Generation of Electricity from Sewage

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Abstract: Instead of using energy to treat waste water; it is actually feasible for one to harness energy from wastes as well as treating it using a Microbial Fuel Cell (MFC). An MFC generates electricity from sewage with the help of bacteria. This research paper investigates the generation of electricity from sewage as well as sewage treatment in the same period. Four cells were used A, B, C and a control. The cells A, B and C all consisted of the anode and the cathode separated by a loamy-sandy soil of electrical conductivity, 160 µS at 22.8°C. The cathode and anodes were made of carbon rods obtained from A size dry cell. The anode and cathode were separated by 25 mm, 50 mm and 75 mm for cells A, B and C respectively. The control cell had no electrical components but shared the other components as those for cell A, B and C. Sewage with COD of 2080 O_2 mg/l was introduced into the cells. Voltage and COD measurements were made every 24 hours and 10 days respectively to investigate performance. Laboratory measurements and recordings were made for 60 days and maximum voltages of 0.426 V, 0.261 V and 0.267 V were recorded for A, B and C respectively. The COD removal efficiencies were over 90 %, for B and C; over 60 % for A and less than 40 % for the control even after 60 days. This asserted that MFCs generated electricity as well as being better waste treatment devices than natural or constructed waste treatment ponds. Results also showed that the further the anode - cathode separation, the lower the voltage that was developed owing to increase in cell internal resistance. This paper furthers the potential to generate green and clean energy by means of an MFC.

Keywords: Sewage, Microbial fuel cell (MFC), Voltage, COD, Bacteria.

INTRODUCTION

Uganda has a very low power per capita rate, at an alarming 0.3 Ton of Oil Equivalent (TOE). This is one of the lowest in the world (AEO, 2006). The Ugandan population depends almost entirely on biomass with wood fuel leading in the standings at 95 % countrywide with the rural sector exercising the highest charts at 99 % [1]. A large amount of the electric power is used by National Water and Sewerage Corporation (NWSC) for waste treatment. Every cubic meter of waste water requires about 0.349 kWh of power during treatment [2]. The NWSC waste treatment plant in Bugolobi currently receives 15,000 m^3/day of waste water. This reciprocates to an annual power requirement of 1910 MWh for just the Bugolobi plant. The situation is rather unimaginable since Uganda's largest population has no access to electricity.

Therefore there is need to develop and improve on existing waste water treatment technologies that are environmentally sustainable in these times of energy scarcity. Studies show that energy can be extracted from organic waste water as chemical energy or electric energy as well as treating the waste water [3-7]. A microbial fuel cell (MFC) is the device used in harnessing electricity from waste water with the help of micro-organisms [8-15]. MFC consists of anode and cathode compartment separated by a PEM [14, 16-18]. There are two reactions that take place in an MFC, reduction and oxi

dation - reddox reaction [10]. Oxidation takes place in the anode compartment and reduction in the cathode compartment [16]. Reduction in the anode compartment is due to the gain of electrons from the organic substrate [3, 14, 15]. The substrate is oxidized in the anode generating a proton and an electron [15]. The process of oxidization which in essence is decomposition is bio-catalyzed by bacteria. Bacteria gain energy by transferring these electrons from the substrate to the anode electrode [9].

The power output of an MFC is dependent on operational conditions and other factors like mass transfer and these factors influence the bio-reactor configurations [3, 15, 17, 20]. The operational factors that affect the power output of the bio-fuel cell are: pH, temperature, concentration of dissolved oxygen and the electrolyte strength [3, 15]. An MFC cannot attain maximum power out put because of a number of factors that arise due over potential related losses like ohmic, concentration polarization, and activation losses [8, 17, 19, 21, 22]. Over potential are resistances to the flow of electrons due to the flow path that the electrons take [11]. The purpose of this study was to produce electricity from sewage using earth as a permeable membrane. In the study, four batch cells were used to determine the voltage developed by the MFC. The relationship between COD removal in waste water and voltage produced by an MFC was also investigated to determine treatment efficiencies with respect to a control (cell without electrical components).

METHODS AND MATERIALS

The material used in the construction of the experimental cells A, B and C included: waste water (sewage with initial

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Fig. (1). Electrical conductivity meter measuring the soil's E.C.

COD of 2080 O_2 g/ml) of V = 880 ml, Carbon electrodes; Sodium Chloride (NaCl) solution, 0.6845 M, plastic cylinders V_B = 1000 ml; soil (sandy loam); Copper wire of L = 7 cm attached to each electrode and plastic containers Vs = 125 ml.

CONSTRUCTING THE CELL EXPERIMENTAL SET UP

Four carbon electrodes were fastened to the V_B container lids to make up the cathode. The Vs containers were perforated at the bottom and at the sides to allow mass flow throughout the cell. Six negative electrodes (Anaerobic) were fastened together, and then fastened to the Vs container using copper wire. The anode consisted of six carbon electrodes, four bundled together and the other two positioned five centimeters off the carbon bundle. The four were dipped into the loam soil and the two were fully dipped into the sewage. The Vs container was completely filled with loam soil covering the bundle of carbon electrodes in Vs.

The V_S container with its electrodes and soil were then, just fully immersed and fastened to the V_B container. Sewage of COD 2080 O_2 mg/l was added to the cell assembly-which is housed by container V_B- fully saturating the soil.

Four cells were constructed; A, B, C and the control. The shortest distance of separation between the anode and the cathode was varied for the cells A, B and C. The anode-cathode distance for A, B and C were 25 mm, 50 mm and 75 mm respectively. The control cell consisted of all components in A, B and C other than the electrodes and external circuit. Two milliliters of Sodium chloride solution (0.6845 M) was added to A, B and C to increase electrical conductivity of sewage.

PREPARATION OF CONDUCTIVE SOLUTION (SODIUM CHLORIDE AND SEWAGE SOLUTION)

Four grams of Sodium chloride were dissolved into 100 ml of water to form a solution. Two milliliters of the solution were each added to cells A, B, C and the control.

DETERMINATION OF THE ELECTRICAL CONDUCTIVITY (E.C) OF THE SOIL TO BE USED AS A MEMBRANE

Soil sample of 20 g was weighed and transferred to a beaker. Distilled water of 50 ml was added to the beaker containing the soil sample. The soil-water mixture was stirred using a glass rod until a soil paste was attained. The mixture was then left to stand for 30 minutes. This allowed the soil to settle. The conductivity meter was then dipped in the upper portion of the separated mixture to measure soil E.C, pH and temperature as illustrated in Fig. (**1**).

PREPARATION OF COD REAGENTS

COD reagent consists of standard Potassium dichromate and concentrated Sulphuric acid containing mercury Sulphate. The prepared reagents were to be used for the determining of COD levels in the cells A, B, C and the control.

1. Standard Potassium Dichromate Digestion Solution

Potassium dichromate of mass 4.913 g was dried at 103 °C in an oven for two hours. The dried sample was then added to 500 ml of distilled water. Concentrated Sulphuric acid of 167 ml and 33.3 g of Hg_2SO_4 was then added to the dichromate solution. The mercury sulphate (Hg_2SO_4) was added and the solution dissolved at room temperature. Distilled water of 100 ml was added to the solution.

2. Sulphuric Acid Reagent

Dissolve 5.5 g of (Ag) $_2SO_4$ in a kilogram of H_2SO_4 and cool. The concentration of a kilogram of the concentrated acid was 16 M.

3. Standard Ferrous Ammonium Sulphate-0.05M

Weighed 19.2 g of Fe $(NH_3)_2(SO_4)_2.6H_2O$ and immediately dissolved it in distilled water, ferrous Ammonium Sulphate is very unstable because it absorbs water from the atmosphere. Added 10 ml of conc.H_2SO_4 to the ferrous solution; cooled and diluted to 1000 ml.

Fig. (2). COD digest Samples; the clear sample is the Blank sample.

PREPARATION OF COD DIGEST SAMPLES

Five COD test tube volumes of 15 ml were cleaned with dilute H_2SO_4. The test tubes were oven dried for an hour. 0.5 ml of sewage was transferred to each COD test tube. Standard Potassium dichromate and concentrated sulphuric acid (16 M) which were prepared earlier were then added in volumes of 2.5 ml and 3.5 ml respectively. The tubes were then capped, shook and cooled. The test tubes were then transferred into a COD digester and heated for 120 minutes at 150°C. A blank, where distilled water was used instead of sewage and transferred to the digester to be the control for the COD test as shown in Fig. (**2**).

MEASUREMENT OF VOLTAGE AND RESISTANCE

The measurement of voltage and resistance was done using a digital multimeter under the conditions; before agitating the cell and after agitating the cell. The readings were recorded every 20 seconds. The highest voltage and resistance readings in this interval were then recorded. After taking the reading for voltage and resistance of a given cell, the cell was then slowly agitated, whirling it (7 clockwise and 7 anticlockwise). This was done for the cells A, B and C. The voltage and resistance readings were taken for the cells in the same sequence as that done during the preliminary test period to measure the parameters for after agitation.

MEASUREMENT OF COD

The digested samples were poured into a 50 ml beaker. The beaker was then filled with distilled water up to the 50 ml mark. The solution in the beaker was transferred into a flask and then three drops of Ferroin indicator were added turning the solution from red to orange. The digest solution in the flask was titrated against FAS solution. The solution turned to light green then colorless and finally to light red (red wine) at the end point. The burette reading was then recorded.

CONSTRUCTION OF PRACTICAL MODEL OF AN MFC

A batch model of 18 liters was constructed to increase on the voltage to be generated. This model was constructed from projections of modifications that were to be made from the experimental cell designs of A, B and C. The modifications were based on the cell configurations that gave the highest voltage.

RESULTS

Voltage

Voltage increased with time for reactors A, B and C (Fig. **3**). The Voltage for all the cells started with a slow increase and rose greatly after day 3.

Cell A had a more steady increment in voltage from day three up to day nine. After day 9 to day 41, there was a slight change in voltage with time as compared to the earlier times. This slight variation in voltage took place at higher voltage. This same pattern in behavior was exhibited by cell B. Cell B exhibited a slightly constant voltage between day 17 and 35. Cell A's fall in voltage started after day 41 and continued steadily up to day 57. Even though cell B exhibited the same behavior in voltage fall with time as A, it on the other hand had a slight fall in voltage with time relative to A.

Cell C had a steady increment in voltage between day 1 and day 19. After day 19, C generally showcased a fall in voltage with a spike of high voltage rise at day 41 which was then followed with a sharp fall in voltage there after (Fig. **3**).

In summary, the three cells A, B and C in Fig. (**3**) exhibit three phases of voltage variation. The first is the voltage rise followed by steady voltage and lastly the voltage fall in the later part of the cell life. The agitated cells also showed the same behavioral trends but exhibited slightly higher voltage values for cell A and a fall in voltages for the cells B and C as shown in Fig. (**4**).

COD

COD values for cells A, B, C and the control generally fell with time as depicted in Fig. (**5**). The fall in COD was steepest during the earlier times of the experimental set up between days 10 and 20. The COD fell from over 2000 to 1000 in about 30 days. Cells B and C continued the steady fall in COD through from days 20 to day 60. The fall in COD for A, and the control cell were slightly lower relative to that of the cells B and C.
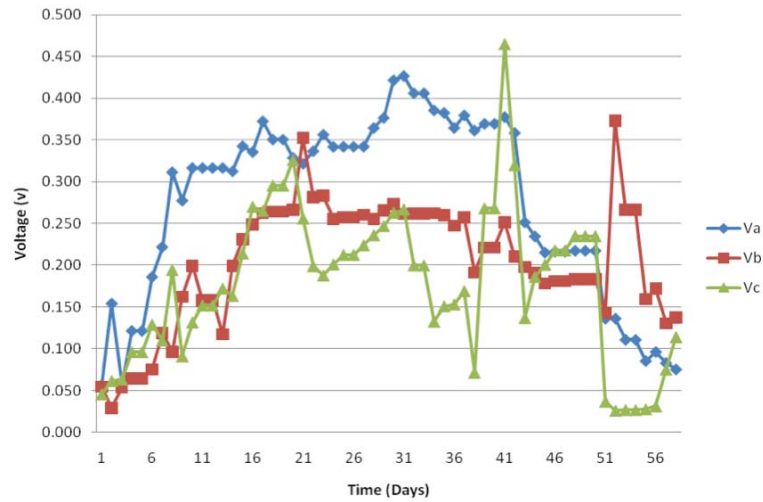
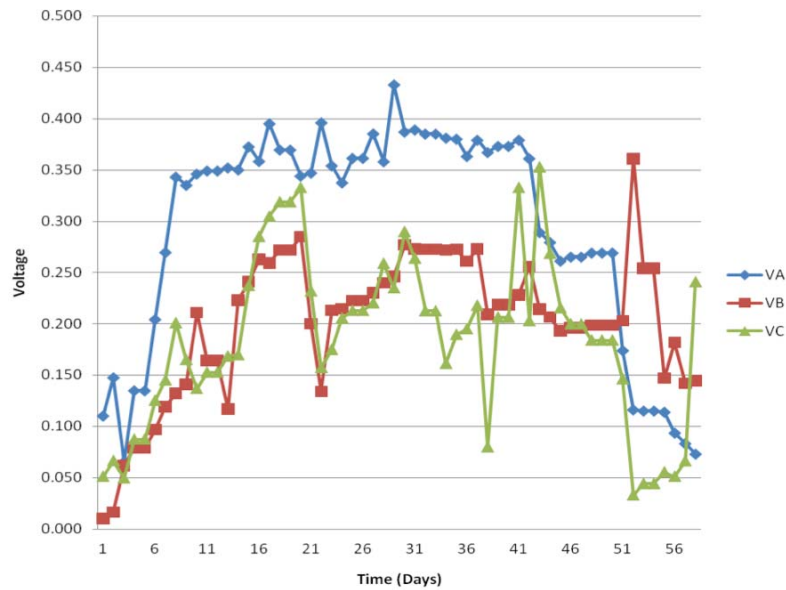**Fig. (3).** Voltage against time for cells A, B and C.

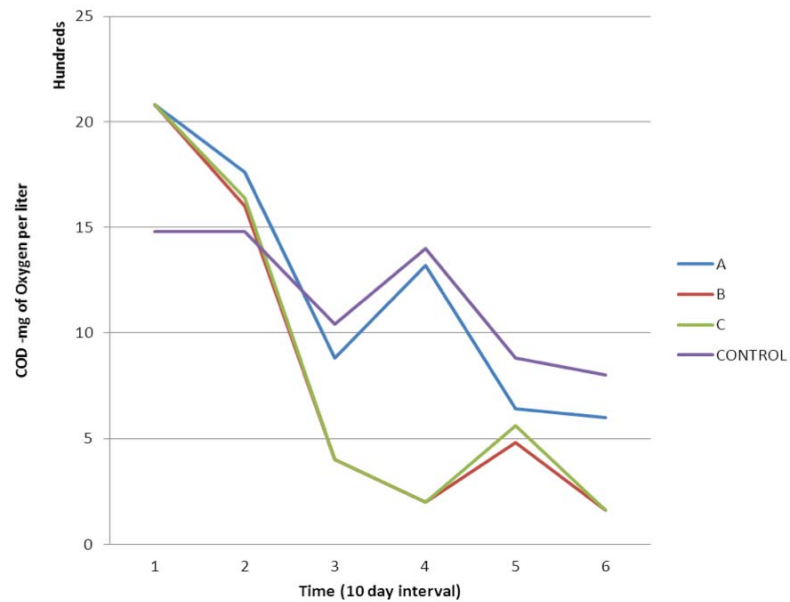**Fig. (4).** Voltage against time for A, B and C after agitation.

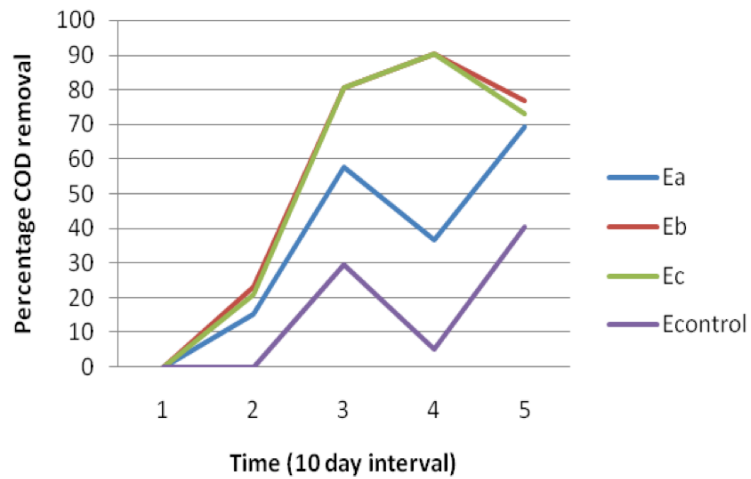**Fig. (5).** COD against time (10 day interval) for cells A, B, C and the control.

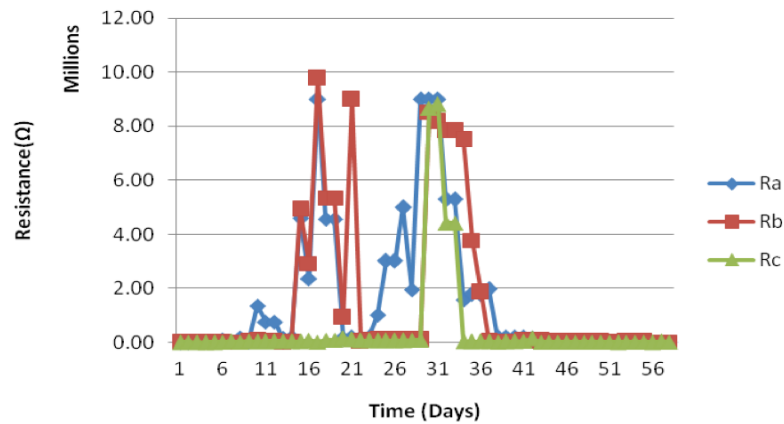**Fig. (6).** removal efficiency for cells A, B, C and the control.

Fig. (7). Internal resistance against time for cells A, B and C.
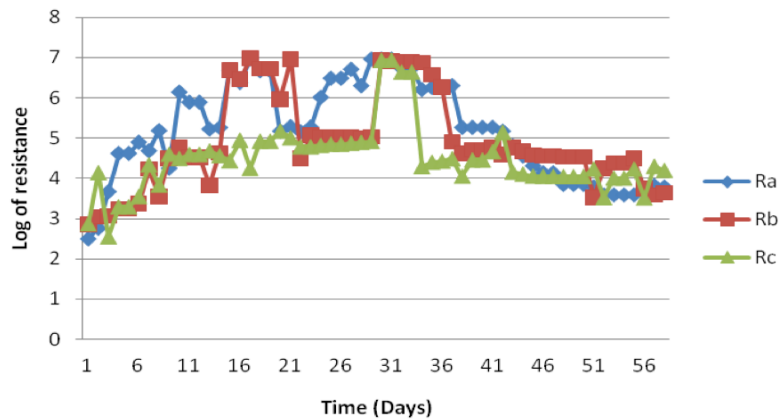

Fig. (8). Semi-logarithmic graph of internal resistance against time (days) for cells A, B and C.

The COD removal efficiency is the ratio of the difference between initial and final COD to initial COD. The COD removal efficiency for cells B and C was at a faster rate than that of the Control and cell A (Fig. **6**). The COD removal efficiency for the control cell was the least efficient. The COD removal efficiency for B and C reached 80 % in less than 30 days of retention time. Cell A and the Control had treatment efficiencies of 58 % and 30 % respectively in the same period.

Internal Resistance of Cells

From Fig. (**7**), the internal resistance for cells A, and B increases greatly during days 13 to 21 and then from 23 to 37. Days 38 to 57 exhibited low internal resistances. There were abrupt increases in resistance for cells A and B on days 15, 17 and 21. Cell C then joined cells A and B in exhibiting spikes in resistance during days 29 to 33. But in general cell C had low internal resistance compared to the cells A and B.

Fig. (**8**) shows a general increase of internal resistance exhibited by all the cells that is A, B and C between day 1 through to day 6. Cells A and B generally exhibited higher values of internal resistance compared to cell C between days 15 and 40. Cell C exhibited the lowest values in general for resistance on the logarithmic scale.

DISCUSSION

Generally, voltage for all the cells A, B and C are divided into three phases; the voltage rise, stationary and fall phase (as shown in Fig. **3**). The voltage rise phase consists of two stages that is the early stage (day 0 – 3) and advanced voltage rise stage (day 4 - 9). The early stage has lower voltage change gradients than advanced voltage. During the early stage, voltage growth is slow because of three reasons: low bacteria population and the bacteria are trying to acclimatize to the cell environment; presence of high concentration of electron acceptors; limited colonization of the anode surface by bacteria [3, 10, 21].

For this reason during the early stage, every time agitation was done on the cells a foul smell was expelled from the cells (as Equation 1.1). The degree of the stench decreased with time from day 0 – 3. On day 4, there was no more smell which meant that there was a low concentration of sulphates in sewage which is similar to similar observations by [11].

$$SO_4^{2-}{}_{(aq)} + 10H^+{}_{(aq)} + 8e\ 4H_2O_{(l)} + H_2S_{(g)} \tag{1.0}$$
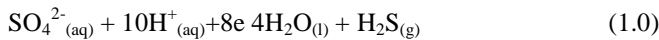
During the advanced voltage rise stage, there was an increase in the bacteria community responsible for the generation of voltage. The steady increase is a factor which is also increased by the bacterial community forming a film/colonizing the anode surface [11]. The stationary phase is of maximum constant voltage. Since the voltage developed entirely depends on bacteria community responsible for voltage development between the anode and cathode; the voltage at this phase is constant since the bacterial community responsible for voltage development is at a constant population [10]. The constant population signifies that the number of bacteria dying is equal to the number that is being reproduced. During this stage, the food available can only sustain a constant bacterial population. The constant population was the maximum achievable population by the bacterial community in correspondence with the available food.

The last stage of voltage change is the voltage fall phase. It is between days 42 and 58 (Fig. **3**). This was due to the fall in COD or food for the bacteria as shown in Fig. (**5**). This would have led to a great fall in bacteria community due to decrease in food quantity [3]. The trend of voltage change that has been discussed above is analogous to the bacteria growth curve. Bacteria growth curve consists of four growth phases, that is; the lag phase, exponential phase, stationary phase and the death phase. The lag and exponential phase correlate to the voltage rise phase. The stationary and voltage fall phases correlate to the stationary and death phase respectively.

PHASE B (EXPONENTIAL PHASE) AND C STATIONARY PHASE AND VOLTAGE VARIATION

If $S(t)$ denotes the concentration of substrate/nutrient in the media and $N(t)$ denotes concentration of bacteria at time t. Bacteria reproduce by fission. A fully grown bacterium reproduces by dividing into two equal daughter cells. Each daughter cell would then grow and further divide into two for each daughter cell making four cells.

The Malthusian's Equation model:

$$\frac{dN(t)}{dt} = kN(t) \tag{2.0}$$

K – Growth rate constant and $K>0$

$$\int \frac{dN(t)}{N(t)} = k\,dt$$

$$N(t) = Ae^{Kt}$$

At time, $t=0$ and $N(0) = A$

$$N(t) = N(0)e^{Kt} \tag{2.1}$$

Since the change in the concentration of bacteria is assumed to be proportional to the change in voltage, then equation 2.1 becomes 2.2:

$$V(t) = V(0)e^{kt} \tag{2.2}$$

$V(t)$ - voltage at time t and $V(0)$ - voltage at time t=0.

But the bacteria growth is best explained using the Jacques Monod model that factors the nutrient parameter $S(t)$ into the equation. The Jacques Monod model equation (3.0) is an improvement of the Malthusian model equation (Equation 2.0).

$$\frac{dN(t)}{N(t)dt} = \frac{rS(t)}{a + S(t)} \tag{3.0}$$

r- Maximum growth rate and a - Half saturation constant

But COD/nutrient ($S(t)$) was depicted to be reducing with time (Fig. **5**). Monod also found that the rate of nutrient (COD) was opposite in sign to bacteria growth but proportional to it:

$$\gamma \frac{dS(t)}{dt} = -\frac{dN(t)}{dt} \tag{3.1}$$

Where γ - growth yield constant

Combining equations 3.0 and 3.1:

$$\gamma \frac{dS(t)}{dt} = -N(t)\frac{rS(t)}{a + S(t)} \tag{3.2}$$

At t=0, $S(0) = S$ and $N(0) = N$

Equation 3.1 is the same as:

$$\gamma \frac{dS(t)}{dt} + \frac{dN(t)}{dt} = 0$$

$$S(t) = S + \frac{N(t) - N}{\gamma}$$

To obtain an expression for bacteria population, $N(t)$:

$$\frac{dN(t)}{dt} = rN(t)\left[\frac{\gamma S + N(t) - N}{\gamma a + \gamma S + N(t) - N}\right] \tag{3.3}$$

The expression for change in bacteria population is similar to change in voltage since voltage production is a factor of bacteria action on the existing substrate $S(t)$. Notice that at the stationary phase of bacteria growth, the rate of change of bacteria population is zero. Therefore:

$$0 = rN(t)\left[\frac{\gamma S + N(t) - N}{\gamma a + \gamma S + N(t) - N}\right]$$

Table 1. Soil Electrical Conductivity

Day	E.C (mS)	pH	Temperature (^{0}C)
0	0.160	5.8	22.8
55	243	6.1	21.5

Solution is $N(t) = 0$ and $N(t) = N - \gamma S$.

This means that at the time when the rate of change bacteria growth (voltage) is zero, either bacterial population (voltage) is zero or the population (voltage) change is constant and is being kept constant by the existing nutrient concentration, S.

Equation 3.3 can be approximated to be equivalent to (with a voltage relationship):

$$\frac{dV(t)}{dt} = \varphi r V(t) \left[\frac{\gamma S + V(t) - V}{\gamma a + \gamma S + V(t) - V} \right] \qquad (3.4)$$

ϕ - This is a constant of proportionality that relates voltage and bacterial population.

Cell A, with an anode-cathode separation of 25 mm developed greater voltage between its electrodes because of small distance in comparison to the other cells that is B (50 mm) and C (75 mm). The distance between the cathode and the anode determines the speed with which the electrons are going to travel between the soil layer and therefore the shorter the distance in a given time, the faster the current and therefore the higher the voltage. This is similar to results by [23]. From ohms law, voltage is directly proportional to current therefore the voltage would also increase. Voltage was slightly enhanced on agitation of cell fuel contents (Fig. **4**). Agitation ensured evenness in the distribution of biodegradable material in the cells. The evenness made the material easily accessible for voltage generation by the bacteria population on the anode electrode surface.

INTERNAL RESISTANCE

Internal resistance of the cells generally increased with time (Fig. **8**). Since ions are responsible for conductivity in the cells then the increase in resistance must be attributed to the decrease in electricity conducting shuttles/carriers (Gil et al., 2003). The electricity conducting shuttles present in sewage include sulphate ions, nitrates, nitrites, ammonium, sulphides, hydrogen ions, phosphates and other salt ions [3, 23, 24]. The concentration of ions like the sulphates, nitrites, nitrates and others were reduced since they are electron acceptors. The sulphate is reduced to sulphide and then given off to the atmosphere as hydrogen sulphide which exhibits an undesirable odour. This odour is given out in high concentration during the first three days of cell life. The nitrates and nitrites are also given off to the atmosphere through the nitrogen cycle [23]. The process of electron acceptor loss led to the decrease in concentration of the ions in the three cells. This led to the decrease in the concentration of conducting ions leaving just the sodium and chloride ions as the ions responsible for conductivity in the cells.

The internal resistance also further increased because of loss of water from the soil which was used as the proton exchange membrane. Initially the soil is saturated with the sewage sample and the conductivity of the soil is higher than 160 µS at 22.8 ^{0}C (Table **1**). The ions responsible for conductivity at this point are those contained in the soil, the added sodium chloride and the salts contained in the sewage. When the soil moisture content decreased, this meant that the migration of ions across the soil membrane from the anode to the cathode became more difficult. Resistance was highest during the times of low moisture content and the resistance greatly varied with moisture content.

It was expected that the internal resistance would increase with time but this was not the case (Fig. **8**). During the early times of ion migration across the soil towards the cathode compartment, there was slow accumulation of ions in the soil (membrane). This accumulation of ions led to an increase in the ion concentration thus an increase in E.C. The increase in ion concentration by far surpasses the effect of moisture content variation. This led to an increase of E.C of the cells or a decrease in electrical resistance of the cells. The E.C increased from 160 µS on day 0 to 243 mS on day 55 (Table **1**).

CONCLUSION

The experimental data obtained showed that it is actually possible to generate electric power from the waste water. The distance between the cells' anode and cathode determined the magnitude of the voltage created between the electrodes. The shorter the distance between the anode and the cathode, the higher the voltage developed between the electrodes. Using soil as a membrane greatly increased the cell's internal resistance therefore the use of soil is not viable option for electricity generation. The MFC cells showed higher treatment efficiency rates than ordinary waste treatment ponds under similar environmental conditions (Fig. **6**). The highest treatment efficiency was 80 % after 20 days whereas that of the control was 30 % after the same number of days. The constructed practical model developed a maximum voltage of about 217 mV on day one from the introduction of the MFC fuel.

RECOMMENDATIONS

The voltage generated was still low and coupled with a high internal resistance lowered the power generated by the cells. The following are the possible studies and changes that should be established to enhance an MFC's power rating:

I.   The electrical conductivity of the MFC fuel solution should be enhanced to levels that do not affect the bacterial community in the sewage/waste as well as to levels that lower the cell's internal resistance to acceptable levels. Electrical conductivity can be increased by increasing on the concentration of electrolytes in the fuel solutions. The concentration of the ions can affect the metabolism of bacterium in the MFC fuel.

II.   Studies on voltage and resistance changes should also be carried out at an hourly or half-hour basis to get a better view of the variation of voltage with time.

III.   Studies should be carried out to establish the most appropriate C/N ratio that gives off the highest electrical voltage. Further studies can also be made through co-digestion of several biodegradable materials to establish which materials will give the highest voltage from the cell.

IV.   Applying of genetic engineering in the development of strains of bacteria that will be highly adaptive, efficient in the break down of the bio material as well as have a high affinity for a variety of bio material

V.   Up scaling of the MFC to larger treatment volumes like septic tanks and industrial food processing waste ponds and with further development, designs should be made that incorporate MFC into waste water treatment plants.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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REFERENCES

[1]   Ministry of Energy and Mineral Development (MEMD). *Annual* Report, **2009**, vol. *4*, p. 22.

[2]   Goldstein, R.; Smith, W. In *Water & Sustainability: U.S. Electricity Consumption for Water Supply & Treatment.* The Next Half Century, Electric Power Research Institute: Palo Alto, CA, USA, **2002**, *4*, pp. 4.

[3]   Mohan, S.V.; Saravana, R.; Raghavulu, V.S.; Mohanakrishna, G.; Sarma P.N. *Bioelectricity production from waste water treatment in dual chambered Microbial Fuel Cell (MFC) using selectively enriched mixed microflora: Effect of catholyte,* Bioengineering and Environmental Centre, Indian Institute of Chemical Technology: Hyderabad 500 007, India, **2006**, pp 5 - 27.

[4]   Logan, B.E. *Energy Sustainability of the Water Infrastructure,* National Water Research Institute: USA, **2008**, pp 30.

[5]   Shukla, K.; Suresh, P.; Berchmans, S.; Rajendran, A. *Biological fuel cells and their applications,* Central Electrochemical Research Institute: India, **2004**, 27 -38.

[6]   Phuc, T.H.; Tae, B.; Chang, I.S. Performance and Bacterial Consortium of Microbial Fuel Cell Fed with Formate. *Energy Fuels*, **2008**, *22*, 164-168.

[7]   Pranab, K. B.; Deka, D. Electricity Generation from Bio-waste Based Microbial Fuel Cells. *Int. J. Energy Inform. Commun.*, **2010**, *1,* 77-92.

[8]   Rabaey, K.; Lissens, G.; Siciliano, S. D.; Verstraete, W., A Microbial Fuel Cell Capable of Converting Glucose to Electricity at High Rates and Efficiency. *Biotechnology*, **2003a**, *18,*1531-1535

[9]   Rabaey, K.; Lissens, G.; Siciliano, S. D.; Verstraete, W. Continuous Microbial Fuel Cells Convert Carbohydrates to Electricity. *Water Sci. Technol.*, **2003b**, *52,* 515-523.

[10]   Rabaey, K.; Verstraete, W. Microbial fuel cells: Novel biotechnology for energy generation. *Trends Biotechnol.,* **2005**, *23*(6), 291-298.

[11]   Rabaey, K.; Lissens, G.; Verstraete, W. Microbial fuel cells: Performances and Perspectives. Biofuels for fuel cells: biomass fermentation towards usage in fuel cells, Available from: http://www.microbialfuelcell.org/www/index.php/component/option n,com_jombib/id,97/task,showbib/ , **2005b**, pp. 1 -8.

[12]   Aelterman, P.; Freguia, S.; Keller, J.; Verstraete, W.; Rabaey, K. The anode potential regulates bacterial activity in microbial fuel cells. *Commun. Agric. Appl. Biol. Sci.*, **2008**, *73*(1), 85-89.

[13]   Allen, R.; Bennetto, M. H. P. Microbial fuel-cells electricity production from carbohydrates. *Appl. Biochem. Biotechnol.*, **1993**, *39*, 27-40.

[14]   Kim, I.S.; Kyu-Jung, C.; Mi-Jin, C.; Verstraete, W. Microbial fuel cells: recent advances, bacterial communities and application beyond electricity generation. *Environ. Eng. Res.*, **2008**, *13*(2), 51-65.

[15]   Rahimnejad, M.; Ghoreyshi, A. A; Najafpour, G.; Jafary, T. Power generation from organic substrate in batch and continuous flow microbial fuel cell operations. *Appl. Energy,* **2011**, *88*(11), 3999-4004.

[16]   Rao, J. R.; Richter G. J.; Vonsturm F.; Weidlich, E. Performance of glucose electrodes and characteristics of different biofuel cell constructions. *Bioelectrochem. Bioenerg.,* **1976**, *3*(1), 139-150.

[17]   Bullen, R. A.; Arnot, T.C.; Lakeman, J.B.; Walsh, F. C. Biofuel cells and their development. *Biosens. Bioelectron.,* **2006**, *21,* 1-2.

[18]   Geun-Cheol, G.; In-Seop C.; Byung, H.K.; Mia, K.; Jae-Kyung, J.; Hyung Soo, P.; Kim, H.J. Operational parameters affecting the performance of a mediator-less microbial fuel cell. *Biosens. Bioelectron.,* **2003,** *18*(4), 334-327.

[19]   Lovley, D.R. The microbe electric: conversion of organic matter to electricity. *Curr. Open. Biotechnol.,* **2008**, *19*(6), 564-571.

[20]   Gil, G.C.; Chang, I.S.; Kim, B.H.; Kim, M.; Jang, J.K.; Park, H.S.; Kim; H.J. Operational parameters affecting the performance of a mediator-less microbial fuel cell. *Biosens. Bioelecton.,* **2003,** *4,* 1-4.

[21]   Ghangrekar, M.M.; Shinde, V.B. Wastewater Treatment in Microbial Fuel Cell and Electricity Generation: A Sustainable Approach, Paper presented in the 12th International Sustainable Development Research Conference, Hong Kong. April 6-8 **2006**.

[22]   Mathuriya, S.; Sharma, V. N. Bioelectricity production from various wastewaters through microbial fuel cell technology. Sevas Educational Society. *J. Biochem. Technol.*, **2009**, *2*(1), 1-2

[23]   Cusick, R.D.; Bryan, B.; Parker, D.S.; Merrill, M.; Mehanna, M.; Kiely, P.D.; Liu, G.; Logan, B.E. Performance of a pilot-scale continuous flow microbial electrolysis cell fed winery waste water. *Appl. Microbiol. Biotechnol.*, **2011**, *89*, 3-6.

[24]   Mohan S. V.; Raghavulu, V. S.; Sarma, P.N. Biochemical evaluation of bioelectricity production process from anaerobic wastewater treatment in a single chambered microbial fuel cell (MFC) employing glass wool membrane. *Biosens. Bioelctron.,* **2008**, *23,* 1326-1332.