Chapter 5

Conclusions, Contributions and Future work

5.1 Conclusion

In this thesis, Bio dry cells, Soil Microbial Fuel cells, and Bio-Electric Air Purifiers are designed and developed is to present a simple innovative construction whose main characteristic comprises the organic wastes and sustainable electrodes to provide reliable power to electrical load under direct energy conversion system. Several conclusions are drawn from this research work and continue presented in this section. Microbial fuel cell (MFC) cell design and operation are addressed first, followed by a summary of the anolyte wastewater quality observed during this study. The choice of catholyte, organic waste is presented with a discussion of the constraints involved with each of the catholyte used in this study. Electricity production impacts of the carbon source pulse tests remain presented and compared using bio dry cells. Finally, the use of data transformations and principal component analysis (PCA) on biological data and the microbial ecology results from this study hold summarised.

5.2 Thesis Contributions

Consistent power production levels of 0.05 mW and 0.20 mW are attained from MFCs operating with a dissolved oxygen (DO) and ferricyanide catholyte, respectively. Power densities are difficult to determine due to uncertainty in the real useful surface area. The power densities are recorded relative to the cathode surface area, also called the effective electrode surface area (EESA) and the PEM surface area, also called the active membrane surface area (EMSA). Power densities calculated with the EMSA remained consistently observed at 50 mW/m^2 and 170 mW/m^2 for MFC#1 and MFC#2, respectively. These are in agreement with values reported in the literature (Oh and Logan, 2006).

5.2.1 Anolyte Wastewater Quality

A COD mass balance is held performed for both MFCs. The COD removal due to electricity generation and measured methane production is almost negligible relative to COD loading, with the following approximate values expressed as percentages of the total COD feed:

- COD removal due to sampling - 23.5%
- COD removal due to electricity production - 1.0%
- COD removal due to methane O^-gas - 0.5%
- calculated COD accumulation in the MFCs - 75%
- measured COD accumulation in the MFCs - 30%

Considering the low percentage of COD removal due to electricity production, the COD mass balance results of both MFCs are nearly identical. Due to the particulate nature of the COD added to the MFCs, solubilization, and substrate utilization rates likely limited the electricity production. Design impacts, such as the relatively small size of the proton exchange membrane, also limited the electricity production in both MFCs. COD that passed through the MFCs continued measured in the anolyte samples drawn from the MFCs. The lack of closure in the COD mass balance credits to unmeasured methane gas, which would have resulted in a lower measured COD accumulation than what is anticipated. The seals of both MFCs are held suspected of allowing constant, low flow gas leakage. During the second experiment of approximately six months, only 25 mL/day of methane gas leakage from each MFC would be required to account for the discrepancy in COD accumulation values.

Nitrogen results based on the TKN analysis showed particulate nitrogen accumulation in the MFCs, supporting the observation of COD accumulation. The prevalence of nitrogen as free and saline ammonia (FSA) in the anolyte samples indicates that some of the particulate nitrogen fed to the MFCs continued solubilized. Nitrogen analyses provided insight into protein hydrolysis processes active in the waste activated sludge in the anode chambers of the MFCs. TKN analyses required a large number of resources and time. Future studies should invest the time and resources into TKN analyses when protein-based investigations remain challenged. The pH of the anolytes is measured throughout the study. The pH of the feed waste activated sludge ranged from 7.4 to 8.2, while the anolytes ranged from 6.4 to 7.6. Anolyte pH is always lower than the feed waste activated sludge. That credit to the accumulation of volatile fatty acids (VFAs) from fermentation processes active in the anolyte. Other literature has suggested that the acclimation time for MFCs operating on a wastewater anolyte could be decreased with acid cation/anaerobic pre-treatment (Rodrigo et al., 2007).

5.2.2 Dissolved Oxygen (DO) versus Ferricyanide as the Electron Acceptor (EA)

Two electron acceptors (EAs) signify are applied in this study. The first MFC, MFC#1, operated with dissolved oxygen (DO) catholyte, while the second MFC, MFC#2, performed with a ferricyanide catholyte. MFC#2 operated at electricity production rates of 2-5 times higher than those observed for MFC#1. COD removal rates are comparable, considering the minimal nature that electricity generation had on COD removal. The increased performance in the ferricyanide catholyte held connected to increased electron acceptor reaction rates. Those above are due to the relatively high ferricyanide concentrations as compared to the DO concentrations. Ferricyanide concentrations are maintained at approximately 40mL, while DO collections are below the maximum threshold of 0.22mL as permitted by solubility limitations.While ferricyanide increases MFC performance, it doesn't constitute a viable catholyte option for future MFC scale-up. Scale-up designs would need to operate with large amounts of ferricyanide, which is inadvisable from both a health and safety and design budget stand-point. Oxygen is a safer and more readily available alternative, but it means limited by solubility, which limits the overall reaction rate. Other studies have used an air cathode system, exploiting the relatively high concentration of oxygen in the air. Mass transfer of oxygen to the cathode under liquid phase conditions continues to be a design challenge.

5.2.3 Carbon Source Pulse Tests (CSPTs)

The dosing levels on a COD mass basis are negligible in comparison to the COD mass equivalence of the feed waste activated sludge. Sodium acetate, glucose and bovine serum albumin (BSA) showed current production responses following dosing, with sodium acetate showing the most substantial effects. Only BSA showed a significant, long-term influence on power production, increasing it by 100% and 25% for MFC#1 and MFC#2, respectively. Aforementioned are held attributed to either or both of the following factors:

- BSA is readily hydrolyzed and provided a nutrient or structural component that increases the activity of electricity-producing microorganisms.
- BSA acts as an electron mediator, moving electrons from active bacteria in the anolyte to the anode surface.

The effects on the organic waste and wastewater variables and full-scale COD mass balance are negligible due to the low COD mass equivalence of the CSPTs. When compared to each other, sodium acetate, glucose and BSA all are displayed similar amounts of COD mass equivalence in the current response to dosing.

The COD removal due to the electricity production of the reactions is typically less than 0.5% of the CSPT COD mass equivalence introduced in the doses. Glycerol dosing doesn’t show an electrical response. The aforementioned are not indicating that glycerol obtained not appropriate, but any current is resulting from glycerol utilization is concealed by the background electricity production from waste activated sludge components in the anolytes.

5.2.4 Data Transformations and Principal Component Analysis (PCA) of Ecological Data

Principal component analysis (PCA) is utilized to perform community-level physiological pro ling (CLPP) of the microbial communities in the MFC anolytes. Several statistical constraints on the datasets, including homoscedasticity, dataset normality and linear correlation between variables, must be optimized before PCA is implemented. Taylor's power law and natural logarithm data transform held evaluated against untransformed data, and both transforms are found to improve the dataset compliance to the statistical constraints. The natural logarithm transformed datasets are worked for PCA in this study because of increased analytical constraint compliance in earlier case studies and consistency between all cases studied.

5.2.5 Microbial Ecology in MFCs

Results from the CLPP performed via PCA on the transformed bio dry cell boxes datasets:

- Microbial community activity differed between samples obtained from the MFCs during two separate experiments, which ran for 28 days and 182 days, respectively.
- Differences in the microbial community activity are observed after acclimation periods of 28 days and 77 days.
- Anode and anolyte samples from the same MFC at the same approximate time are similar with respect to the microbial community profile, waste activated sludge samples showed very similar microbial community profiles.
- The microbial community profile of MFC#1 is appeared to lag behind the microbial community prole observed from MFC#2, which may be related to the lower operational state of MFC#1

- Dosing of sodium acetate and glucose appeared in the organic waste to result in a convergence of the microbial community profiles of the two MFCs, indicating a similar response in each MFC.
- Glycerol dosing and MFC acclimation periods appeared to result in a divergence of the microbial community proles of the two MFCs, indicating distinct responses in each MFC. BSA dosing has resulted in little to no effect on the microbial community profiles in the two MFCs.

The acclimation period is initially decreased functional diversity in the MFCs, though longer periods saw functional diversity levels return to those observed in the waste activated sludge samples carbon source dosing decreased functional diversity levels in the MFCs, through BSA addition resulted in a partial return to waste activated sludge levels, indicating that BSA is increasing the microbial communities' capability to utilize a greater range of carbon sources.

5.2.6 Prototype development

New idea based microbial fuel cell prototypes as shown in figures 5.2 to 5.6 is a grass-root innovation of IIT(BHU), Varanasi and CSIR-National Aerospace Laboratories; Bangalore has introduced a new game-changing technology to managing the organic waste and simultaneously generates electricity at household level for creating value, especially waste to wealth by using bin type and throwing garbage in the bin that does not mean that it is the end. The future and next-generation MFCs using cow dung and hollow activated carbon are developed and shown in figures drawn below. The introduced practically proven Green Think Box is the most promising emerging Indian technology is a local solution for the global application regarding carbon footprint.

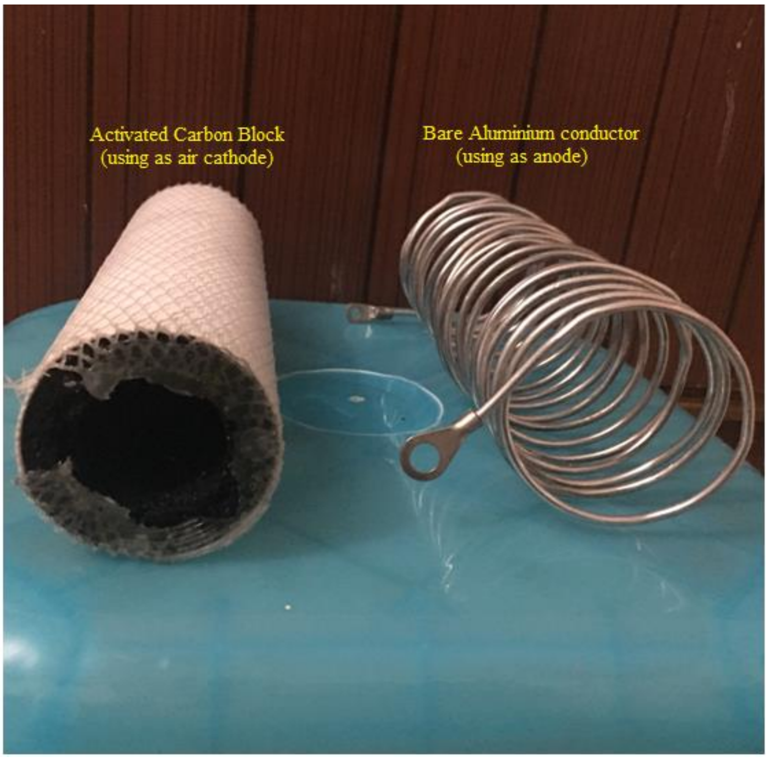

Figure 5.1: Future Microbial Fuel Cell Components

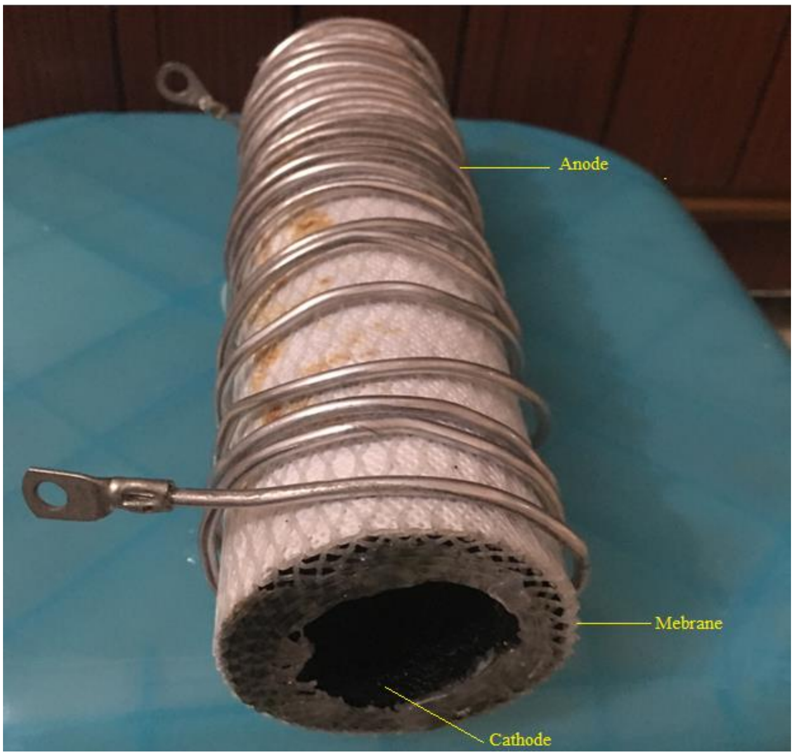

Figure 5.2: Next-generation Microbial Fuel Cell

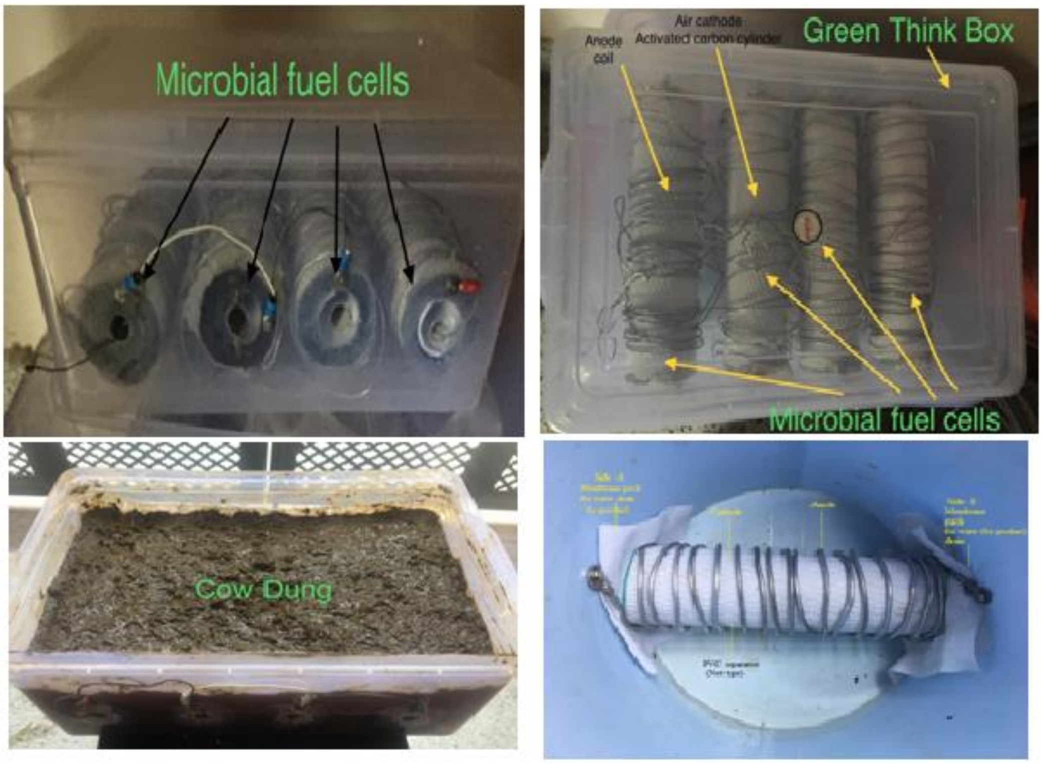

Figure 5.3: Microbial Fuel Cell assembly in a chamber

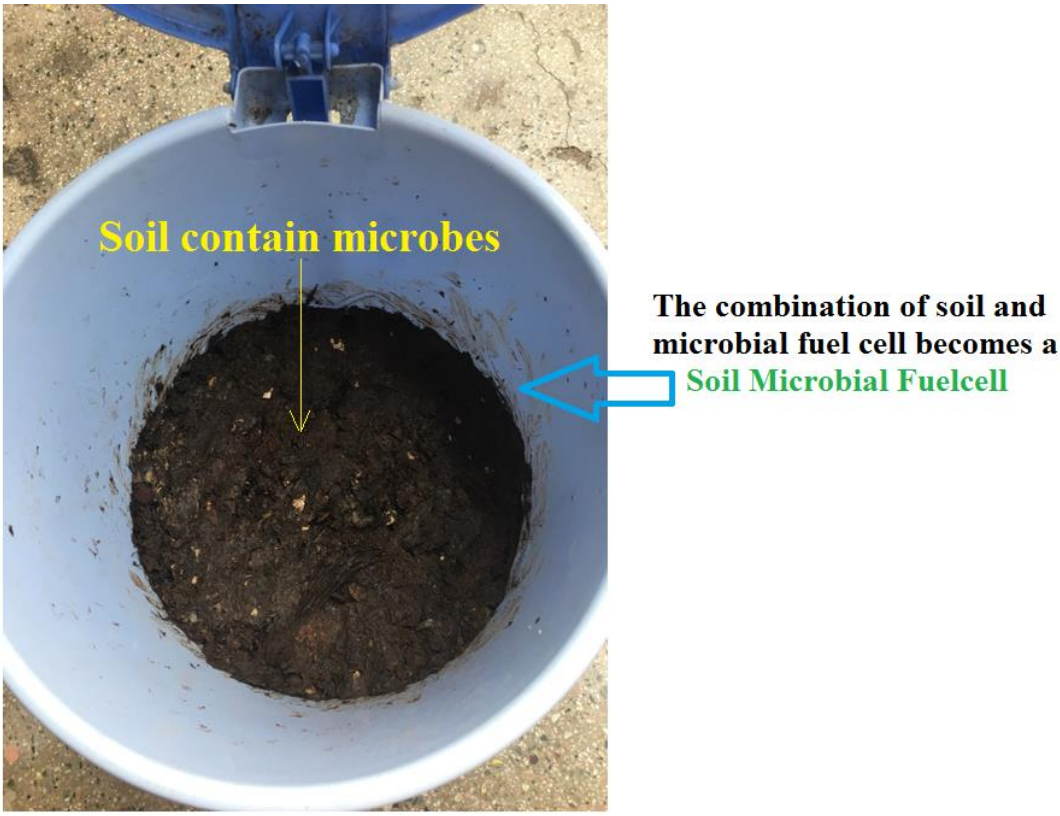

Figure 5.4: Soil microbial Fuel cell (SMF)

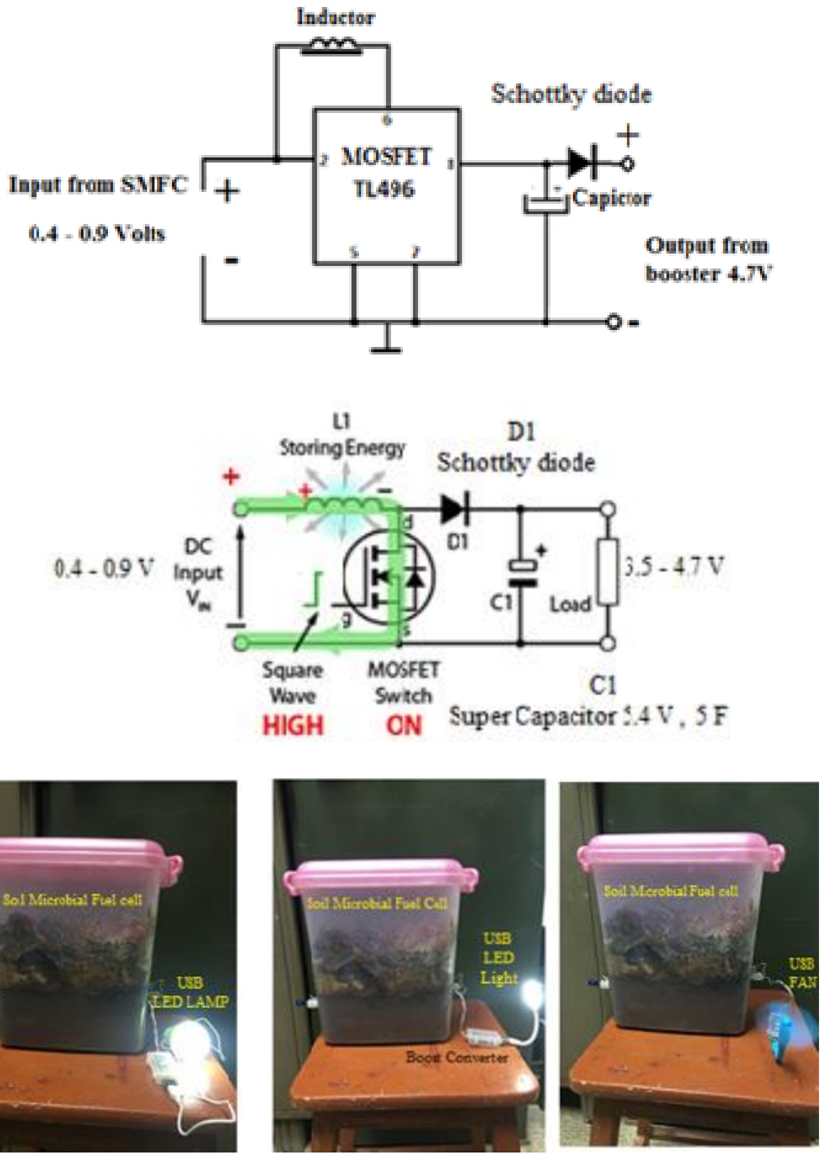

Figure 5.5: DC Booster Circuit

Figure 5.6: Emergency light using standalone type MFC

5.2.7 Harit Urja Marg Deepak

The development of Hybrid Bio-Solar Street Light System for rural areas where conventional electrical supply is not available as shown in figure 5.7. The whole purpose of this grass-root innovation is the most hopeful solution to illuminate the remote areas using green energy automatically according to dawn and dusk.

Figure 5.7: Hybrid Bio-Solar Street Light System

5.2.8 Bio-electric purifier

To design and development of Green Think Leaf and Green Think box as shown in figure 5.8 is a unique self-powered portable air pollution control equipment serves as an alternative solution to reduce air pollution at indoor or outdoor and harvesting electricity simultaneously.

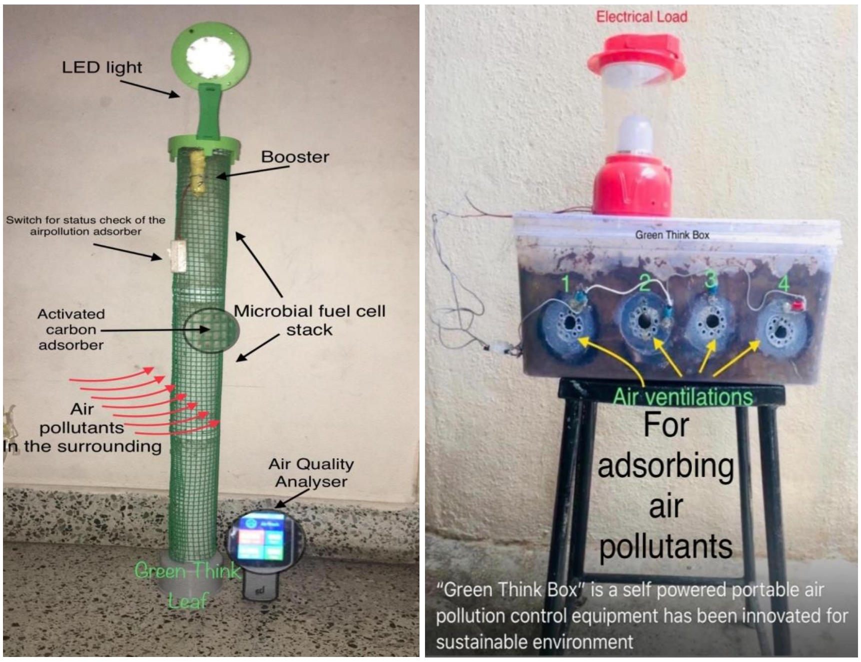

Figure 5.8: Bio-Electric air purifier using MFC

Air pollution is one of the biggest threats to the environment and affects everyone: humans, animals, crops, cities, forests, aquatic ecosystems.

Figure 5.9: Bio-Electric air purifier using MFC technology

In India, especially in metropolitan cities. Daily, dirt, smoke, and dust is kicked up into the atmosphere from excavating and demolition type construction activities and transportation. Planting trees as much as possible might help in tackling air pollution in general and cannot be the only solution and at this juncture, addressing the challenge of air pollution in India. Bio-Electric Air purifier has been innovated as an alternative solution to reduce air pollution as shown in figure 5.9.

Bio-Electric Air purifier as an air pollution controller or pollutants adsorbent equipped with microbial fuel cells runs via enabling bacteria to do what they do best, oxidize and reduce organic pieces is a combination of :

(i) In India, cow dung is accepted as a purifier and has an essential role in preserving the environment. Cow dung is used from ancient times in agriculture as it has a significant role in plant growth promotion and plant protection. It is also being used in various religious practices as a purifier.

(ii) Activated carbon filtration is a commonly used technology based on the adsorption of contaminants onto the surface of a filter. This method is effective in removing certain organics such as unwanted taste and odors, micropollutants.

(iii) An MFC is a bio-electrochemical device that harnesses the power of respiring microbes to convert organic matter into pollutants directly into electrical energy. At its core, the MFC is a fuel cell, which transforms chemical energy into electricity using oxidation-reduction reactions.\

5.3 Scope for future work

- The production of electricity using anolytes, DO/Salt, and carbon is the primary contribution of this thesis. Further, in-spite of electricity generation, the treatment can also be done for surrounding air as well as water.
- The analysis of the amount of electricity produced is done using data transformation and principal component analyzer. The analysis time for microbes development can be increased to observe electricity production.

- The number of MFCs can be increased to evaluate the acclimation periods to analyze the ecological performance of microbial community profiles by increasing the residential periods.
- The prototypes can be improved into commercialized form by design scale-up.
- The large production of green energy lights for remote areas can also be done to serve the society.
- Large Bio-electric air purifiers can be developed for sustainable environment.