

Table of Contents

| Contents/Chapters | Page No. |
|---|---------------------|
| List of Figures | xv |
| List of Tables | xviii |
| Abbreviations | xx |
| Preface | xxiii |
| 1.0. Introduction | 1 |
| 2.0. Literature Review | 8 |
| 2.1 History of Microbial fuel cell | 10 |
| 2.2 Principle of MFC | 10 |
| 2.3 Material used in the MFC system | 11 |
| 2.3.1 Anode | 12 |
| 2.3.2 Cathode | 13 |
| 2.3.3 Membranes | 13 |
| 2.3.4 Substrates | 14 |
| 2.3.4.1 Glucose | 14 |
| 2.3.4.2 Acetate and Butyrate | 14 |
| 2.3.4.3 Lignocellulose | 15 |
| 2.3.4.4 Cellulose | 15 |
| 2.3.4.5 Wastewater | 16 |
| 2.4 Configuration of MFC | 17 |
| 2.4.1 Single chamber MFC | 17 |
| 2.4.2 Dual-chamber microbial fuel cells | 18 |

| | | |
|---------|--|----|
| 2.5 | Electrogenic microorganisms and extracellular electron transfer pathways | 18 |
| 2.5.1 | Electroactive Biofilms | 20 |
| 2.6 | EET pathways by electrogens | 24 |
| 2.6.1 | EET pathways in Gram-negative bacteria | 24 |
| 2.6.1.1 | Metal reducing pathway in <i>S. oneidensis</i> MR-1 | 24 |
| 2.6.1.2 | Porin cytochrome pathway in <i>Geobacter sulfurreducens</i> | 27 |
| 2.6.1.3 | The Pio pathway in <i>Rhodopseudomonas palustris</i> TIE-1 | 30 |
| 2.6.1.4 | Metal-oxidizing pathway in <i>Sideroxydans lithotrophicus</i> ES-1 | 31 |
| 2.6.1.5 | Electron transfer pathway in <i>Thermincola potens</i> JR | 32 |
| 2.6.2 | EET pathways in Gram-positive bacteria | 33 |
| 2.6.2.1 | EET pathway in <i>Lysinibacillus varians</i> GY32 | 33 |
| 2.6.2.2 | EET pathway in <i>Carboxydothemus ferrireducens</i> | 34 |
| 2.6.2.3 | EET pathway in <i>Enterococcus faecalis</i> | 36 |
| 2.6.3 | EET pathway in Yeast | 37 |
| 2.7 | Application of EET | 38 |
| 2.7.1 | Bioremediation of pollutants | 38 |
| 2.7.2 | Biomining | 40 |
| 2.7.3 | Nanomaterial synthesis | 41 |
| 2.7.4 | Bioenergy and biogas generation | 42 |

| | | |
|----------|--|----|
| 2.8 | Yeast as anode biocatalyst | 43 |
| 2.8.1 | Factors affecting the performance of the yeast-based MFCs | 51 |
| 2.8.2 | Strategies to enhance the electron transfer from yeast cell to the anode | 52 |
| 2.8.2.1 | Addition of artificial and natural mediators | 53 |
| 2.8.2.2 | Yeast extract as a sustainable mediator | 56 |
| 2.8.2.3 | Anode surface modification | 57 |
| 2.8.2.4 | Genetically modified yeast | 60 |
| 2.8.2.5 | Yeast surface display technique | 61 |
| 2.8.3 | Applications of yeast-based MFCs | 62 |
| 2.8.3.1 | Electricity generation | 62 |
| 2.8.3.2 | Alcohol production | 63 |
| 2.8.3.3 | Biohydrogen production | 63 |
| 2.8.3.4 | Biosensing | 64 |
| 2.8.3.5 | Wastewater treatment | 64 |
| 2.8.3.6 | Desalination of water | 66 |
| 2.9 | Utilization of food waste in MFC | 66 |
| 2.10 | Machine learning | 74 |
| 2.10.1 | Machine learning methods | 75 |
| 2.10.1.1 | Supervised machine learning | 75 |
| 2.10.1.2 | Unsupervised machine learning | 76 |
| 2.10.1.3 | Semi-supervised learning | 76 |
| 2.10.1.4 | Reinforcement learning | 76 |
| 2.10.2 | ML algorithms | 76 |

| | | |
|----------|--|----|
| 2.10.2.1 | Neural networks | 76 |
| 2.10.2.2 | Linear regression | 77 |
| 2.10.2.3 | Logistic regression | 77 |
| 2.10.2.4 | Clustering | 77 |
| 2.10.2.5 | Decision trees | 77 |
| 2.10.2.6 | Random forests | 77 |
| 2.10.3 | Decision tree Model | 78 |
| 2.10.3.1 | Root nodes | 79 |
| 2.10.3.2 | Decision Nodes | 79 |
| 2.10.3.3 | Leaf Nodes | 79 |
| 2.10.3.4 | Sub-tree | 79 |
| 2.10.3.5 | Pruning | 79 |
| 2.10.3.6 | Entropy | 79 |
| 2.10.3.7 | Information Gain | 80 |
| 3.0 | Bioelectricity generation using sweet lemon peels as anolyte and cow urine as catholyte in a yeast-based microbial fuel cell | 83 |
| 3.1 | Introduction | 83 |
| 3.2 | Material and methods | 87 |
| 3.2.1 | Raw material collection | 87 |
| 3.2.2 | Substrate preparation for the anode and its pre-treatment | 87 |
| 3.2.3 | Substrate characterization | 88 |
| 3.2.4 | Catholyte preparation & characterization | 88 |
| 3.2.5 | Anode biocatalyst | 88 |
| 3.2.5.1 | Isolation and identification of cellulolytic bacteria | 88 |

| | | |
|---------|---|-----|
| 3.2.5.2 | Isolation of genomic DNA | 89 |
| 3.2.5.3 | 16S rRNA gene sequencing | 90 |
| 3.2.6 | Microalgae culture | 90 |
| 3.2.7 | MFC construction | 91 |
| 3.2.8 | MFC operation | 92 |
| 3.2.9 | MFC characterization | 93 |
| 3.2.10 | Statistical analysis | 95 |
| 3.3 | Results and discussion | 96 |
| 3.3.1 | Ultimate and Proximate analysis of sweet lime peel | 96 |
| 3.3.2 | 16s rRNA sequencing of isolated bacteria | 98 |
| 3.3.3 | Analysis of power generation/polarization curve and internal resistance | 99 |
| 3.3.4 | Pollutant removal and organic substrate consumption | 106 |
| 3.3.5 | Algae biomass yield | 108 |
| 3.4 | Conclusions | 108 |
| 4.0 | Bioelectricity generation by using cellulosic waste and spent engine oil in a concentric photobioreactor-microbial fuel cell | 112 |
| 4.1 | Introduction | 112 |
| 4.2 | Material and methods | 114 |
| 4.2.1 | Sample collection | 114 |
| 4.2.2 | Pretreatment of cellulosic waste | 114 |
| 4.2.2.1 | Characterization of cellulosic waste | 115 |
| 4.2.2.2 | Anolyte preparation and characterization | 115 |
| 4.2.3 | Microalgae cultivation | 116 |

| | | |
|---------|---|-----|
| 4.2.3.1 | DNA extraction, amplification and sequencing of microalgae | 116 |
| 4.2.4 | Preparation of catholyte | 117 |
| 4.2.4.1 | Characterization of catholyte | 117 |
| 4.2.5 | Anode inoculum and characterization | 117 |
| 4.2.6 | MFC construction and operation | 118 |
| 4.2.6.1 | MFC characterization | 120 |
| 4.2.7 | Characterization of microbial community at anode | 120 |
| 4.2.7.1 | Preparation for scanning electron microscopy (SEM) analysis | 121 |
| 4.2.8 | Statistical analysis | 122 |
| 4.3 | Results and Discussion | 122 |
| 4.3.1 | Proximate and ultimate analysis of dried substrates | 122 |
| 4.3.2 | Identification of microalgae strain | 124 |
| 4.3.3 | Power generation | 125 |
| 4.3.4 | Substrate degradation and nutrient removal | 131 |
| 4.3.5 | Dried algae biomass yield | 134 |
| 4.3.6 | Microbial community and diversity | 134 |
| 4.4 | Conclusions | 139 |
| 5.0 | Bioelectricity generation by microbial degradation of banana peel waste biomass in a dual-chamber <i>S. cerevisiae</i> -based microbial fuel cell | 142 |
| 5.1 | Introduction | 142 |
| 5.2 | Materials and methods | 144 |
| 5.2.1 | Substrate collection and preparation | 144 |
| 5.2.1.1 | Preparation of dried banana peel powder | 144 |

| | | |
|---------|--|-----|
| 5.2.1.2 | Preparation of banana slurry | 144 |
| 5.2.1.3 | Substrate preparation | 145 |
| 5.2.1.4 | Substrate characterization | 145 |
| 5.2.2 | Anode biocatalyst | 145 |
| 5.2.3 | MFC construction | 145 |
| 5.2.4 | MFC operation | 147 |
| 5.2.5 | MFC characterization | 148 |
| 5.2.6 | Sampling, PCR amplification, metagenomic analysis | 150 |
| 5.2.7 | Statistical analysis | 151 |
| 5.3 | Results and discussion | 151 |
| 5.3.1 | Anode modification by activated charcoal | 151 |
| 5.3.2 | Ultimate and proximate analysis of banana peel | 153 |
| 5.3.3 | Analysis of power generation from MFC | 154 |
| 5.3.3.1 | Polarization curve | 158 |
| 5.3.4 | COD removal and substrate digestion | 163 |
| 5.3.5 | Analysis of indigenous microbial consortia | 165 |
| 5.4 | Conclusions | 168 |
| 6.0 | Optimization of banana peel waste based microbial fuel cells by machine learning | 170 |
| 6.1 | Introduction | 171 |
| 6.2 | Materials and methods | 174 |
| 6.2.1 | Substrate preparation | 174 |
| 6.2.2 | Anode biocatalyst | 175 |
| 6.2.3 | Design of MFC | 175 |
| 6.2.4 | Experimental layout and data generation | 176 |

| | | |
|---------|---|------------|
| 6.2.5 | Decision tree regression, computational and experimental validation | 180 |
| 6.2.6 | Software and statistical analysis | 181 |
| 6.3 | Results and Discussion | 181 |
| 6.3.1 | Decision tree evaluation | 181 |
| 6.3.1.1 | Voltage | 182 |
| 6.3.1.2 | Current density | 188 |
| 6.3.1.3 | Power density | 195 |
| 6.3.2 | Model validation | 199 |
| 6.3.2.1 | Computational validation | 199 |
| 6.3.2.2 | Experimental validation | 204 |
| 6.4 | Conclusions | 207 |
| 7.0 | Overall Conclusion and Future Perspective | 209 |
| 7.1 | Overall conclusion | 210 |
| 7.2 | Future research needs and engineering implications | 211 |
| 8.0 | References | 214 |
| | List of Publications | 253 |