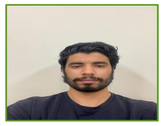
Members Team 111



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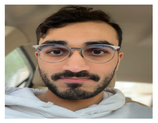

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202031800

Microbial Fuel Cells: Paving the Way for Sustainable Waste Treatment and Electricity Production

Chemical Engineering :Senior Design Project II: Term 242

King Fahd University of Petroleum and Minerals

COLLEGE OF CHEMICALS AND MATERIALS
Chemical Engineering Department

Introduction & Design Concept

The rising global demand for clean energy and effective wastewater treatment has prompted interest in sustainable, dual-purpose technologies. Microbial Fuel Cells (MFCs) offer a novel solution by using electrogenic bacteria to break down organic matter in wastewater while simultaneously generating electricity. This project explores the development and performance evaluation of a cost-effective, lab-scale MFC system.

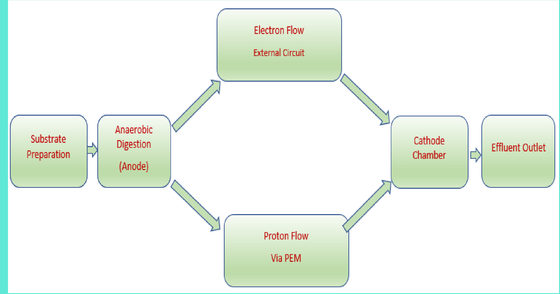
Project Objectives

- To develop a dual-chamber MFC prototype that treats wastewater and generates electricity using microbial metabolism.
- To simulate microbial growth, biofilm dynamics, and energy efficiency using MATLAB, COMSOL, and DWSIM.
- To experimentally evaluate the effect of different anode materials on voltage output using statistical analysis in MINITAB.
- To assess the feasibility of MFCs for sustainable and decentralized wastewater treatment.

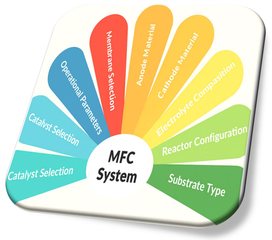
Key Features of Design Concept

- Cylindrical chambers made from acrylic
- Graphite felt as base electrode material
- Glucose-based synthetic wastewater for controlled microbial growth
- Removable modules for maintenance and testing
- Real-time voltage, pH, and DO monitoring ports

Final Design Block Diagram



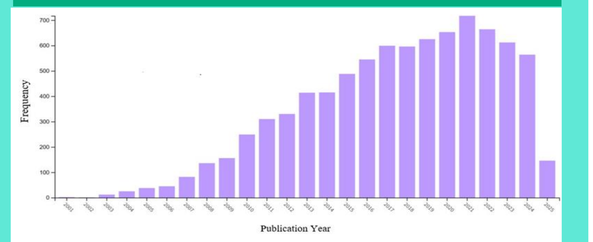
Design Concept Fan & Prototype



Recent Studies on MFC

MFCs have attracted rising global interest over the past two decades for their dual role in clean energy and wastewater treatment. Research in this field has grown steadily since 2001, with a major surge after 2010, reflecting the global shift toward sustainable bio-electrochemical technologies.

Web of science yearly view of research studies on MFC



Some Selective Recent Studies on MFC

Publication Year	Authors	Journal Name	Brief Description
2025	Rathinavel et al.	Carbon Trends	Investigated biomass-based carbon anodes for MFC electricity using septic tank wastewater.
2025	Zhu et al.	Int. Journal of Hydrogen Energy	Optimized MFC power generation using a pulsating gas-liquid-solid fluidized bed.
2025	Wang et al.	Applied Energy	Explored how electromagnetic waves enhance MFC performance and pollutant degradation.
2025	Potrykus et al.	Bioresource Technology	Modeled MFCs' response to external load variations in single, series, and parallel configurations.
2025	Feng et al.	Energy Conversion & Management	Developed an MFC-electrolytic cell system for treating shale gas wastewater and oil-based sludge.
2025	Zhou et al.	Journal of Water Process Engineering	Investigated nickel-doped porous carbon anodes to enhance MFC wastewater treatment efficiency.
2025	Zhao et al.	Int. Journal of Hydrogen Energy	Developed a capacitive bioanode to improve MFC stack performance and energy storage.
2024	Javanmard et al.	Process Safety & Environmental Protection	Revolutionized microbial fuel cells using Biochar's energy conversion odyssey.
2024	Garimella et al.	Annals of Microbiology	Explored the bacterial electron transportation for microbial fuel cells for power generation.
2023	Roy et al.	Membranes	Reviewed MFC construction and applications for sustainable wastewater treatment.

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Simulation Softwares

We used four simulation platforms to analyze MFC performance.

DWSIM (Chemical Process Simulator): Performed mass & energy balances; thermodynamic evaluation.

COMSOL Multiphysics: Visualized biofilm formation and species transport in the anode chamber.

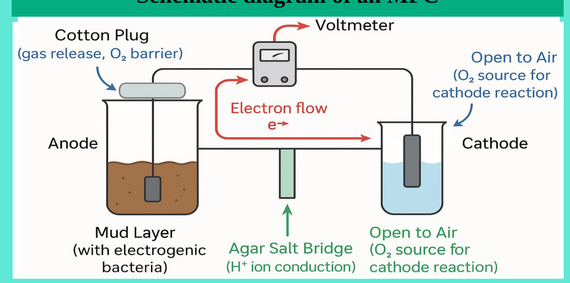
MATLAB: Simulated microbial growth (Monod model) and electrode kinetics (Butler-Volmer).

Minitab: Conducted ANOVA & Fisher post-hoc tests for material performance analysis.

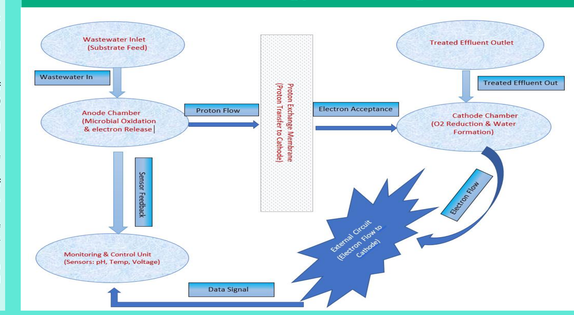
Experimental Procedure

- Substrate: Glucose-based synthetic wastewater.
- Anode Materials Tested: Graphite Felt, Graphene, Carbon Nanotube, Stainless Steel, Platinum.
- Setup: Dual-chamber MFC with external resistor and voltage logger
- Data Collected: Voltage output, microbial activity, material stability.

Schematic diagram of an MFC



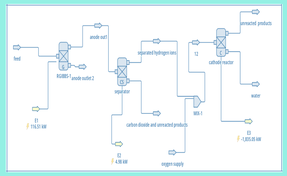
MFC Prototype Summary



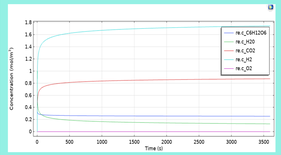
Simulation & Experimental Evaluation of MFC

We investigated performance of the MFC prototype using DWSIM, MATLAB, COMSOL, and MINITAB. Each tool provided unique insights into the system's electrochemical behavior, microbial activity, and material efficiency, Below are some selective tables, graphs, codes, and equations.

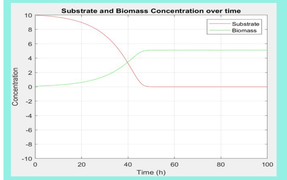
Simulated MFC Model (DWSIM)



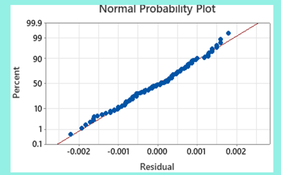
Concentration of Reactants Over Time (COMSOL)



Substrate and Biomass Concentration (COMSOL)



Normality Testing Code for Residuals (MINITAB)



Scientific Principles of MFC Operation

Anode Reaction: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$

Cathode Reaction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Overall Reaction: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

Material Properties from Stream Junctions (DWSIM Simulations)

Object	water	unreacted products	oxygen supply	feed	anode outlet 2	anode out1	12	Unit
Temperature	292.778	297.267	298.15	298.15	298.15	298.15	297.267	K
Pressure	101325	101325	101325	101325	101325	101325	101325	Pa
Mass Flow	0.698756	1.31395	2	0.659581	0.604617	0.0504546	2.01271	kg/s
Density (Liquid 1)	997.656	996.561	996.328	1007.2	1008.09	0	996.561	kg/m3
Molar Weight (Liquid 1)	18.0153	18.0153	18.0153	72.5613	77.0087	0	18.0153	kg/kmol

MATLAB Code for Anode Material Testing

Values for Governing Eq. | Governing Eq.

Key Findings

- Platinum anodes demonstrated the highest voltage output with low overpotential.
- Simulations confirmed critical performance aspects: DWSIM verified energy and mass balance; COMSOL showed strong biofilm development; MATLAB captured effective microbial growth.
- Statistical analysis using MINITAB (ANOVA & Fisher tests) validated significant differences among electrode materials, highlighting Platinum as the top-performing option.

Conclusions, Recommendations, and Limitations

Conclusions

- MFC prototype achieved dual wastewater treatment and power generation.
- Platinum anodes appeared as the best option in tests and simulations.
- Softwares confirmed design validity and revealed bottlenecks.

Recommendations

- Scale up the MFC system for the applications of the real-world wastewater.
- Investigate the low-cost alternatives to Platinum electrodes.
- Extend software simulations to optimize full-scale system dynamics.

Limitations

- Platinum electrodes tend to increase overall system cost.
- Simulation tools lacked built-in libraries for MFC.
- Prototype performance not yet validated in real-world settings.

Acknowledgements

Senior Design Coordination Team

Department of Chemical Engineering

KFUPM