Chapter 4

Bio Dry Cell - A Novel Green Energy Conversion System

4.1 Introduction

Sustainable electricity production and effective waste management are two significant concerns leading to the 21st century. Natural sources of electricity generation, while viable, are not often possible in many regions of the world. Water usage is continually rising with global populations, making it increasingly necessary to eco-friendly and effective waste treatment alternatives. Microbial fuel cells (MFCs) are rapidly gaining popularity in both alternative energy production and waste treatment. While typical waste treatment systems appropriate biological treatment under aerobic conditions to degrade the organic components in the waste, MFCs appropriate microorganisms to degrade natural ingredients under anaerobic conditions, through this process, electrons are liberated and provide the energy produced by the MFCs. Elementary MFC studies use simple systems with single microorganism and simple substrates (Kim, Choi, Jung and Kim, 2000). Several organisms are found to behave ideally under anaerobic conditions, readily freeing electrons during biodegradation of the substrate, including some Shewanella and Geobacter species (Bond and Lovley, 2003; Ringeisen, Ray and Little, 2007). The use of available electron mediators in early research is appreciable, but the concept of membrane-less MFCs became prominent only in the late 1990s and continues to be more widely researched over MFCs operated with mediators (Gil et al., 2003; Moon, Chang and Kim, 2006). Over the past decade, many improvements have been performed concerning system design and materials.

Further studies have begun to focus on naturally diverse microbial systems and substrates, such as those provided in wastewater (Moon et al., 2006; Min, Kim, Oh,

Regan and Logan, 2005; He, Minteer and Angenent, 2005; Aelterman, Rabaey, Clauwaert and Verstraete, 2006; You, Zhao, Jiang and Zhang, 2006). Further research stays required in many areas, including the use of multiple MFC reactor systems, the influence of various operational parameters, overall MFC performance and system responses to disturbance and upset. A microbial fuel cell is an emerging technology designed to harness earth's most abundant promising bioenergy source (organic waste) and yield self-sustainable electricity both during the day and night. In 1911, British botanist Potter had proposed a method to produce electricity using microbes that oxidised organic substrates. During the 80's decade, electron transfer intermediates and catalysts are widely used for improving output power from microbial activities.

This technique has attracted particular attention from researchers as it represented a promising solution for energy generation in green and bio-compatible manner. In 1999, Researcher Tatsuo Yagishita et al. have studied Synechococcus with glucose to make electricity production. In the University of Massachusetts, researchers found that iron-reducing bacteria Rhodospirillum could metabolise carbohydrates and produce electricity. Later, researchers have demonstrated that bacteria in organic waste could transfer electrons externally to electrodes in a closed chamber. During the past ten years, with improved electrode materials and methods, this concept is enough matured to a technology that has paved a practical way for electricity generation with biodegradable wastes.

Despite their potential, today's practical microbial fuel cells are costly regarding fabrication, output power and demonstrate persistent performance limitations. Present work addresses the issue by designing the architecture of fabricating bio dry cell in simple steps. Based on this cost-effective, innovative design, this thesis work significantly increases the output power of the bio dry cell and potentially establishes a unique design

platform for a scalable and sustainable low-cost bio dry cell stack for the stand-alone renewable energy system. In this chapter, the operation and microbial ecology of two MFCs of bio dry cell are compared during an acclimation period and a subsequent carbon source dosing period. MFC#1 is operated with a dissolved oxygen catholyte, while MFC#2 is operated with a ferricyanide catholyte. The acclimation period is approximately 77 days in duration, lasting from system start-up to the first carbon source pulse test (CSPT). The CSPTs involved the dosing of a known amount of a specific, soluble carbon source. Sodium acetate, glucose, glycerol, and bovine serum albumin (BSA) are chosen and dosed in that order. The carbon source dosing period is approximately 60 days in duration. Evaluation of MFC operation included monitoring of electricity production and anolyte quality as outlined in Chapter 2. The microbial ecology is evaluated using BDC boxes and principal component analysis (PCA) as outlined in Chapter 3.

4.2 Microbial Fuel Cell (MFC) System

4.2.1 System Design, Operation, Materials, and Experimental Methods

The MFC system design and materials are described in Chapter 2. The system is operated for a total of 182 days, consisting of the acclimation period of 77 days, the carbon source dosing period of 60 days and a post-experimental monitoring period of 45 days. Both MFCs are controlled at 0.3V while the current produced from each MFC is measured. The system is operated under a fed-batch mode with 100 mL of waste activated sludge fed every 3 hours following the removal of a 100 mL sample of the wastewater anolyte. Sampling and feeding methodology are shown in detail in section 4.3.2. The anolyte and the waste activated sludge feed is investigated for chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN) and pH. The dissolved oxygen and ferricyanide concentrations are obtained to measure in the catholyte of MFC#1 and MFC#2, respectively. The top

space gas composition of each MFC is also analysed for nitrogen, carbon dioxide and methane. The anolyte and waste activated sludge feed samples are fractionated via centrifugation and filtration, then preserved before digestion and analysis. During system operation, carbon source pulse tests (CSPTs) is performed by injecting a small, known amount of COD in the form of a known, soluble substrate. The MFC system operation and experimental methods are provided in detail in Chapter 2, while the CSPTs act is explained in Chapter 3. Analytical methods and reagent/solution chemistry move implemented in detail in section 3.3.

Shifts in the microbial ecology of the wastewater anolyte in each MFC is identified for PCA of datasets obtained using bio dry cell boxes. Wastewater anolyte sampling and BDC box preparation and analytical methods are conferred in section 3.2.5 and 3.3. Dataset pre-treatment, transformation and PCA methods are presented in Chapter 3. As discussed in Chapter 2, evaluation of electrochemical performance, such as current and power production are usually reported after normalisation to the active surface area of the transport media. The MFCs are identical with anodes having a surface area of 10 cm^3, cathodes are having a surface area of 10 cm^3 and the proton exchange membranes having a surface area of 7 cm^3. The effective electrode surface area (EESA) is equal to the cathode surface area, while the active membrane surface area (EMSA) is equal to the PEM surface area. The EESA and EMSA are both used to report current and densities for this study. The surface area is used to calculate the associated mass which is distinguished for each instance. From Chapter 2, the EESA and EMSA are assumed to bound the actual active surface area, providing minimum and maximum densities for electrical variables, respectively.

4.2.2 MFC Differentiation

The differentiation between the two MFCs are used in this study and held made through the catholyte composition in each MFC. The first MFC, MFC#1uses a phosphate-buffered, a saline solution with a constant supply of air bubbled through it. The dissolved oxygen (DO) is functioned as the electron acceptor at the cathode surface of MFC#1. MFC#2 uses a phosphate-buffered, ferricyanide solution. The ferricyanide serves as the electron acceptor at the cathode surface of MFC#2. The catholyte composition is discussed further in the MFC system description in Chapter 2.

4.2.3 CSPTs and BDC box Experimental Organization

Tables 4.1 and 4.2 are presented in Chapter 3 as Tables 3.3 and 3.4 and represent the experimental organization and case nomenclature used with the carbon source pulse tests (CSPTs) and Bio dry cell box during this study. They are presented here for ease of reference.

Table 4.1: ECO plate Case Organization for PCA

Case #	ECOplates Used	Comparison Significance
1.0	All	Entire ECO plate Set Comparison
2.0	2,3,4,5	Bulk Solution vs. Anode Scraping Samples
3.0	1,4	Inoculant vs Endpoint (Experiment #1)
4.0	1,6	Inoculants Comparison
5.0	6,7,8	Inoculant vs Steady States (Experiment #2)
6.0	7,8,9,10	Pre and Post Sodium Acetate Comparison (both MFCs)
7.0	9,10,11,12	Pre and Post Glucose Comparison (both MFCs)
8.0	11,12,13,14	Pre and Post Glycerol Comparison (both MFCs)
9.0	13,14,15,16	Pre and Post BSA* Comparison (both MFCs)

*Bovine Serum Albumin

Table 4.2: Carbon Source Pulse Test Substances

Substance	COD Mass per Pulse (mg)	Solution Preparation
Sodium Acetate	50 (1 pulse)	2.441g per 100 mL DI
	2.857 (3 pulses)	1 mL above solution to 16.5 mL DI
Glucose	2.857 (4 pulses)	0.089g per 100 mL DI
Glycerol	2.857 (4 pulses)	0.078g (0.0621 mL) per 100 mL DI
Bovine Serum Albumin (BSA)	2.857 (4 pulses)	0.068g per 100 mL DI

4.3 System Acclimation Period Comparison

Results from the MFC acclimation period stand divided into three sub-sections. The current and power production of each MFC are presented and discussed by first, allowing for an operational comparison. Results of the analysis of the wastewater anolyte, catholyte and top space gas are obtained from each MFC and compared next, with emphasis on a COD mass balance, ferricyanide concentration in the MFC#2 catholyte and methane appearance in the top space gas. Finally, shifts in microbial community ecology and activity during the acclimation period are evaluated and discussed.

4.3.1 Current and Power Production

Table 4.3 presents current and power production results for MFC#1 and MFC#2 during the acclimation period. The average coulombs per day are calculated by dividing the sum of the coulombs produced during the acclimation period by the duration of the acclimation period.

Table 4.3: Acclimation Period: Coulomb and Power Production

Electrical Variable	MFC#1	MFC#2
Average Coulombs per day	5.49	26.34
Maximum Power (mW)	0.066	0.347
Average Power (mW)	0.020	0.093

The average power is calculated similarly, while the maximum power is identified from the acclimation period data. For each MFC, the controlled voltage is 0.3V and the duration of the acclimation period is equal. Therefore, differences in coulomb production and power levels are solely due to differences in current. MFC#1 generated approximately 20% of the current and power that MFC#2 could be achieved. The lower current levels observed for MFC#1 are a direct result of the electron acceptor used. Oxygen is relatively insoluble, with a solubility of less than 7 mg/L under the operational conditions of this study.

This is equivalent to a maximum concentration of less than 0.22 mM. The measured DO concentration range in the MFC#1 catholyte during the acclimation period is 3.1-5.6 mg/L, which is equivalent to 0.10-0.18 mm. By contrast, ferricyanide concentrations in the MFC#2 catholyte are maintained at levels approaching 42 mL. In addition to a lower electron acceptor concentration, oxygen reduction kinetics are relatively slow as compared to that of ferricyanide. Therefore, the lower concentration and slower kinetics of oxygen-limited the operation of MFC#1 during the acclimation period. Using the average power calculated for each MFC and the EESA and EMSA, upper and lower estimates of the average power densities for each MFC are calculated. For MFC#1, the EESA resulted in a power density of 0.73 mW/m^2 while the EMSA resulted in a power density of 29.3 mW/m^2.

For MFC#2, the EESA results in a power density of 3.29 mW/m^2 while the EMSA results in a power density of 132.5 mW/m^2. Power densities are calculated with the EMSA which are comparable to power densities reported in the literature for similar systems run with glucose as a substrate (Oh and Logan, 2006). Current and power production is known to be limited when the surface area of the PEM is less than that of the electrodes (Regan and Logan, 2009).

4.3.2 Organic waste Anolyte, Catholyte and Head Space Gas Analyses

Table 4.4 presents COD which is the result during the acclimation period for the anolyte samples and headspace gas. The analytical procedures and equations are required for these calculations as presented in Chapter 2. The COD Feed represents the COD mass equivalence of the waste activated sludge feed to the MFCs. The carbon source pulses, anolyte samples, electricity generation and methane production COD mass equivalences are represented by COD CSP, COD_{Smpl}, COD_{Elec} and COD_{Gas}. From these terms and Equation 2.4, the mass of COD is accumulated in each MFC, and COD_{Acc} is calculated. For MFC#2, the ferricyanide reduction is converted to a COD mass equivalence for comparison to the electricity generation results of MFC#2. A 95% condense interval is also presented.

As it is expected from the current and power production results, the COD removal due to electricity production in MFC#2 is greater than that in MFC#1. All other terms in the COD balance are similar for both MFCs. These results represent the accumulated totals from approximately 35 samples.

Table 4.4: Acclimation Period: Cumulative Chemical Oxygen Demand Results

COD Variable	**MFC#1 (mg)**	**MFC#2 (mg)**

COD_{Feed}	11300 1990	11300 1990
COD_{CSP}	0 0	0 0
COD_{Smpl}	1976 1193	2399 1400
COD_{Elec}	35.0 1.2	168.1 31.5
COD_{Gas}	83.0 115.0	86.0 85.8
COD_{Acc}(Equation 2.4)	9210 3300	8660 3510
COD_{Ferri}		149.2 303.7

Several points are evident from the data in Table 4.4.

- the COD withdrawn from both MFCs is approximately 20% of the COD fed to both MFCs
- the removal of COD due to electricity production is approximately 4 times higher in MFC#2
- the removal of COD in the MFCs is primarily due to the removal of the COD through sampling
- COD associated with methane production is comparable to the COD equivalence of electricity production
- Both MFCs appeared to be accumulating a majority of the COD fed
- The change in the ferricyanide concentration in the catholyte is in agreement with that expected on the basis of the current generation in MFC#2, though the 95% condense interval is much greater.

The 95% condense intervals are associated with the results which represent the accumulated error associated with the multiple sample analysis. Coulombic efficiencies are not calculated due to the large condense intervals. The pH of the feed and anolyte samples is also determined during the acclimation period. The pH of the feed ranged from 7.6 to 7.9, while the anolyte samples are ranged from 6.4 to 7.2 and 6.9 to 7.5 for MFC#1

and MFC#2, respectively. Both MFCs show lower pH values than the waste activated sludge feed. This is attributed to the accumulation of volatile fatty acids (VFAs) in the anolyte during any fermentation processes which are likely active during MFC operation. The lower pH values of the MFC#1 anolyte suggested a greater accumulation of VFAs as a result of more fermentation processes being active. With lower electricity production, active bacteria in MFC#1 are more likely involved in fermentation processes than bacteria in MFC#2.

Figure 4.1 presents the acclimation period nitrogen concentrations for the feed and both MFCs along with error bars that describe 95% condense levels. The analytical procedures required to obtain these results are presented in Chapter 2.There are a few key conclusions from Figure 4.1.

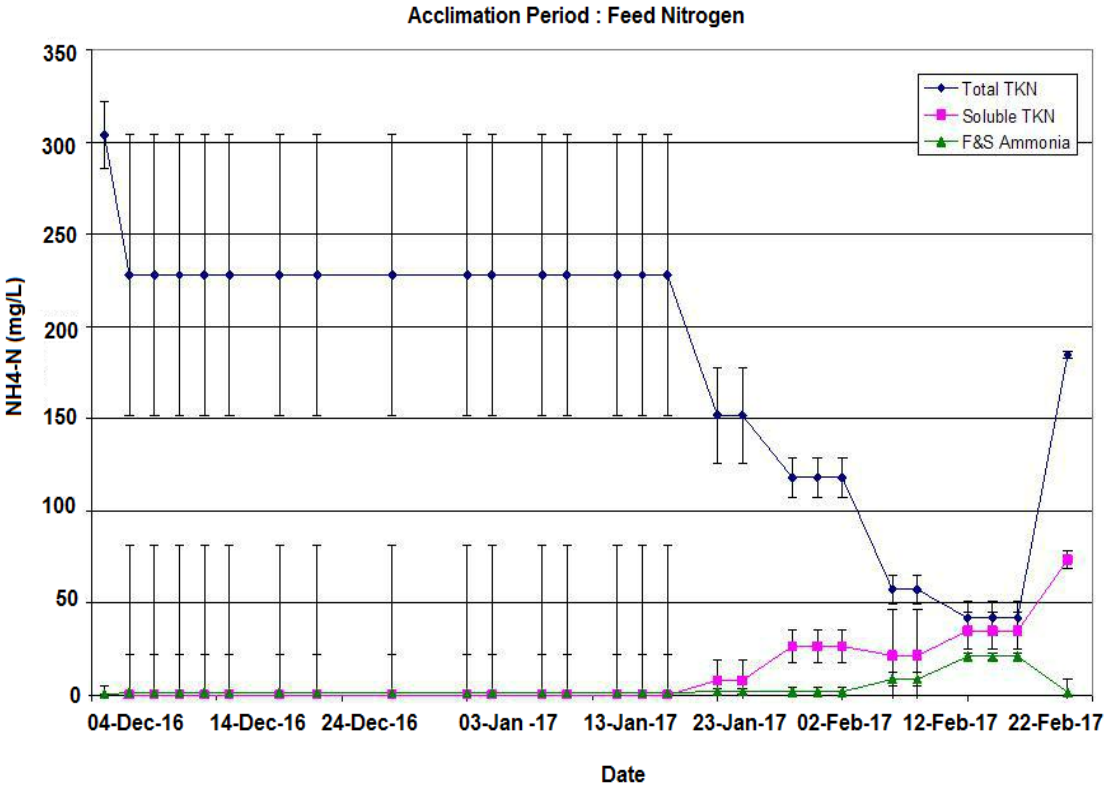

Figure 4.1: Nitrogen Content Results from the Acclimation Period

- Feed waste activated sludge NH_4-N content is present in the particulate matter for most of the acclimation period

- NH_4-N content in MFC#1 samples is less than 50 mg/L throughout the acclimation period
- NH_4-N content in MFC#2 samples is 50-100 mg/L throughout the acclimation period
- NH_4-N content in both MFC anolyte samples is primarily composed of free and saline ammonia (FSA)

Both MFCs behave similarly in concerning nitrogen analysis. While nitrogen species in the feed are primarily particulate, the steady event of soluble, primarily FSA, nitrogen from both MFCs suggests that these particulate nitrogen species moved solubilised and converted to ammonia. With feed nitrogen levels significantly prominent than the samples, nitrogen accumulation in the MFCs is apparent.

4.3.3 Bio dry cell technology

A bio dry cell device has its operation analogous to normal Microbial fuel cells (MFCs) and Biofuel cells (BFCs). The transformation of the ecological data are obtained from the BDC box, principal component analysis (PCA) is performed. Figure 4.2 shows the functional layers of the BDC box.

The purpose of this case and set of sub-cases is to compare the initial microbial community in the waste activated sludge to that in the anolytes of both bio dry cell-based MFCs following an acclimation period of 77 days. It moved hypothesised that the microbial communities of the MFCs would show significant differentiation from that of the first waste activated sludge, identifying the existence of these shifts during MFC start-up and acclimation. However, no hypothesis is held suggested as to how MFC#1 and MFC#2 may differ.

The air cathode side uses a stainless-steel mesh, granular activated carbon and anode side uses a thin aluminium sheet. It is conducted for four patterns of experiments

in this work. First, air cathode side copper thin-film sheet is fixed with by using a stainless-steel nut bolts and in anode side, carbon fibre cloth is fastened with by using a galvanised nut bolt.

Second, anode side thin aluminium mesh substrate set is a mesh by using a galvanised nut bolt. Third, air cathode side stainless steel mesh is fixed with by using a stainless steel nut bolts, and an anode side, carbon fibre cloth is set by using a galvanised nut bolts.

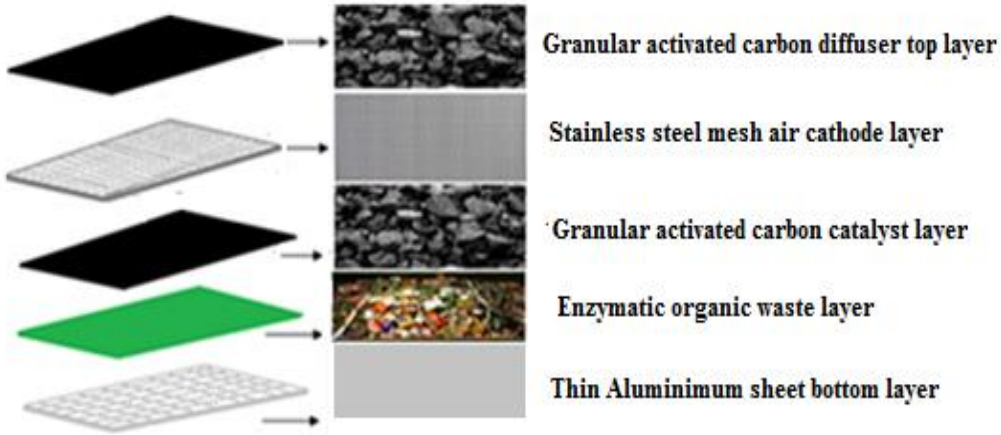

Fig.4.2 Schematic diagram of the individual layers in the device

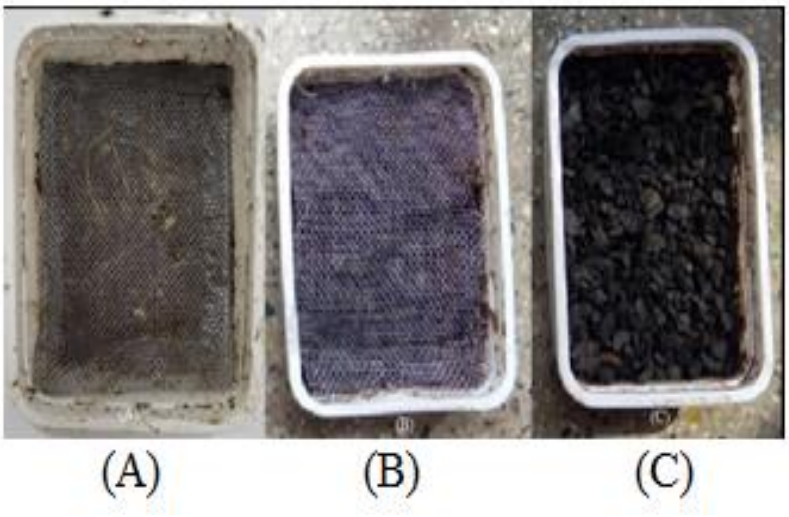

Fig. 4.3 (A) Anode (B) Cathode (C) Granular Activated Carbon

Fourth, anode side thin aluminium sheet substrate is fixed the sheet by using a galvanised nut bolts. At first, organic waste is managed in a domestic size pedal-operated

dustbin from the kitchen, which is continued and maintained for 30-45 days for the enzymatic process. Then, 200g of dry organic waste and 50g of wet organic waste to make the low-moisture electrolyte is used to accomplish the task of this present work. From the table 1, thin Aluminium sheet of 100 x 150 x 0.2 mm thickness as an anode, stainless steel mesh of 100 x 150 x 0.2 mm thickness as a cathode are selected for current collector [21-22] and granular activated carbon (GAC) of 4-7 mm diameter is equally utilized as a catalyst and diffuser layer. Those layers stand illustrated in Fig. 4.2 and 4.3.

4.4 Response to kitchen waste Dosing

Table 4.5 presents the current and power production results for Bio dry cell-based MFC#1 and MFC#2 during sodium acetate dosing.MFC#1 is operated at approximately 25% to 30% of MFC#2 levels for all three electrical variables and is presented in Table 4.5. Similar to the performance comparison during the acclimation period, the lower current levels are observed for MFC#1 and a direct result of the electron acceptor is used. The measured DO concentration range in the MFC#1 catholyte during sodium acetate dosing is 4.3-6.9 mg/L, which is equivalent to 0.13-0.22 mL.

Table 4.5: Sodium Acetate Dosing: Coulomb and Power Production

Electrical Variable	**MFC#1**	**MFC#2**
Coulombs per day	7.12	27.60
Maximum Power (mW)	0.050	0.162
Average Power (mW)	0.024	0.095

Ferricyanide concentrations in the MFC#2 catholyte are held maintained at levels approaching 40 mL. A lower electron acceptor concentration and slower electron acceptor kinetics are limited MFC#1 operation during kitchen waste dosing.

4.4.1 Current and Power Production

Using the average power calculated for each MFC and the EESA and EMSA, upper and lower estimates of the average power densities for each MFC obtained calculated. For MFC#1, the EESA resulted in a power density of 0.87 mW/m^2 while the EMSA resulted in a power. The power density of 34.9 mW/m^2. For MFC#2, the EESA resulted in a power density of 3.37 mW/m^2. While the EMSA resulted in a power density of 135.9 mW/m^2.

Concerning current and power production, kitchen waste dosing appeared to increase the production only slightly when compared to results from the acclimation period. Extraordinary energy values are found to be lower, while average power values are higher. The current measurements carried out during this study are on the order of 0.01mA. This resulted in a system with a strong sensitivity to variations in current.

Current responses are immediately observed following kitchen waste. These responses are particularly profound in MFC#1, due to the lower operational current as compared to MFC#2. Figure 4.4 illustrates an increase in the MFC#1 current of 0.06mA over approximately 1.5 min and in response to sodium acetate dosing, which is indicated with the red line. Responses of this sensitivity raise the question as to the possibility of future application of MFC-like devices as sensors for readily biodegradable COD.

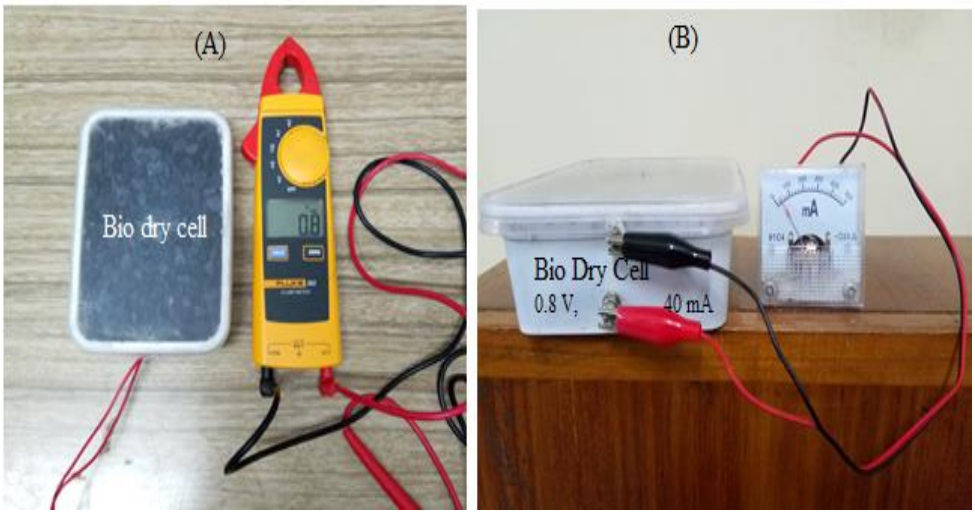

Fig. 4.4: Detection of the electricity in a bio dry cell

4.4.2 Organic waste Anolyte, Catholyte and Head Space Gas Analyses

Table 4.6 presents the COD results for the anolyte samples and headspace gas during sodium acetate dosing. The analytical procedures and calculations are presented in Chapter 2. The COD balance results during sodium acetate dosing are similar to those for the acclimation period. COD removal due to electricity production in MFC#2 is prominent than that in MFC#1.

Table 4.6: Sodium Acetate Dosing: Cumulative Chemical Oxygen Demand Results

COD Variable	**MFC#1 (mg)**	**MFC#2 (mg)**
COD_{Feed}	2172 244	2172 244
COD_{CSP}	58.6 2.9	58.6 2.9
COD_{Sample}	365 195	660 189
COD_{Elec}	10.6 0.4	41.2 7.7
COD_{Gas}	13.1 44.2	17.6 17.9
COD_{Acc} (from Equation 2.4)	1841 487	1512 462
COD_{Ferri}		11.1 280.7

Also, the COD removal due to the sampling of MFC#2 anolyte is noticeably elevated than that of MFC#1. All other terms in the COD balance are similar for both MFCs.

The ferricyanide catholyte results for MFC#2 are comparable to the electricity results. These results represent the accumulated totals from approximately nine samples. The 95% confidence intervals are associated with the results represents the accumulated error associated with the multiple sample analysis. Coulombic efficiencies are obtained not determined due to the large confidence intervals. The pH regarding the feed ranged from 7.6 to 7.8, while the anolyte samples ranged from 6.6 to 7.1 and 6.9 to 7.4 for MFC#1 and MFC#2, respectively.

These results are nearly identical to those observed during the acclimation period. Lower observed pH values in the MFC anolytes as compared to the waste activated sludge feed are associated with the accumulation of volatile fatty acids (VFAs) in the anolyte during fermentation processes.

Figure 4.5: Bio Dry Cell Box Current Response to Kitchen waste dose

Figure 4.4 presents the electricity detection results for the feed and both MFCs during kitchen waste dosing. Both MFCs behave similarly to each other with respect to nitrogen content results. The nitrogen content results during sodium acetate dosing are similar to those observed during the acclimation period. The total nitrogen levels in the waste activated sludge feed are approximately twice those observed in the anolyte samples, indicating further particulate nitrogen accumulation. The prevalence of FSA in the anolyte samples indicate that particulate nitrogen species are solubilised during MFC operation.

4.5 Microbial Ecology

The purpose of this case and set of sub-cases is to compare the anolyte samples drawn from both MFCs, before and after kitchen mixed waste dosing. It is hypothesized that the

microbial communities of the MFCs would have converging shift responses, due to the natural substrate dosing. Because mixed organic waste is classified as a protein, it held hypothesized that the initial microbial community activity shift would be due to amine and amino acid utilisation.

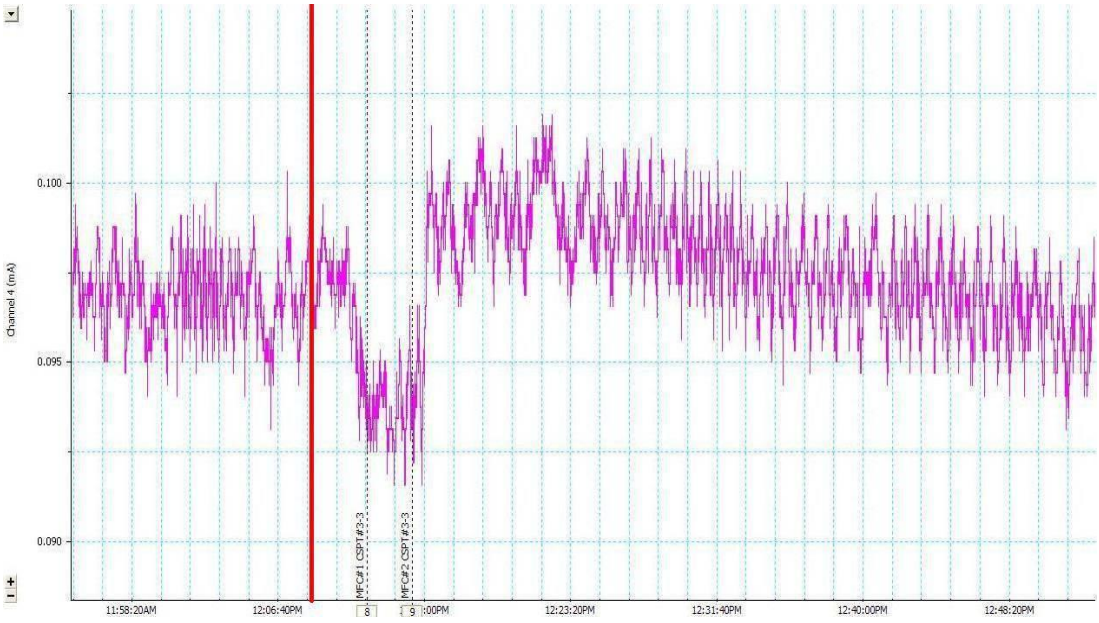

Figure 4.6: MFC#1 Current Response to mixed kitchen waste Pulse

Zak et al. (1994) defined functional diversity as the numbers, types, activities, and rates at which a suite of substrates is applied by the bacterial inhabitants. Each bio dry cell box is evaluated for the functional diversity indices: substrate diversity, substrate richness and substrate evenness. Definitions of these indices and their analytical methods remain presented in Chapter 3.

Fig. 4.7: Pedal-operated dustbin for the collection of kitchen waste

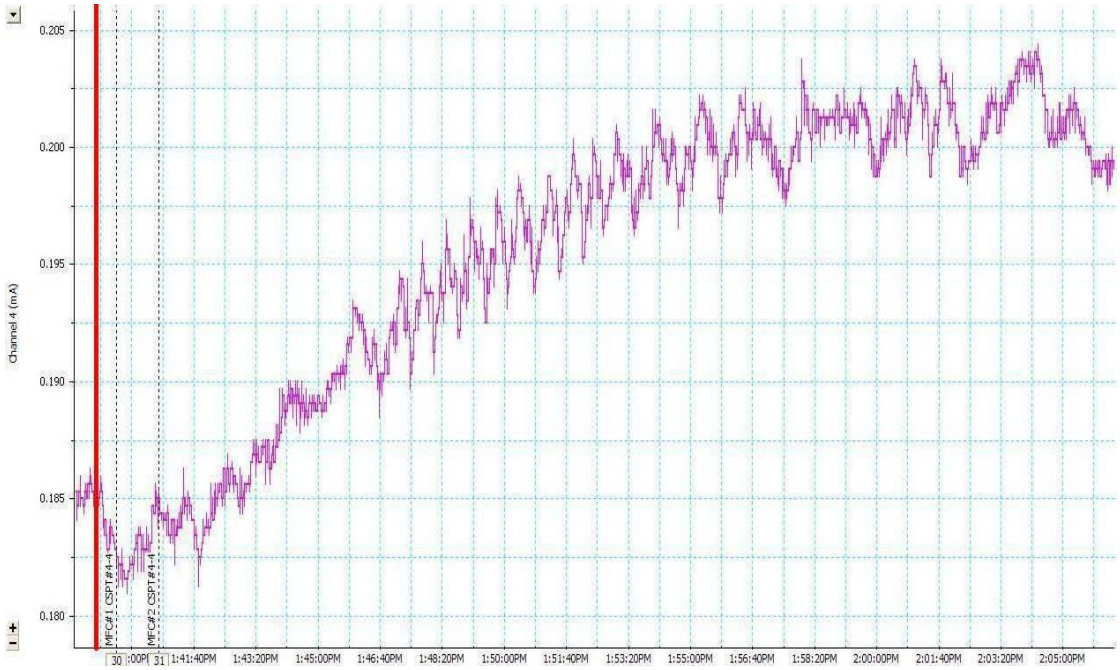

Figure 4.8: MFC#2 Current Response to mixed kitchen waste Pulse

4.6 Functional Diversity of Bio Dry Cell

Figure 4.9 contains normalized voltage results from Bio dry cell box #1 to #12 and #13 to #24, prepared from bio dry cell box #1 and the initial kitchen waste activated sludge.

Figure 4.10 contains normalized results from Bio dry cell box #1 to #48 prepared from bio dry cell box #2 and the initial kitchen waste is activated. From Figures 4.9 and 4.10, the functional diversity is compared for kitchen waste anolyte samples taken before, between, and after the carbon source pulse tests (CSPTs).

Figure 4.9: Bio Dry Cell Box #1 Voltage response

Figure 4.10: Bio Dry Cell Box #2 Current response

In addition, points at the beginning and end of the acclimation period are also compared. From the results, it appeared that both MFCs behaved in the same manner throughout the experiment, the test specimen (well-sandwiched layer of the bio dry cell) is placed in the brick-shaped microchamber. The addition of the carbon sources during the CSPTs has

little effect on the substrate evenness. The substrate diversity is dropped to 85% to 90% of the substrate diversity of the initial waste activated sludge after the first three CSPTs but increased to about 92% of the substrate diversity of the initial waste activated sludge following bovine serum albumin (BSA) addition.

The substrate richness showed a similar trend to that of the substrate diversity but magnified such that values are as low as 73% of the substrate richness of the initial waste activated sludge. A typical bio dry cell box functional diversity index is as shown in Figure 4.11.

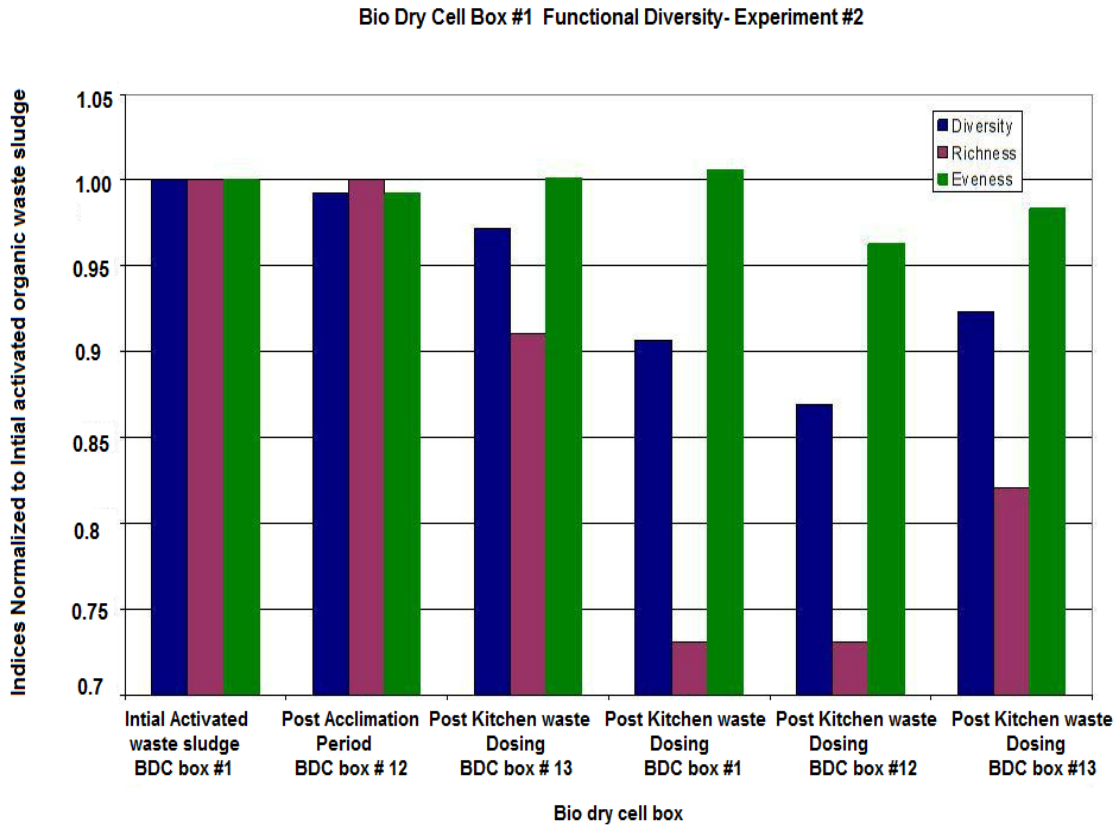

Figure. 4.11: A typical bio dry cell box Functional Diversity Indices for Experiment #2

The bio-voltaic conversion performance evaluation of the cell is carried out under at real-time environmental ambient condition by measurement of the electrical parameters. The experimental setup along with the measurement instruments is shown in Figures 4.9 and 4.10. The no-load terminal voltage/open-circuit voltage (OCV) response of the bio-voltaic

cell is shown in Figure4.9. After measuring instrument selector knob placed at voltage range, OCV sharply increases to 19.2 V within a fraction of a second. The short-circuit current (SCC) density response of the bio dry cell is shown in Figure.4.10. After measuring instrument selector knob placed at the current range, SCC sharply increased to and stabilized at 167 mA within a fraction of a second. In repeated experiments, the maximum OCV is observed in individual bio dry cell box to reach from 600 to 900 mV. The discharge current density with a direct short circuit path junction increased from 10 to 110mA. Combined voltage and the current characteristic curve of a typical bio dry cell are as shown in Figure.4.12.

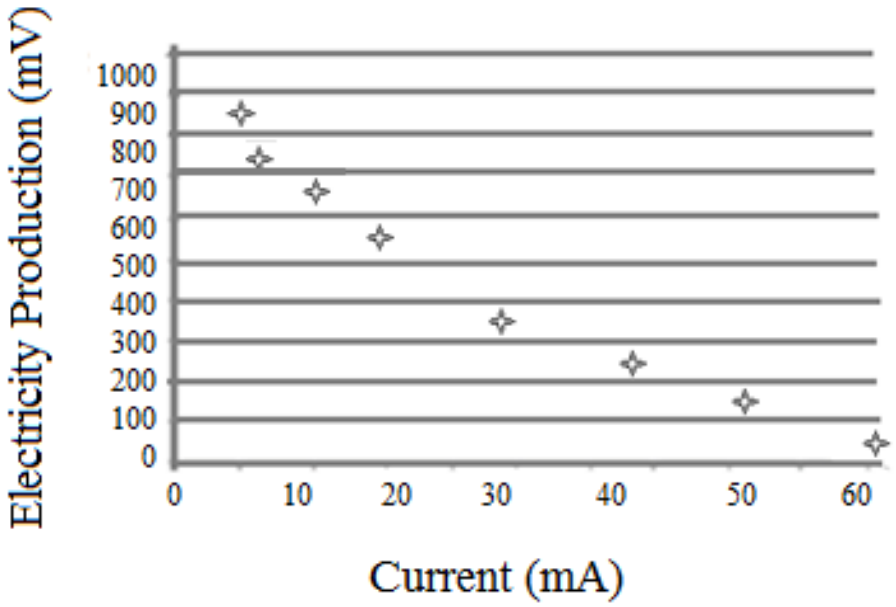

Figure 4.12: Bio Dry Cell Box #1 and #2 Characteristic curve and electricity production measured as a function of voltage in the millivolt (mV) and current in milliampere (mA)

This is further support for the existence of and needs to accommodate an acclimation period during MFC system commences up. The addition of specific carbon sources during operation decreased the functional diversity of the microbial community in the anolyte slightly, though the addition of BSA appeared to negate some of the diminished functional diversity. The regular importance of BSA on microbial community

activity may have been partially responsible for the increased functional diversity. This Electrochemical properties or particular nutrients or structural components could have allowed greater diversity in the microbial community activity. Finally, the particular MFC and catholyte choice do not affect the trends in functional differences, indicating that these system variables do not influence the diversity of the microbial inhabitant's activity.

4.7 Conclusions

The surface area of the PEM as compared to the surface area of the electrodes is known to have a significant effect on electricity production in MFCs (Oh and Logan, 2006). Due to the significantly smaller PEM surface area when compared to the electrodes used in this study, uncertainty in the actual active surface area arose. Aforementioned works are made it difficult to report with confidence, power densities for comparison to other studies. From the acclimation period, average power productions of 0.020 mW and 0.093 mW held observed for BDC #1 and BDC #2, respectively. When it is normalised by the active membrane surface area (EMSA) of 7 cm^2, power densities of 29.3 mW/m^2 and 139.5 mW/m^2 continued recognised. These values are comparable to the amounts reported in the literature (Oh and Logan, 2006).

Approximately 79% of the COD fed to the MFCs during the acclimation period is calculated to accumulate within the MFCs, primarily as particulate. 96% of the COD removed from the MFCs is found in the anolyte samples, while the remaining 4% is observed in electricity and methane production. In addition to COD accumulation, nitrogen is calculated to accumulate in the MFCs as well. BDC #1 and BDC #2 are found to diverge in microbial community activity after the acclimation period. The only exception is carboxylic acid utilisation, which is continued generally unchanged after the acclimation period. Those obtained above are associated with a continued anaerobic environment and fermentative processes resulting in the same volatile fatty acids (VFAs)

being present throughout the acclimation period. During kitchen waste sludge dosing, average power productions of 0.024 mW and 0.095 mW are observed for bio dry cell box #1 and bio dry cell box #2, respectively. Specific values are nearly identical to those recognised during the acclimation period. Current production responses to kitchen waste sludge dosing are found to be immediate and significantly larger than acknowledgements to the other carbon sources. Approximately 75% of the COD fed to the MFCs during sodium acetate dosing is calculated to accumulate within the MFCs, primarily as particulate. 92% of the COD removed from the MFCs is found in the anolyte samples, while the remaining 8% is held observed in electricity and methane production. In addition to COD accumulation, nitrogen is calculated to accumulate in the MFCs as well. The microbial community activity of BDC #1 only responded to sodium acetate dosing in the carboxylic acid utilisation, while BDC #2 responded concerning all the carbon source classifications.

The microbial community activity in BDC #1 appeared to be converging to a similar point as the community in BDC #2 after lagging during the acclimation period. During kitchen waste dosing, average power productions of 0.027 mW and 0.096 mW are held observed for BDC #1 and BDC#2, respectively. These values are nearly identical to those witnessed during the acclimation period and sodium acetate dosing. Current production responses to glucose dosing are found to be gradual with a magnitude several times lower than the response to sodium acetate. Approximately 71% of the COD is fed to the MFCs during glucose dosing is calculated to accumulate within the MFCs, primarily as particulate. 92% of the COD is removed from the MFCs which is found in the anolyte samples, while the remaining 8% is held found in electricity and methane production. In addition to COD accumulation, nitrogen is calculated to accumulate in the MFCs as well. The results of glucose dosing showed further evidence that the microbial

community activity of BDC#1 converges to a similar point as the community in BDC#2 after lagging during the previous operation. The response of the microbial community activity in BDC#1 to the glucose dosing is more pronounced than the response observed for BDC#2. During mixed kitchen waste dosing, average power productions of 0.032 mW and 0.098 mW are held observed for BDC#1 and BDC#2, respectively. Absolute values are nearly identical to those recognised previously. No current production responses to glycerol dosing are continuously identified. Aforementioned are held attributed to a lower biodegradability or competing interactions with volatile fatty acids in the anolyte. Approximately 67% of the COD fed to the MFCs during glycerol dosing is calculated to accumulate within the MFCs, primarily as particulate. 94% of the COD is removed from the MFCs is found in the anolyte samples, while the remaining 6% is held recovered in electricity and methane production.

During bovine serum albumin (BSA) dosing, average power productions of 0.062 mW and 0.122 mW are held observed for BDC#1 and BDC#2, respectively. These values are significantly prominent than those witnessed during the previous operation. Current production responses to BSA dosing are similar to the responses seen with glucose dosing. Two hypotheses are proposed to address the higher current levels following BSA dosing. Increased current may have been due to interactions of a particular nutrient or structural component on the power-producing bacteria activity. The extended course may also have been due to electrochemical properties of BSA allowing the molecule to act as an electron mediator between current producing bacteria and the anode surface. Approximately 20% of the COD fed to the MFCs during BSA dosing is calculated to accumulate within the MFCs, primarily as particulate. 97% of the COD is removed from the MFCs is found in the anolyte samples, while the remaining 3% is held found in electricity and methane production. The significant increase in COD removal due to

anolyte sampling is attributed to higher concentrations of COD in the anolyte samples after a manual agitation of the anolytes on April 19th, 2017. In addition to COD accumulation, nitrogen is calculated to accumulate in the MFCs as well. Nitrogen as particulate is seen to rise significantly following the manual agitation of the anolytes on April 19th, 2007, confirming earlier observations of nitrogen accumulation in the BDC based MFCs. BDC#2 showed almost no response in microbial community activity following BSA dosing. In contrast, BDC#1 showed significant shifts in a microbial community activity. BSA enables BDC#1 to approach the microbial community activity of BDC#2 except in amine and amino acid utilisation. This highlighted the differing responses between the two BDC based MFCS, which may remain attributed to the two hypotheses proposed earlier. Each hypothesized activity may have been prevalent in one MFC and not the other.

The functional diversity of the microbial communities of each bio dry cell box are calculated and compared to identify any further ecological trends. The indices used to evaluate the functional diversity are the substrate diversity, substrate evenness and substrate richness. All three indices are observed to decrease during the acclimation period of the MFC operation. However, given enough acclimation time, the functional diversity of the microbial communities in the wastewater anolyte are found to approach the same levels as those in the initial waste activated sludge. The addition of several carbon sources during MFC operation has little effect on the substrate evenness but resulted in drops of approximately 15% in substrate diversity as compared to the initial waste activated sludge. The only exception is the addition of bovine serum albumin, which is observed to increase the substrate diversity to approximately 92% of the initial waste activated sludge values. Substrate richness is found to behave in the same manner

as substrate diversity. Finally, the functional diversity trends are observed to be independent of the specific MFC and catholyte used.