

**Development and Performance Evaluation of Microbial  
Fuel Cells for Simultaneous Treatment of Organic Waste  
and Bioelectricity Generation.**



**Thesis submitted in partial fulfilment for the**

**Award of Degree**

**DOCTOR OF PHILOSOPHY**

**By**

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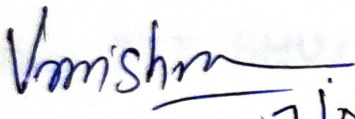
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## Abbreviations

A	Surface area
APHA	American Public Health Association
ASTM	American Society for Testing and Materials methods
BBM	Bold basal medium
BDP	Dried banana peel powder
BDW	Dried banana peel wastewater
BDY	Dried banana peel with <i>S. cerevisiae</i>
BPW	Banana peel waste
BS	Banana slurry
BSW	Banana slurry wastewater
BSY	Banana slurry with <i>S. cerevisiae</i>
BW	Banana peel waste
CB	Cellulolytic bacteria
CCD	Central composite design
CE	Coulombic efficiency
COD	Chemical oxygen demand
COD <sub>f</sub>	Final chemical oxygen demand
COD <sub>i</sub>	Initial chemical oxygen demand
DNSA	3,5-Dinitrosalicylic acid
E <sub>Cell</sub>	The electromotive force of the MFC
F	Faraday's constant
F-MFC	Fruit peel powder based MFC
FP	Mixed fruit peels

HPTCL	High pressure and temperature pretreated sweet lime peel slurry
I	Current
J	Current density
MB	Dried microalgae
MFC	Microbial fuel cell
ML	Machine Learning
M-MFC	Dried microalgae powder based MFC
MO <sub>2</sub>	The molecular weight of oxygen
N-MFC	Newspaper powder based MFC
NP	Non-Pretreated
OCV	Open circuit voltage
OG	Oil and grease
P	Pretreated
PCL	Pretreated peels
PCLY	Pretreated peel with yeast
PCLYB	Pretreated peel with yeast and bacteria
PD	Power density
R	External resistance
R <sub>ext</sub>	External resistance
R <sub>int</sub>	Internal resistance
RSM	Response surface methodology
SC	Slurry Concentration
SEO	Spent engine oil
SSM	Stainless steel mesh
T	Temperature

TDS	Total dissolved solids
TE	Treatment efficiency
TFS	Total Fixed Solids
TS	Total solids
TSS	Total suspended solids
TVS	Total Volatile Solids
V	Voltage
$V_{\text{anode}}$	The volume of the anode chamber
YMFC	<i>S. cerevisiae</i> -Microbial fuel cell
YPD	Yeast Extract-Peptone-Dextrose
$\Delta\text{COD}$	Change in the COD over time (t)

## **Preface**

Organic waste generation, particularly food waste, is a significant global issue with substantial environmental consequences. According to the Food and Agriculture Organization (FAO) of the United Nations, approximately one-third of the food produced for human consumption worldwide is lost or wasted each year, amounting to about 1.3 billion metric tons of food waste annually. The improper management of organic waste leads to greenhouse gas emissions, water and soil pollution, and air pollution. Leachate, a liquid byproduct of organic waste decomposition, can contain pollutants that seep into the soil and contaminate water sources, leading to water pollution. Moreover, the decomposition of organic waste can generate odorous gases, contributing to air pollution and creating unpleasant living conditions for nearby communities. Microbial Fuel Cells (MFCs) have shown promise as a technology for organic wastewater treatment. One of the primary advantages of MFC is the production of electricity during the wastewater treatment process. As microorganisms break down organic substrate, and release electrons as part of their metabolic processes. The first objective explores the potential of pretreated sweet lime peel slurry as an anolyte with yeast and bacteria anode biocatalyst for bioenergy generation in MFCs. Sterilised cow urine was used as catholyte and *Chlorella pyrenoidosa* strain as cathode biocatalyst. Three H-shaped dual-chamber MFCs were fabricated using two plastic containers operating with no inoculum, *Saccharomyces cerevisiae* as only inoculum and co-culture of *Saccharomyces cerevisiae* with isolated cellulolytic bacteria, respectively, in the anode chamber. The anode was prepared using a rectangular stainless-steel mesh; the cathode was a cylindrical graphite rod. The maximum open-circuit voltages achieved by co-culture of bacteria and *S. cerevisiae* were  $792.33 \pm 1.53$  mV and  $481.33 \pm 3.51$  mV, respectively. The maximum power densities in these two MFCs were found to be  $22.20 \pm 1.28$  mW/m<sup>2</sup> ( $210.66 \pm 6.11$  mA/m<sup>2</sup>) and  $204.80 \pm 1.28$  mW/m<sup>2</sup> ( $640.0 \pm 2.0$  mA/m<sup>2</sup>) correspondingly. Results noticeably disclosed that microorganisms consumed the

carbon source available in sweet lime peel. Thus, the sweet lime peel can be an inexpensive alternative for operating MFCs. In the second objective, newspaper powder, dried dead microalgae biomass and mixed fruit peel powder were separately targeted as substrate for the growth of an isolated cellulolytic bacteria inside the anode chamber of three different MFCs. At cathode, bold basal medium with spent engine oil was used as catholyte. An isolated and acclimatized microalgae was used as cathode biocatalyst in order to perform bioremediation of spent engine oil wastewater at cathode chamber. The MFC with newspaper powder showed highest maximum power density of  $34.88 \pm 1.00 \text{ mW/m}^2$ . Both fruit peel powder and dried microalgae powder-based MFCs achieved almost parallel maximum power densities of  $15.57 \pm 0.49 \text{ mW/m}^2$  (at  $161.1 \pm 2.54 \text{ mA/m}^2$ ) and  $16.00 \pm 0.32$  (at  $163.3 \pm 1.66 \text{ mA/m}^2$ ), respectively. The anode chambers of all MFCs reflected chemical oxygen demand (COD) removal efficiencies in range of 65 - 86 %. At anode chamber, maximum COD removal of 86.25% was achieved by microalgae powder based MFC. The removal percentage of oil and grease were 37.7%, 42.3% and 29.1% for fruit peel, newspaper powder and microalgae powder based MFCs respectively. Up to 76-80% nitrate-nitrogen, 96-97% ammonium-nitrogen, 90-94% phosphate-phosphorous removal was observed in all the MFCs. Microbial community analysis revealed that Proteobacteria, Firmicutes and Bacteroidetes were the dominant phyla present in all the three anodic biofilms. The third objective evaluates the performance of *S. cerevisiae*-based H-shaped microbial fuel cell with banana peel waste as substrate, operated for 30 days in three cycles. Dried banana peel and banana slurry substrates were prepared with initial COD of  $1126 \pm 41 \text{ mg. L}^{-1}$  and  $1366 \pm 64 \text{ mg. L}^{-1}$  respectively. Dried banana peel powder was fed into two MFCs, one with no inoculant and the other with *S. cerevisiae*. Dried banana peel powder without inoculant yielded negligible power output, whereas dried banana peel powder with *S. cerevisiae* generated a maximum power density of  $2.2 \pm 0.1 \text{ mW.m}^{-2}$ . The banana peel slurry was fed into two different MFCs one was with *S. cerevisiae* and another was without *S.*

*cerevisiae*. Banana slurry with *S. cerevisiae* generated a maximum power output of  $86.9 \pm 0.4$  mW. m<sup>-2</sup>. Banana peel slurry without inoculation, generated a maximum power output of  $44.6 \pm 0.8$  mW. m<sup>-2</sup>. Microbial community analysis indicated that the high-power output obtained from banana slurry-based MFCs was due to the presence of indigenous microbial consortia. Up to 70-88% COD removal was recorded in MFCs with banana slurry, however, 18-44% of COD removal was observed in MFCs with dried banana peel powder. It was also observed that the simple saccharides available in banana peel waste were consumed by *S. cerevisiae* and other indigenous microbes in the anode chamber. The microbial community released electrons in the anode chamber, which were responsible for voltage generation in MFC. In the fourth objective, MFC was operated using banana peel slurry as substrate with baker's yeast as external inoculum. Decision tree algorithms were applied for optimizing the input parameters of MFC. Input variables including temperature, pH, resistance, pretreatment of slurry and slurry concentration were optimized for achieving the maximum power density in MFC. Total five combination were obtained by the decision tree model that led to high power density. All five combinations were also tested for validation. Experimental validation of decision tree models showed accuracy in range of 77 to 99%. In order to obtain high power density, the best combination was determined by accuracy level and experimental validation. The best set of rules for high power density was  $41.47 \text{ mL/L} < \text{slurry concentration} < 87.5 \text{ mL/L}$ ,  $22.44 \text{ }^\circ\text{C} \leq \text{temperature} < 36.25 \text{ }^\circ\text{C}$ ,  $5.23 \leq \text{pH} < 7.25$ , slurry was pretreated and  $\text{resistance} < 285 \text{ } \Omega$ . It was also observed that temperature, resistance and pretreatment were the most influential input parameters to achieve high power density. Results obtained in this work can be directly implemented at pilot and industrial scale without further experimental trails.