MICROBIAL FUEL CELL – AN ALTERNATIVE ENERGY SOURCE FOR T&T

Roshan Ramoutar[1], Denyse Ramganase[2], Josann Mc Intosh-Adbool[3], Antonio Bleasdell[4], Jameel Rooplal[5] and Davinder Pal Sharma[6*].

Faculty of Science & Technology, The University of the West Indies, Trinidad
Email: Davinder.Sharma@sta.uwi.edu *(Corresponding author)

Abstract*:* The microbial fuel cell (MFC) is a bio-electrochemical system that uses bacteria from wastewater to convert organic molecules directly into electrical energy under anaerobic conditions. In the present study we used a dual chamber MFC for electricity generation and performance improvement. The performance of the MFC was optimized by: (a) setting up five MFC's using different combinations of electrodes of varying surface areas, (b) using wastewaters from different locations within Trinidad & Tobago and (c) providing additional supply of oxygen in the cathode chamber. Aluminum mesh and Platinum/Carbon 40% (PtC40%) cloth of different ratios were used as electrodes whereas Nafion-212 was used as the ion exchange membrane inside of an MFC reactor with capacity of 150 ml per chamber. Samples collected from various site in Trinidad i.e. Cascadoux, Nariva swamp, Caroni swamp, Guaracara River and a cow farm located at Cunupia, were tested for their electrical capabilities. The highest voltage of 850 mV was achieved from the cow farm sample using a cylindrical shaped aluminum mesh electrode of ratio 6:1. The PtC40% with ratio 2:1 for the cow farm had the best stability. The results were very attractive and demonstrated that wastewater containing animal faeces, urine or chemical pesticides are ideal for energy generation. This supports that an MFC is an option as an alternative source of electrical energy.

Keywords: *Microbial fuel cell, Dual chamber, Alternative energy source, Wastewater.*

https://doi.org/10.47412/YDQV9793

1.0 Introduction

An MFC is bio-electrochemical system capable of producing electricity from the degradation of organic compounds in wastewater [1]. The advantages of using MFC's include having an endless supply of carbon sources provided by the contaminants in the wastewater as well as a reduction in the overall energy consumed throughout the wastewater treatment process, since the amount of electricity generated while removing contaminants could be adequate to power the wastewater treatment processes [2]. MFC's can be constructed in a variety of configurations, such as single chamber, dual-chamber, up flow, flat and tubular designs. A common design is a dual-chamber MFC, shown in Fig.1, is an "H" shape, traditionally comprising of two bottles which are attached by a tube containing a separator. This separator is generally a cation exchange membrane (CEM), also known as a proton exchange membrane (PEM). Examples of CEM include Nafion, Ultrex or a plain salt bridge [3]. Fundamental to this design is selection of a membrane that permits the passage of protons between the chambers. The "H" design uses a tube to separate the chambers, but it should be noted that the tube is not necessary. Once the anode and cathode chambers are separated, they can be constrained against either side of the membrane and clamped together to form a large surface [4].

Although there are a variety of MFC reactors throughout the world, all reactors operate based on the same underlying principles. All MFCs possess a pair of battery-like terminals, i.e. the cathode and anode[5]. The electrodes are linked via an external circuit, and an electrolyte solution aids electricity conduction. Electrical current is generated by the voltage difference between the anode and cathode, as well as the electron flow in the circuit. In a MFC, the substrate, which is the organic matter or biomass, is oxidized at the anode. This process produces carbon dioxide, protons and electrons, which transfer to the electrode. Microorganisms play the role of biocatalysts, similar to chemical fuel cells. The electrons produced at the anode end up in the cathode via the external electrical circuit. The protons produced at the anode go to the cathode by means of the exchange membrane. An oxidant (usually oxygen) is reduced at the cathode [6]. The following equations explain the elementary processes in MFCs for the case of a glucose-fed system [7]:

$$\text{Anode: } C_6H_{12}O_6 + 6\,H_2O \rightarrow 6\,CO_2 + 24\,H^+ + 24e^- \quad (1)$$

$$\text{Cathode: } 24\,H^+ + 24\,e^- + 6\,O_2 \rightarrow 12\,H_2O \quad (2)$$

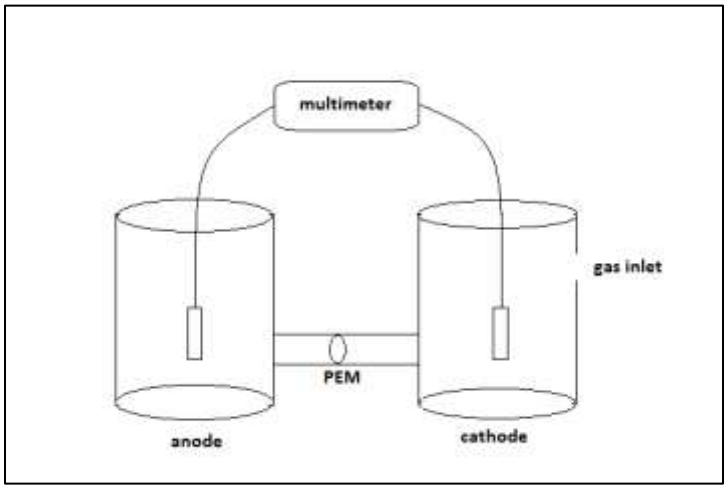

Figure 1: Schematic of MFC prototype design.

The main objective of this study was to enhance the previously designed prototypes of microbial fuel cells for improved electricity generation using wastewater from various sources and different electrode combinations.

In 2004 Bruce E. Logan demonstrated the effect of changing the cathode surface area used in the MFC on power production. He increased the area from 22.5cm^2 to 67.5cm^2 and realized a significant increase in the voltage acquired from the system [8]. In 2010 Franks and Nevin showed that a smaller volume MFC chamber may deliver more power density than a larger chamber. They investigated a prototype of volume 1.3m^3 which sustained 24mW whereas a chamber of 0.03m^3 sustained 36mW of power [9]. This prototype takes advantage of the attributes of micro-benthos organisms, that thrive in oxygen-deficient water with their main source of energy from metabolising other dead organisms or remains anaerobically. It therefore suggested miniature uses of the MFC to mimic such an environment. By using these miniature prototypes, they were able to investigate parameters like energy capture efficiency, mass transfer efficiency, and voltage efficiency which influence the efficiency of the MFC's performance. They also were able to discover the existence of the biofilm building up on the anode which directly affects power output.

These previous studies are only two of many that inspired the choice in variables and the size of chambers for this study.

2.0 MFC System Description

Components of the MFC system used during present study are shown in Fig.2. The anode and cathode chambers each of volume 150ml were manufactured by Adams & Chittenden Scientific Glass Company. There is a flange on one side of each chamber where the membrane can be placed and outlets on the other side of each chamber which can be sealed using rubber caps if needed. The electrode materials chosen to carry out tests on the different samples were aluminum mesh and (PtC40%). These materials are chosen since they are chemically stable when placed in the wastewater samples, conductive and biocompatible. The aluminum mesh was readily available and relatively inexpensive, while the PtC40%, though costly, is capable of having a large surface area for a small volume of electrode material.

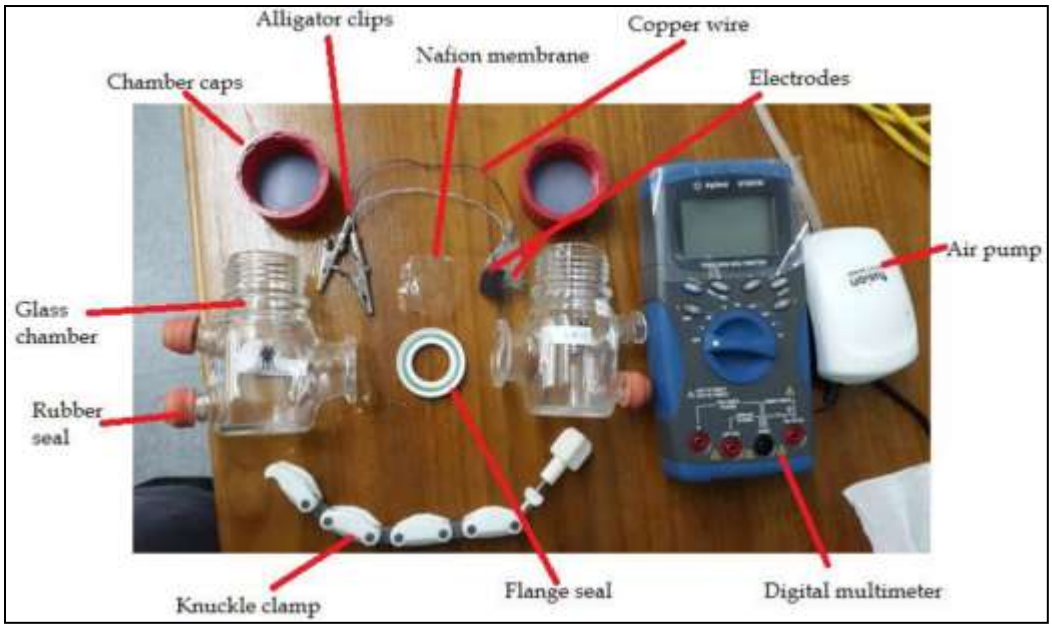

Figure 2: Components of MFC system.

3.0 Methodology

The microbial fuel cell was set up as illustrated in Fig.3. Plugs were attached to the outlets on the side of the anode chamber to keep the chamber airtight since the aim was to provide an anaerobic environment for the sample. The membrane was secured, using the knuckle clamp, between the anode and cathode chambers. Through this membrane was the only form of contact between both chambers. An incision was made in the rubber cap of the anode chamber for a single CAT.5e wire to be pushed through then resealed using a glue gun. A single CAT.5e wire was used so as to limit variations in results due to any residual build-up of charges on separate/ adjacent wire surfaces. The anode was attached to this wire and placed in the centre of the chamber so that when the sample is added it will be evenly distributed around the anode. The cathode was connected to one end of a single CAT.5e wire using the glue gun and placed in the cathode chamber with the wire leading out of the top side outlet [10].

To calibrate, the anode chamber was filled with distilled water so no air was left under the cap, while the cathode chamber was filled with distilled water up to just under the level of the outlet. The lid was secured onto both chambers, ensuring both electrodes were fully immersed in water. The set up was then checked for leaks and alligator clips were connected to both the wires leading out of the chambers. The anode was connected to the negative terminal of a voltmeter, while the clip leading from the cathode was connected to the positive terminal. The voltmeter was set to millivolts and switched on to measure the potential difference generated between the MFC chambers. Voltage readings were manually taken, hourly, for as many consecutive hours as possible, until the voltage readings were diminished. The calibration chambers were run for the full length of the entire study to use as a comparison.

Figure 3: MFC setup

Wastewater samples were collected from various locations around Trinidad including: Nariva Swamp [11], Cascadoux Trace, Caroni Swamp, Guaracara River and a cow farm located in Cunupia [12]. Five litre samples of each were collected and stored in an ice-cooler immediately after collection to slow their metabolic processes so they perform at their optimum under laboratory conditions later on.

After calibration of the MFCs testing of the wastewater samples was commenced by replacing the distilled water in the anode chamber with wastewater samples. This was repeated for the anode to cathode ratios of 2:1, 6:1 and 10:1 using aluminum mesh as the electrodes, and 2:1 using Pt/C 40% as the electrodes [13]. An electric air pump was used to pump fresh atmosphere into the cathode chambers during the study n order to maintain the chamber's affinity to H^+ ions crossing the membrane.

The apparatus was allowed to run for between three (3) and five (5) days before their voltages were diminished. Data was collected every hour during daylight hours but not during the night when the lab was closed. The results were tabulated and graphs were plotted for analysis.

4.0 Results and Discussion

The objective of the present study was to examine the performance of the two chamber microbial fuel cell for electricity generation. This was done by varying the anode to cathode surface area ratio combinations, and varying the shape and material used for these combinations and using samples collected from different locations. These locations were chosen based on their backgrounds and the type of waste they may be exposed to currently. Nariva Swamp and Cascadoux Trace were chosen for their seclusion and remoteness to human interference, where it is expected to be populated with naturally occurring microbes that feed off natural wastewater instead of artificial waste. The Guaracara River is located amongst many industrial sites where artificially produced waste, both from industry and civilian occupation, may run off into the river. It is expected that microbes that feed off harmful chemicals be present in these samples. The cow farm located in Cunupia should contain animal faeces, urine and pesticides and therefore should be home for microbes that feed off these compounds.

Fig. 4 shows the results of the Guaracara sample and with both Aluminum mesh chambers there is a sharp increase in voltage for the first 8-10 hours, then a gentle decrease until the 28th hour, indicating that metabolism in these chambers accelerated rapidly depleting the compounds in the sample too early. After which there were very sharp peaks and troughs until around the 45th hour, when it began to stabilise. The graph for the Pt/C cloth showed a sharp increase for the first few hours then a steady increase until around 28th hour and remained at a relatively steady voltage till the 67th hour where it dropped drastically. The MFC behaved very differently for aluminum and platinum/carbon electrodes. The highest voltages achieved by the Al mesh 2:1, 6:1 and Pt/C were 863mV, 766.5mV and 616.5mV respectively.

It is also clear that the Al-6:1 graph ended abruptly at about the 55th hour. This was because the anode chamber became pressurised overnight by the build-up of gases and blew the caps off the chamber, as they were found several feet away from the MFC apparatus.

Fig.5 shows voltages achieved for Caroni samples with highest voltages being 739mV, 624.7mV and 914.5mV for Pt/C, Al 6:1 and Al 2:1 respectively. The Al mesh 2:1 ratio produced the highest overall voltage, however, it was the most unstable of all the electrode combinations. The 2:1 Pt/C 40% ratio displayed the most stability of all the electrode combinations used. The general values were much more stable than that of the Guaracara samples and that stability was maintained at a higher value.

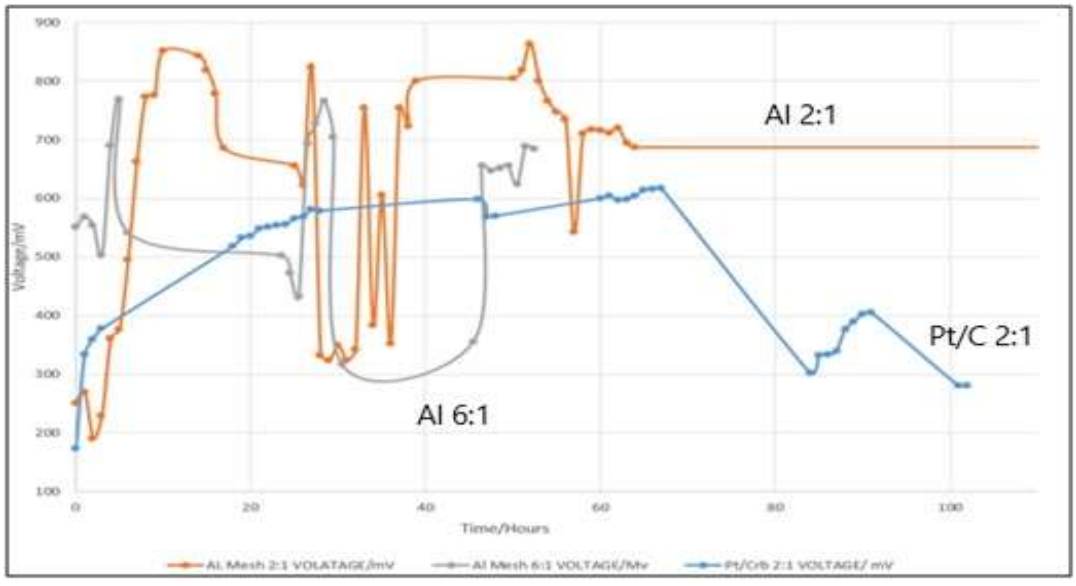

Figure 4: Results from the Guaracara sample.

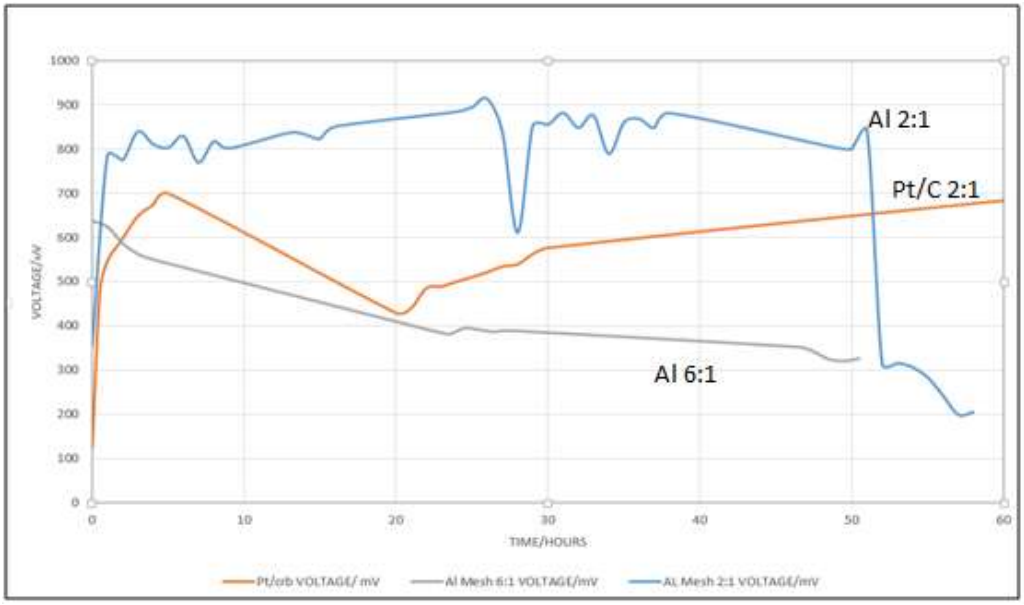

Figure 5: Results from the Caroni sample.

The cow farm sample produced the most interesting results which are displayed in Fig.6. Results show the most stable output with the 6:1 and 2:1 Aluminum mesh, increasing sharply in the first 3 hours and then fluctuated between 700mV and 850 mV till the end of the study. The Pt/C output was the most stable, though it was the lowest. It remained between 488.7mV and 596mV from the 10th hour to the 80th hour. This was the most stable result of the entire study.

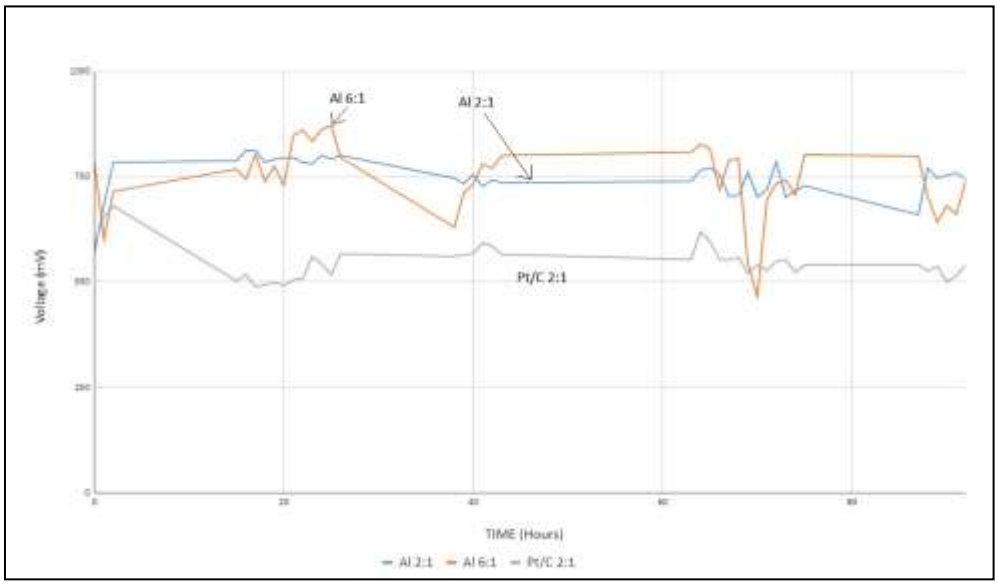

Figure 6: Results from the Cow Farm sample

Throughout the study it was noticeable that the voltage readings were constantly fluctuating as can be seen on all the resulting graphs. This may be in part due to the change in pH levels of the anode chamber as microbes respire anaerobically. The difference in pH between the chambers may increase and affect the

rate of respiration of the microbes. Fluctuations may also be brought about by the build-up of internal resistance inside the chambers which may result in the development of a natural voltage threshold. At this point only above a certain potential difference (between the sample and the electrodes) would electrons flow from the anode to cathode chamber.

Many precautions were taken during this study but there were some factors that were unavoidable due to limited resources. The temperature of the chambers was kept at a constant 25°C by setting them up in a temperature-controlled lab so as to eliminate heat energy as a variable. When handling the samples, they were exposed to as little atmosphere as possible by keeping lids tightly sealed and transferring to chambers quickly. By doing this, the microbes' environment was constant and should not affect their population count by making oxygen available. A change in population count would become a random variable causing more fluctuations in the results.

To further this investigation toward the optimization of MFC's for electricity generation a number of recommendations of improvements could be made. Firstly, the results from different materials for PEM's such as Ultrex CMI-700 could be compared with results from this study, Nafion 212, and determine which material is better suited.

Also following from the stability of the PtC40% electrode used, testing samples under a larger anode to cathode ratio using this material should be done to determine whether higher maximum voltages would be obtained with more voltage stability. Since readings were not taken at night when the lab was closed, as the equipment remained running, using a computerised system connected to the MFC to obtain hourly voltage readings would make for better analysis of the results obtained.

Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) tests [14] should be carried out on samples both before and after testing, so that the wastewater treatment capability of the MFC can also be analysed. These tests would reveal the amount of oxygen is 'demanded' or needed by either biological or chemical components in the samples, which ultimately gives a very good idea of the amount or concentration of active microbes present in the sample.

Finally, since one of the MFC's chambers blew open due to pressure build up it would be useful to connect a pressure and gas sensor to the anode chamber as a means to collect, measure and test the gases produced by the micro-organisms [15].

5.0 Conclusion

Using the MFC to reverse the build-up of waste while producing valuable resources at an attractively low cost could be the answer to two of the world's bigger concerns, power and waste. During the present study, the highest overall effective voltage, while very unstable, was found to be 850 millivolts achieved when using a 150 ml Cunupia cow farm sample, and the Al 6:1 anode to cathode configuration, with the anode rolled in a cylindrical geometry, and a Nafion 212 membrane. The electrode array which produced the most stabile voltage was the 2:1 anode to cathode ratio of Pt/C40%, in a flat square geometry, with the Nafion 212 membrane. The samples from Guaracara River, the cow farm located in Cunupia, and Caroni Swamp, all generated desirable voltages. The results of this project have demonstrated the relevance of MFC research in Trinidad and Tobago; with the large number of privately own animal farms throughout the country the possible applications that microbial fuel cells have to offer should be explored to the fullest.

References

[1] K. Rabaey, W. Verstraete. Microbial fuel cells: novel biotechnology for energy generation. *Trends in Biotechnology* 23 no. 6, (2005) 291-298.
[2] J. N. Ma, H. Ni, D. Su, X. Meng. Bioelectricity generation from pig farm wastewater in microbial fuel cell using carbon brush as electrode. *Internation Journal of Hydrogen Energy* 41 no. 36, (2016) 16191-16195.
[3] FuelCellsEtc. (n.d.). Retrieved November 30, 2015, from https://fuelcellsetc.com/store/DS/nafion-comparison-chart.pdf
[4] B. E. Logan et.al. Microbial fuel cells: methodology and technology. *Environmental Science and Technology* 40 no. 17,(2006) 5181-5192.
[5] Z. Du, H. Li, T. Gu. A state of the art review on microbial fuel cells: a promising technology for wastewater treatment and bioenergy. *Biotechnology Advances* 25, no. 5 (2007) 464-482.
[6] M. C. Potter. Electrical effects accompanying the decomposition of organic compounds. *Proceedings of the Royal Society of London. Series B, Containing Papers of a Biological Character* 84, no. 571 (1911) 260-276.
[7] N. S. N. Hisham, et.al. Microbial fuel cells using different types of wastewater for electricity generation and simultaneously removed pollutant. *Journal of Engineering Science and Technology* 8, no. 3 (2013) 317-326.
[8] B. E. Logan, J. M. Regan. Microbial fuel cells—challenges and applications. *Environmental Science and Technology* 40 no. 17, (2006) 5172-5180.
[9] A. E. Franks, K. P. Nevin. Microbial fuel cells- a current review. *Energies* 3, (2010) 899-919.
[10] B. Logan, S. Cheng, V. Watson, G. Estadt. Graphite fiber brush anodes for increased power production in air-cathode microbial fuel cells. *Environmental Science & Technology* 41, no. 9 (2007) 3341-3346.
[11] E. J. Peters, V. Joseph. An evaluation of the compliance of the water pollution control rules in Port of Spain, Trinidad. *West Indian Journal of Engineering* 38, no. 1 (2015).
[12] Renewable Energy Committee, 2011. *Framework for Development of a Renewable Energy Policy for Trinidad and Tobago*.
[13] N. S. N. Hisham et. al. "Microbial fuel cells using different types of wastewater for electricity generation and simultaneously removed pollutant. *Journal of Engineering Science and Technology* 8, no. 3 (2013) 317-326.
[14] Z. Ge,, J. Li, L. Xiao, Y. Tong, Z. He. Recovery of electrical energy in microbial fuel cells: brief review. *Environmental Science & Technology Letters* 1, no. 2 (2013) 137-141.
[15] M. Rahimnejad, A. Adhami, S. Darvari, A. Zirepour, S. Oh. Microbial fuel cell as new technology for bioelectricity generation: a review. *Alexandria Engineering Journal* 54, no. 3 (2015) 745-756.