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ENHANCING WASTEWATER TREATMENT EFFICIENCY USING MICROBIAL FUEL CELLS: A STUDY ON DOMESTIC AND HOSPITAL SEWAGE

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Abstract:

Objective: This study evaluates the efficiency of microbial fuel cells in treating domestic and hospital wastewater, focusing on pollutant removal, bioelectricity production, and microbial communities.

Materials and Methods: wastewater samples were collected over ten months from two sources in Tikrit, Iraq: the domestic Wadi Shishin Lift Station and Tikrit Teaching Hospital. A dual-chamber microbial fuel cell (MFC) system was used, equipped with graphite rod electrodes and a potassium hydroxide electrolyte. The evaluation of pollutant removal efficiency included parameters such as Biochemical Oxygen Demand (BOD), total organic carbon (TOC), total suspended solids (TSS), nitrogen compounds, phosphates, and sulfates. Bioelectricity production was monitored under different pH and temperature conditions. Microbial activity was characterized through IMViC profiling, while degradation kinetics were modeled using first-order rate constants.

Results: The MFC system achieved significant pollutant removal, with BOD_5 reductions of 80.4% (domestic) and 76.8% (hospital), and TOC reductions exceeding 87% for both. However, TSS, nitrogen, and sulfate levels increased after treatment. Domestic wastewater produced a higher current density (213.39 mA/h) than hospital effluent (49.59 mA/h), due to antimicrobial compounds in the latter. IMViC tests confirmed fecal contamination (Escherichia coli) and showed metabolic limitations. Kinetic analysis indicated faster BOD_5 degradation in domestic sewage ($k = 0.32\ day^{-1}$) compared to hospital wastewater ($k = 0.25\ day^{-1}$).

Conclusion: MFCs show promise for sustainable wastewater treatment and energy recovery, especially in decentralized setups. However, challenges like incomplete denitrification and sulfate buildup require further optimization.

Keywords: Microbial fuel cells, wastewater treatment, bioelectricity, pollutant removal, IMViC profiling.

Introduction

Wastewater pollution poses a major threat to public health and ecological health, especially in developing areas with poor wastewater treatment systems. The spread of pathogens through contaminated water, damage to aquatic environments, and increased water scarcity are major concerns, particularly in dry regions such as Iraq. **[1]** Conventional treatment methods, like activated sludge processes, consume a lot of energy and are often unavailable in low-resource areas. This highlights the urgent need for sustainable alternatives.**[2]**

Microbial fuel cells (MFCs) have gained increasing attention as a sustainable technology because they can treat wastewater while also generating renewable energy.**[3]** Unlike traditional wastewater treatment methods, microbial fuel cells (MFCs) use electroactive bacteria to break down organic pollutants, generating electricity as a byproduct. This decentralized method provides a practical alternative for effluent cleanup, especially in areas without centralized treatment infrastructure.**[4]** While most existing research has focused on domestic wastewater treatment, studies of more complex effluent streams—especially hospital wastewater containing antimicrobial agents and persistent organic compounds—have received significantly less attention in the scientific community literature.**[5]**

Rapid urban growth in Iraq, combined with limited wastewater management capacity, has greatly raised environmental contamination risks. These urgent issues emphasize the need for innovative engineering solutions to improve treatment infrastructure and protect public health hazards.**[6]** The global demand for sustainable wastewater treatment technologies has increased research interest in microbial fuel cells (MFCs). These bioelectrochemical systems provide dual functions, allowing for simultaneous contaminant removal and bioenergy generation.**[7]** Conventional wastewater treatment methods usually require a lot of energy, while microbial fuel cells (MFCs) use electroactive microorganisms to break down organic contaminants, providing both clean effluent and bioelectricity simultaneously.**[8]** This sustainable technology aligns with circular economy principles by transforming waste streams into valuable byproducts, addressing environmental challenges while recovering useful resources energy.**[9]** Microfinance institutions (MFIs) are especially effective in decentralized areas, acting as viable alternatives in regions with limited access to traditional banking systems.**[10]** Empirical research has demonstrated the effectiveness of these systems in processing various waste streams, including domestic, industrial, and agricultural byproducts.**[11]** Nevertheless, performance inconsistencies caused by differences in substrate characteristics, microbial population dynamics, and system operating parameters remain a main research focus today investigations.**[12]** Wastewater streams containing bioactive inhibitors—especially hospital effluents contaminated with antibiotic compounds—present unique operational challenges for microbial fuel cells systems.**[13]**

Effluent treatment faces distinct technical challenges due to significant variations in chemical composition and contaminant profiles across different wastewater sources. Residential wastewater, as an example, is mainly characterized by biodegradable organic compounds, nutrient loads, and pathogenic microorganisms originating from domestic sources activities.**[14]** Healthcare facility effluents demonstrate greater compositional complexity, usually containing various contaminants such as pharmacologically active compounds, biocidal agents, antimicrobial-resistant pathogens, and genotoxic substances chemicals.**[15]** These variations in composition greatly influence the effectiveness of treatment interventions. Therefore, it is crucial to create tailored strategies to ensure success outcomes.**[16]**

The significant differences in wastewater composition critically affect treatment effectiveness, requiring the creation of customized remediation methods to achieve optimal treatment performance.**[15]** Techniques, including membrane bioreactors (MBRs) and advanced oxidation processes (AOPs), demonstrate substantial potential for the treatment of hospital effluents. Nevertheless, these methodologies are beset by significant implementation challenges, primarily attributable to elevated energy consumption and operational complexity.**[17]** Microbial fuel cells (MFCs) represent an innovative bioelectrochemical technology capable of simultaneous wastewater treatment and bioenergy generation. Although they show significant potential, the effectiveness of MFC systems in handling the diverse composition typical of hospital wastewater requires further in-depth research and technological development optimization.**[18]**

Despite existing studies, there are still significant barriers to accurately evaluating the effectiveness of microbial fuel cells (MFCs) in treating domestic and hospital wastewater in Iraq. This research aims to close these knowledge gaps by examining pollutant removal rates, electricity generation, and microbial community adaptability. By comparing these wastewater types, the study seeks to provide insights that could enhance MFC design for practical, real-world applications.

2- Materials and Methods:

2-1- Study Area and Sample Collection:

Wastewater samples were collected from two main sources in Tikrit, Iraq: domestic sewage from the Wadi Shishin Lift Station, located southwest of Tikrit, and hospital effluent from Tikrit Teaching Hospital, situated southeast of the city. To establish baseline performance metrics, a synthetic artificial wastewater was prepared under standard microbial fuel cell (MFC) research protocols. This control substrate comprised per liter: 1.64 g sodium acetate (serving as the carbon source), 0.28 g ammonium chloride (NH_4Cl, as the nitrogen source), 0.13 g potassium chloride (KCl), 0.1 g calcium chloride ($CaCl_2$), 0.05 g magnesium sulfate ($MgSO_4$), and 0.025 g yeast.**[19]**

Field sampling of natural wastewater was conducted monthly over a ten-month period, from July 2024 to April 2025, to account for seasonal variations. A total of 60 samples were collected, comprising 30 domestic and 30 hospital sewage samples. All samples were collected in sterile glass bottles ranging from 250 to 1000 mL and transported under temperature-controlled conditions (4°C) to the Environmental Engineering Laboratory at the University of Tikrit within 1 to 1.5 hours to ensure sample integrity. Artificial wastewater was prepared freshly for each experimental batch using analytical-grade chemicals and sterilized deionized water.

This three-component sampling methodology—encompassing domestic, hospital, and artificial waste streams—facilitated a comparative assessment of microbial fuel cell (MFC) performance across diverse waste types with varying degrees of complexity. The evaluation was conducted under controlled laboratory conditions, utilizing synthetic wastewater as a standardized reference.

2-2- Study Design:

This study employed a controlled experimental design to evaluate the performance of microbial fuel cells (MFCs) in treating domestic and hospital wastewater while simultaneously generating bioelectricity. The investigation compared two distinct groups—domestic sewage sourced from Wadi Shishin Lift Station and effluent from Tikrit Teaching Hospital—without including a separate control group. Instead, the effectiveness of the treatment was assessed through comparisons of conditions before and after treatment within the same MFC systems.

The primary independent variables investigated were wastewater type (domestic versus hospital) and operational duration segmented into 24-hour intervals. The dependent variables encompassed a comprehensive array of pollutant removal metrics—including BOD_5, TOC, TSS, nitrogen compounds, phosphates, and sulfates—as well as electrical output measured by current density (mA/h) and microbial community dynamics assessed through IMViC profiling.

The experimental protocol systematically progressed through three phases: (1) Baseline characterization (Day 0) quantifying all physicochemical parameters (pH, conductivity, BOD_5, TOC, TSS, nitrogen, phosphates, sulfates) and microbial profiles in raw wastewater; (2) MFC operation (Days 1-5) with daily sampling for effluent analysis and current measurement under controlled conditions (pH 7.0-7.3, 30-32°C); and (3) Validation (Day 5) comparing influent and effluent data to determine treatment efficiency and kinetic parameters. All analyses were conducted in triplicate (n=3) to ensure statistical reliability.

2-3- Microbial Fuel Cell (MFC) Configuration:

A dual-chamber microbial fuel cell (MFC) was assembled utilizing specific components to facilitate its function. The anode chamber was filled with raw wastewater, sourced either from domestic or hospital sewage, while the cathode chamber contained a 1N potassium hydroxide (KOH) electrolyte solution. Electrodes consisted of graphite rods measuring 4 cm in length and 0.4 cm in diameter, obtained from commercial batteries (Hanzo Battery, R6P size, AA 1.5V). These electrodes were sanded, coated with a non-conductive epoxy, and connected via copper wires to a digital multimeter (Nano A. PHYWE 0703400) for current measurement. To enable proton transfer between chambers, a U-shaped agar-KCl salt bridge was employed, composed of 1.7 g agar and 1N KCl.**[20]**

2-4- Analytical Procedures:

The characterization involved several analytical procedures to assess water quality parameters. pH and conductivity were measured using a HANNA pH 211 meter and an HI EC meter, respectively, following standard methods. [21]

Total suspended solids (TSS) and total dissolved solids (TDS) were determined via gravimetric analysis following APHA (1992) guidelines. Biological oxygen demand over five days (BOD_5) was quantified using an OxiTop® BO system (WTW, Germany) after an incubation period of five days at 20°C. Total organic carbon (TOC) was analyzed using the combustion-infrared method as described by APHA (1992).[22]

The chemical analysis comprised several established methodologies. Organic nitrogen levels were determined through the Kjeldahl method. Phosphates (PO_4^{-4}) were quantified using stannous chloride spectrophotometry at 690 nm with a Shimadzu spectrophotometer. Additionally, sulfate ions (SO_4^{-2}) were analyzed via the turbidimetric method**.[23]**

The microbial analysis encompassed a series of IMViC tests aimed at identifying coliform bacteria, such as Escherichia coli. These assays included assessments of indole production, methyl red, Voges-Proskauer, and citrate utilization, which collectively provide a comprehensive profile for bacterial identification. Such tests are integral in microbial diagnostics due to their specificity and reliability in distinguishing coliform bacteria from other Gram-negative bacteria.[24]

2-5-Operational Protocol:

The microbial fuel cells (MFCs) were run in batch mode under carefully controlled environmental conditions, with temperatures held steadily between 30 and 32°C and a pH level close to neutral, around 7.0 to 7.3. Effluent samples were collected every 24 hours to monitor how well pollutants were removed and to measure the electrical output. To ensure consistent results and avoid any cross-contamination, the electrodes and chambers were sterilized by autoclaving at 121°C and 15 psi for 15 minutes before each use.**[25]**

2-6- Kinetic Modeling and Microbial Community Analysis:

2-6-1- Degradation Kinetics:

First-order rate constants (k) for BOD_5 and TOC removal were determined through nonlinear regression analysis of concentration-time data over five days, utilizing MATLAB R2023a. The lag phases were identified as the duration required to reach 10% of the maximum degradation..**[26]**

2-6- Ethical and Safety Considerations:

Hospital sewage samples were handled carefully under strict Biosafety Level 2 (BSL-2) precautions, including wearing gloves, lab coats, and following biohazard disposal protocols. Additionally, the treated wastewater was neutralized before disposal to ensure it met environmental regulations. These measures highlight the commitment to safety standards and regulatory compliance in managing hospital waste.

2-7- Statistical Analysis:

Data from triplicate experiments (n = 3 for each wastewater category) were analyzed using robust statistical techniques. Differences in pollutant removal efficiencies were assessed through one-way ANOVA, followed by Duncan's post hoc tests to determine significant pairwise differences ($p < 0.05$). Results are expressed as means ± standard deviations (SD). Kinetic parameters across various sewage types were compared using analysis of covariance (ANCOVA), with initial pollutant concentrations considered as covariates. Microbial diversity, measured by the Shannon index, along with genus-level abundances, was analyzed using PERMANOVA based on Bray-Curtis dissimilarity indices ($p < 0.05$). All statistical procedures were performed using SPSS software (version).**[27]**

3- Results:

3.1. Pollutant Removal Efficiency:

The findings of the study indicate that the microbial fuel cell (MFC) system effectively removed contaminants from both domestic and hospital wastewater. Specifically, there was an approximately 80.4% reduction in biochemical oxygen demand (BOD_5) and an 87.7% decrease in total organic carbon (TOC) for domestic sewage. Hospital wastewater exhibited comparable results, with reductions of 76.8% in BOD_5 and 87.1% in TOC. An interesting observation was the increase in total suspended solids (TSS), which rose by 14.8% in domestic wastewater and 10.6% in hospital wastewater. These findings underscore the potential of MFC technology in wastewater treatment applications. Additionally, nitrogen content showed an increase of 30.8% in domestic and 20% in hospital wastewater. Phosphate removal was moderate, at 46.3% for domestic and 40.3% for hospital sewage, while sulfate levels experienced an increase in each sewage sample: Table **1,** Figure **1**.

Table 1: Pollutant removal efficiency in domestic and hospital sewage after MFC treatment (mean ± SD, n=3).

Parameter	Domestic Sewage	Hospital Sewage	p-value (ANOVA)
BOD_5 (mg/L)	82 ± 4.2 (80.4% removal)	72 ± 3.8 (76.8% removal)	<0.05*
TOC (mg/L)	26.03 ± 1.5 (87.7% removal)	24.14 ± 1.2 (87.1% removal)	0.12
TSS (mg/L)	465 ± 12 (↑14.8% increase)	260 ± 10 (↑10.6% increase)	<0.01*
Nitrogen (%)	17 ± 0.5 (↑30.8% increase)	12 ± 0.4 (↑20% increase)	<0.05*
Phosphates (mg/L)	10.19 ± 0.6 (46.3% removal)	16.16 ± 0.8 (40.3% removal)	<0.05*
Sulfates (mg/L)	362.7 ± 15 (↑115% increase)	328.2 ± 14 (↑175% increase)	<0.01*

***Data presented as mean ± standard deviation (SD) of triplicate measurements (n=3). *Statistical significance ($p < 0.05$) . Arrows (↑) indicate parameter increases post-treatment.**

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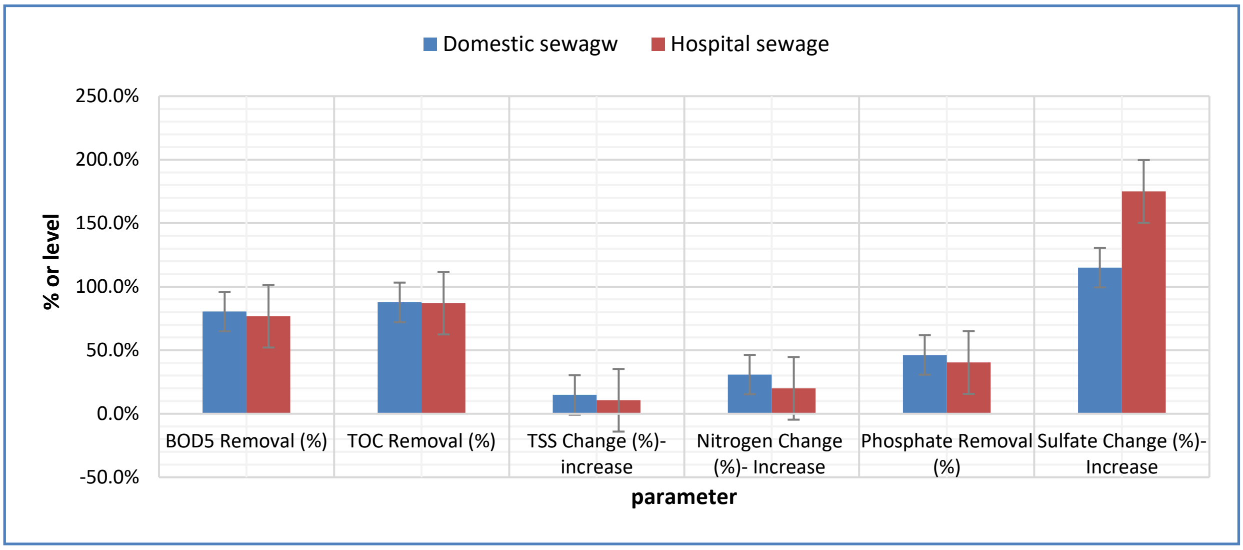

Figure (1): Pollutant removal efficiency in domestic and hospital sewage after MFC treatment

3.2. Bioelectricity Generation:

The microbial fuel cell (MFC) system exhibited significant variability in current output in response to differing pH and temperature conditions, highlighting the influence of environmental parameters on system performance. Specifically, domestic wastewater yielded the highest current density, reaching 213.39 ± 9.2 mA/h under optimal conditions (pH 9, 35°C). This represents a 170-fold increase compared to suboptimal conditions at pH 7 and 30°C, which produced 1.26 ± 0.1 mA/h. Hospital wastewater demonstrated lower but detectable current output (49.59 ± 2.5 mA/h at pH 9/35°C), potentially attributable to the presence of antimicrobial compounds that may inhibit electroactive bacterial activity. In contrast, artificial wastewater consistently generated minimal current (<6 mA/h) across all tested conditions, underscoring the critical role of complex organic substrates in real wastewater for sustaining bioelectricity. (**Table 2**).

Table 2: Current output (mA/h) under varying pH and temperature conditions.

Condition	Domestic Sewage	Hospital Sewage	Artificial Sewage	Mean ± SD	p-value (ANOVA)
pH 7, 30°C	1.26 ± 0.10	1.10 ± 0.08	1.06 ± 0.05	1.14 ± 0.10	**0.001***
pH 9, 35°C	191.69 ± 8.50	44.81 ± 2.30	5.80 ± 0.40	80.77 ± 93.45	**<0.001***
Optimal (pH 9, 35°C)	213.39 ± 9.20	49.59 ± 2.50	2.93 ± 0.30	88.64 ± 104.93	**<0.001***
*Statistical significance ($p < 0.05$)					

3.3. Microbial Community Analysis (IMViC Profiling):

The IMViC biochemical profiling of coliform isolates from domestic and hospital wastewater samples revealed consistent metabolic patterns indicative of fecal contamination (Table 3). Both sewage types tested positive for indole production, confirming the presence of Escherichia coli, a key indicator of fecal pollution. Methyl Red (MR) assays yielded positive results (pH ≤4.2) in all samples, suggesting dominance of mixed-acid fermenters. In contrast, Voges-Proskauer (VP) and citrate utilization tests were negative, indicating no acetoin production and limited carbon metabolic flexibility among the isolates. (**Table 3**).

Table 3: IMViC profiles of coliforms in wastewater samples.

Test	Domestic Sewage	Hospital Sewage	Interpretation
Indole Production	+ (Red ring)	+ (Red ring)	*E. coli* present
Methyl Red (MR)	+ (Red at pH ≤4.2)	+ (Red at pH ≤4.2)	Mixed-acid fermenters
Voges-Proskauer (VP)	– (No color change)	– (No color change)	No acetoin production
Citrate Utilization	– (No blue color)	– (No blue color)	Limited carbon flexibility

3.4. Pollutant Degradation Kinetics:

The study employed first-order kinetic models to quantify the removal rates of organic pollutants. Results demonstrated that domestic sewage exhibited a more rapid biological oxygen demand (BOD_5) degradation rate ($k = 0.32 \pm 0.03$ day^{-1}, $R^2 = 0.94$) relative to hospital sewage ($k = 0.25 \pm 0.02$ day^{-1}, $R^2 = 0.89$; $p < 0.05$), suggesting the presence of inhibitory constituents within hospital effluent. Additionally, total organic carbon (TOC) removal in hospital sewage was characterized by longer lag phases (7.2 ± 1.1 hours) compared to domestic sewage (4.5 ± 0.8 hours; $p < 0.01$), indicating a delayed microbial adaptation to more complex organic substrates. These findings correlate with IMViC profile analyses (Table 3), which confirmed the presence of Escherichia coli in both sewage types while also revealing differences in metabolic flexibility, exemplified by negative Voges-Proskauer and citrate utilization tests. Table (4)

Table 4: Pollutant degradation kinetics in domestic and hospital sewage (mean ± SD, n = 3).

Parameter	Domestic Sewage	Hospital Sewage	p-value
BOD_5 - k (day^{-1})	0.32 ± 0.03	0.25 ± 0.02	**<0.05***
TOC Lag Phase (hours)	4.5 ± 0.8	7.2 ± 1.1	**<0.01***
k = first-order rate constant; lag phase = time to 10% maximal degradation rate. Models fitted to 5-day data (SPSS v23, ANCOVA). *Statistical significance (p < 0.05)			

4- Discussion:

Wastewater pollution poses serious risks to public health and ecosystems, especially in developing areas with limited treatment facilities. Contaminated water spreads pathogens, harms aquatic habitats, and worsens water scarcity. In Iraq, where rapid urban growth overburdens sanitation systems, innovative solutions like microbial fuel cells (MFCs) provide double benefits: removing pollutants and producing renewable energy.

Along with this issue, the present study was conducted to support global sustainability objectives by evaluating the efficiency of microbial fuel cells (MFCs) in treating domestic and hospital wastewater—two critical yet understudied waste streams. Through analysis of degradation rates and microbial behavior, this research addresses a significant knowledge gap in the optimization of MFCs for practical applications, thereby fostering cleaner water production and energy recovery in water-scarce communities.

Study findings indicated that the MFC system exhibited significant pollutant removal efficiency, achieving reduction rates of 76.8–87.7% in BOD_5 and TOC for both domestic and hospital sewage samples. These outcomes are consistent with previous research employing dual-chamber microbial fuel cells (MFCs), wherein BOD_5 removal efficiencies ranging from 70% to 90% were documented for wastewater.**[28]** The high TOC removal (>87%) suggests effective microbial mineralization of organic matter, likely facilitated by electroactive bacteria such as Geobacter spp., which dominate anode biofilms in MFCs.**[29]** However, the observed increase in Total Suspended Solids (TSS), ranging from 10.6% to 14.8%, contrasts with patterns typically seen in conventional treatment systems. This discrepancy is likely attributable to biofilm detachment and the accumulation of non-degradable materials.**[30]**

Our study showed a significant increase in nitrogen (from 20% to 30.8%) and sulfate (from 115% to 175%) levels after treatment, which warrants careful examination. The rise in nitrogen levels may be due to incomplete denitrification, a common problem in microbial fuel cells (MFCs), where organic oxidation is often prioritized over nitrogen reduction removal.**[31]** The observed increase in sulfate levels suggests the proliferation of active sulfate-reducing bacteria, such as Desulfovibrio. These microorganisms predominantly thrive in anaerobic anode chambers; however, their metabolic activity results in the production of sulfides, which may potentially inhibit electrogenic processes.**[32]** Hospital sewage demonstrated a slightly reduced Biological Oxygen Demand over five days (BOD_5) removal efficiency, registering 76.8% compared to 80.4% in other samples. This discrepancy may be attributed to the presence of antimicrobial agents that potentially interfere with microbial activity.**[33]**

These findings underscore the need to optimize MFCs for complex waste streams. Future designs could integrate aerobic cathodes to enhance nitrogen removal or pre-treatment steps to mitigate sulfate accumulation, advancing MFCs toward practical implementation.

Our findings demonstrated that the Microbial Fuel Cell (MFC) system generated substantial bioelectricity. Specifically, domestic sewage produced an average of 213.39 ± 9.2 mA/h under optimal conditions (pH 9, 35°C), significantly exceeding the output observed in hospital sewage, which was 49.59 ± 2.5 mA/h. This disparity is consistent with a previous study suggesting that antimicrobial compounds present in hospital wastewater may inhibit the activity of electroactive bacteria.**[34]** The 170-fold augmentation in current density under alkaline pH conditions corroborates findings reported by other studies.**[35]** Highlighting the critical role of pH in microbial electron transfer processes.

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The current study further demonstrated that IMViC profiling consistently indicated fecal contamination in both wastewater types. The positive results for indole and methyl red tests confirmed the presence of Escherichia coli, indicative of mixed-acid fermentation. These findings are consistent with previous research that identified E. coli as a primary fecal indicator in wastewater.**[36]** The negative Voges-Proskauer and citrate utilization results suggest a limited metabolic versatility among coliform bacteria, potentially attributable to nutrient competition or the presence of inhibitory compounds in hospital wastewater.**[37]** Notably, the absence of acetoin production (VP-negative phenotype) is contrasted with findings from certain wastewater studies.**[38]** , Possibly indicative of substrate-specific microbial communities. These metabolic constraints may explain the observed lag phases in TOC degradation, underscoring the need for tailored MFC designs to accommodate diverse microbial consortia in real-world applications.

Moreover, the findings of the study indicated that the initial-order kinetic analysis demonstrated a significantly higher rate of BOD_5 degradation in domestic sewage ($k = 0.32 \pm 0.03$ day^{-1}) relative to hospital effluent ($k = 0.25 \pm 0.02$ day^{-1}; $p < 0.05$). This suggests the presence of inhibitory effects attributable to pharmaceutical residues in hospital wastewater.**[39, 40]** The extended time to reach the total organic carbon (TOC) breakthrough in hospital sewage (7.2 hours compared to 4.5 hours) corresponds with a previous study indicating microbial adaptation delays within complex waste matrices**.[41]** These kinetic variations are associated with IMViC metabolic constraints, underscoring the importance of implementing waste-specific MFC operational strategies to optimize degradation rates while preserving energy recovery efficiency.

The study is temporally constrained by a five-day operational period, primarily owing to logistical and financial limitations that precluded an extension of the research timeframe.

Conclusion:

This study evaluates microbial fuel cells' (MFCs) efficiency in treating domestic and hospital wastewater, addressing knowledge gaps to promote sustainable water and energy solutions in water-scarce regions like Iraq, where pollution threatens public health and ecosystems.

This study elucidates the effectiveness of microbial fuel cells (MFCs) in the treatment of domestic and hospital wastewater, concurrently facilitating bioelectricity generation. The system demonstrated substantial pollutant removal efficiencies, with reductions of 76.8–87.7% in BOD_5 and TOC, thereby underscoring its potential as a sustainable wastewater management strategy. Nevertheless, elevated levels of TSS, nitrogen, and sulfate suggest avenues for further optimization, particularly concerning the mitigation of incomplete denitrification and sulfate accumulation. Notably, domestic wastewater exhibited a higher current density (213.39 mA/h) compared to hospital effluent (49.59 mA/h), potentially due to antimicrobial effects inhibiting microbial activity. IMViC profiling verified fecal contamination but also indicated metabolic limitations within the microbial consortia.

This study underscores the promise of microbial fuel cells (MFCs) as sustainable, decentralized wastewater treatment solutions, especially in water-scarce areas. Future research should focus on long-term stability, biofilm dynamics, and microbial community analysis to enhance scalability and efficiency.

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Ultimate article endorsement and guarantee: Bilal A. Alarabi.

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The authors state that they have no conflicts of interest concerning this study.

Abbreviations:

MFC: Microbial Fuel Cell
BOD_5:5-day Biochemical Oxygen Demand
TOC: Total Organic Carbon
TSS: Total Suspended Solids
TDS: Total Dissolved Solids
IMViC: Indole, Methyl Red, Voges-Proskauer, Citrate—a biochemical test suite for coliform identification
ANOVA: Analysis of Variance
ANCOVA: Analysis of Covariance
PERMANOVA: Permutational Multivariate Analysis of Variance
SD: Standard Deviation
BSL-2: Biosafety Level 2
mA/h: milliampere per hour).

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