily from the zero reading up to about 150 minutes for all wastewater samples after which the current values started decreasing. At about 150 minutes, sugar wastewater was found to have highest value of current generated, followed by brewery wastewater. This was followed by abbatoir wastewater, followed by juice wastewater while dairy/milk wastewater has the lowest value of current generated. At about 300 minutes, the values of current generated were tending towards zero for all wastewater sample, therefore, the experiment was stopped at 300 minutes. The current generated against Time was represented on Figure 3 below;

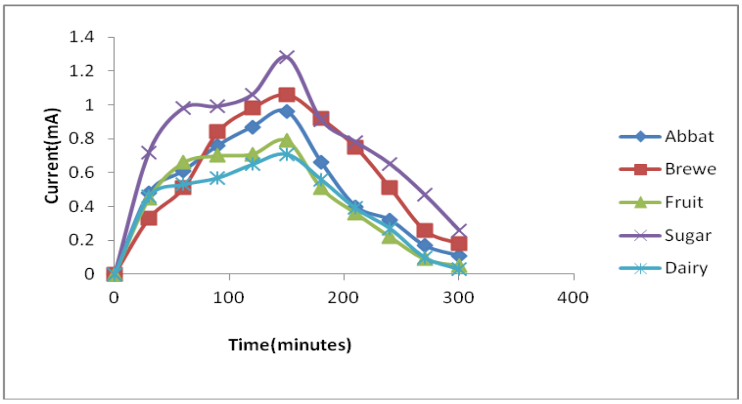

Figure 3. Plot of Current generated against Time for wastewater samples

Effect of Agitation

To study the effect of agitation on current generation, the anodic chamber of the MFC was placed on a digital agitator and agitated with the magnetic stirring bead placed inside the chamber at a speed of 40 revolutions per minute (rpm).

Figure 4. Experimental Setup with Anodic Chamber Agitated

The experiment was repeated for 300 minutes for each of the wastewater samples and the current generated were also measured and recorded at 30 minutes intervals. The values of the current generated was observed to be higher than the values of current generated without agitation for each of wastewater samples throughout the experimental period and was observed to follow similar trend with sugar wastewater found to have highest value of current generated, followed by brewery wastewater, followed by abattoir wastewater, followed by juice wastewater while dairy/milk wastewater has the lowest value of current generated. The values of current generated against Time was represented in Figure 5 below;

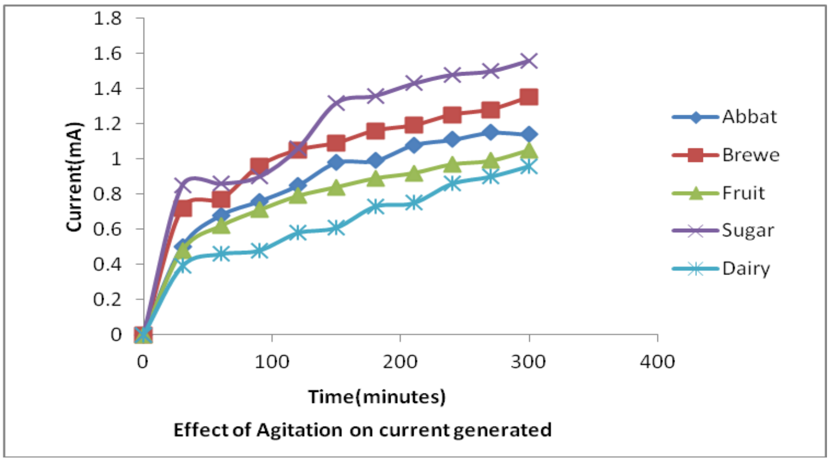

Figure 5. Effect of agitation on Current generated against Time for wastewater samples

Effect of Temperature

To study the effect of temperature on current generation, all the five wastewater samples were experimented each initially at 25^{o}C, and after 150 minutes, temperature was increased to 35^{o}C. The experimental data obtained indicated that performance of MFC was slightly increased with increase in temperature from 25^{0}C to 35^{0}C for each of the wastewater samples. The result was not unexpected since most of the microorganisms isolated in the wastewater samples are mesophillic organisms. The increase in the current generated by increase in temperature can be explained by the law of thermodynamics which indicates an increase in kinetic energy for increase in temperature by continuous excitation of the energy level of the microorganisms. The current generated was observed to follow similar trend with sugar wastewater found to have highest value of current, followed by brewery wastewater, followed by abattoir wastewater, followed by juice wastewater while dairy/milk wastewater has the lowest value of current generated. The current generated against Time was represented in Figure 6 below;

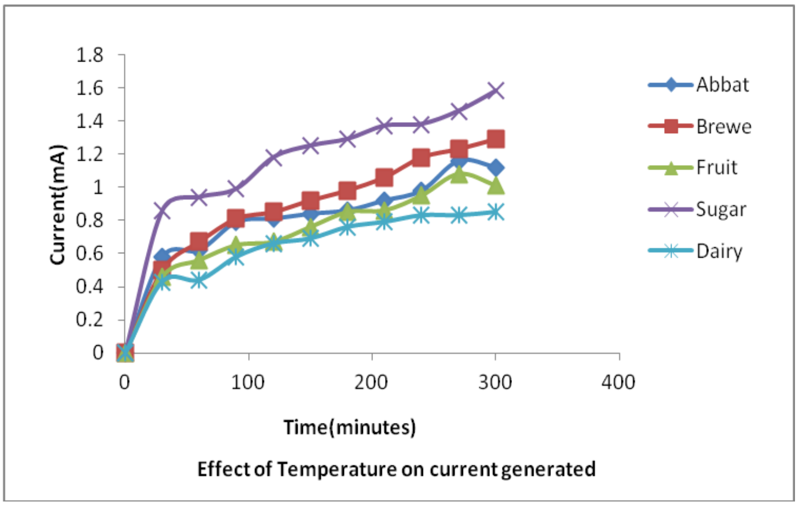

Figure 6. Effect of temperature on Current generated against Time for wastewater samples

CONCLUSION

Microbial Fuel Cells can be used effectively and efficiently for current generation in wastewater effluents. Also, since the microorganisms responsible for substrate degradation for electricity generation were already present in the wastewater, increase in temperature and wastewater agitation can serve as effective ways of improving electricity generation using MFCs. The study also revealed that potassium ferricyanide catholyte could be used effectively as mediator in power generation using Microbial Fuel Cell technology. The microbial electricity generation technology is still in an early stage of development in Nigeria but shows great promise as a new method towards renewable electricity generation. Also,the current concerns about climate change and global warming require developing new methods of energy production using renewable and carbon-neutral sources such as the generation of electricity from negative value streams using the microbial fuel cell technology.

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