IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Energy Recovery And Water Desalination Using Microbial Fuel Cell

[1]Aiswarya S Shenoy, [2]Binslet Biju, [3]S Athulya, [4]Harshananda T N

[1]Student, [2]Student, [3]Student, [4]Assistant Professor

[1]Department of Civil Engineering, [2]Department of Civil Engineering, [3]Department of Civil Engineering, [4]Department of Civil Engineering,

[1] Adi Shankara Institute of Engineering and Technology Kalady, Ernakulam, India, [2] Adi Shankara Institute of Engineering and Technology Kalady, Ernakulam, India, [3]Adi Shankara Institute of Engineering and Technology Kalady, Ernakulam, India,
[4] Adi Shankara Institute of Engineering and Technology Kalady, Ernakulam, India,

Abstract: Fresh water, a renewable but finite resource, faces scarcity due to excessive human consumption. With less than 3% of global water being fresh, desalination is crucial, albeit energy-intensive and costly. This project investigates sustainable solutions using microbial desalination cells (MDCs), powered by electro-active bacteria in dairy wastewater. Biochar from nutmeg enhances bacterial efficiency by increasing surface area. Potassium permanganate aids fuel cell function, while ceramic membranes support economical ion exchange. Monitoring includes energy production capacity, and desalination efficiency. The desalination efficiency can be measured based on the chloride content which is indirectly correlated to salinity. The characteristics of dairy waste water and sea water was studied. Dairy waste water showed a high pollution level. So, biological treatment should be provided. The feasibility of MDC in the pretreatment of dairy waste water is investigated through this project. The efficiency of MDC under various parameters like biochar concentration, potassium permanganate addition, number of days of treatment, electrode capacity will be analysed through this project. Key objectives include evaluating desalination potential of MDC using dairy waste water substrate aided with activated carbon as anolyte material, to study effect of nutmeg biochar on voltage generation, to understand the feasibility of potassium permanganate as electron acceptors in MDC, to analyze the treatment efficiency of MDC for dairy waste water.

***Index Terms* -** Additives, biochar, ion exchange membranes, Microbial desalination cell

I. INTRODUCTION

Freshwater scarcity has emerged as a critical global issue, significantly impacting human health, agriculture, industry, and environmental sustainability. Driven by an array of interrelated factors including rapid population growth, climate change, pollution, over-extraction, and geographical disparities the challenge of securing adequate freshwater resources is becoming increasingly urgent. Presently, only about 3% of Earth's water is freshwater, with a mere fraction of less than 1% readily accessible for direct human use in rivers, lakes, and shallow aquifers This scarcity is exacerbated by the expanding global population, which now exceeds 7 billion, leading to heightened demand for water across urban, agricultural, and industrial sectors. Concurrently, climate change is disrupting precipitation patterns and intensifying the frequency and severity of extreme weather events, such as droughts and floods, which further strain available water resources. Pollution from industrial activities, agricultural runoff, and inadequate waste management is contaminating freshwater sources, rendering water unsafe for consumption and increasing the cost of water treatment. Over-extraction of groundwater and surface water for various uses leads to the depletion of natural reserves, degrading ecosystems and threatening long-term water availability. Additionally, arid and semi-arid regions face chronic water shortages due to limited natural freshwater resources, with economic barriers exacerbating these issues by hindering the development of necessary water infrastructure and management systems.

In contrast, saline water—comprising approximately 97% of Earth's water— remains largely unsuitable for most human applications due to its high salt concentration. This presents a significant challenge as converting saline water into potable water becomes crucial for addressing the deficit in accessible freshwater. Desalination technologies have emerged as key solutions for this problem, offering methods to remove salts and impurities from saline sources.

Microbial Desalination Cells harness the power of microorganisms to remove salts from water, transforming saline and brackish water into potable sources. This technology operates through the use of microbial processes to desalinate water while simultaneously treating wastewater. Traditional desalination methods, while effective, are often limited by high energy requirements and operational costs. In response to these challenges, the development of Microbial Desalination Cells (MDCs) represents a promising advancement in the quest for sustainable water treatment solutions. Microbial Desalination Cells leverage the capabilities of microorganisms to address two major global issues simultaneously: freshwater scarcity and wastewater management. MDCs use microbial electrochemical processes to desalinate water while simultaneously treating wastewater. This dual functionality is achieved through the interaction of microorganisms with electrodes in a specially designed cell, which facilitates both ion removal and pollutant degradation. The core operation of MDCs involves microorganisms that produce bioelectricity as they metabolize organic matter in wastewater This bioelectricity drives the desalination process by generating an electrochemical gradient that removes ions from the water. The result is a reduction in salinity and the production of cleaner, potable water. At the same time, the technology helps in treating wastewater, including challenging contaminants such as black water, thus enhancing environmental sanitation. MDC have the potential to produce potable water from abundant ocean sources, improving access to clean water in arid and underserved regions. Additionally, the bioelectricity generated by MDCs can provide power to isolated and rural areas where traditional energy infrastructure may be lacking or economically unfeasible. Since the inception of MDC technology, extensive research has been conducted to explore its applications, optimize its performance, and address its limitations.

II. Microbial Fuel Cell

Microbial Desalination Cells harness the power of microorganisms to remove salts from water, transforming saline and brackish water into potable sources. This technology operates through the use of microbial processes to desalinate water while simultaneously treating wastewater. Traditional desalination methods, while effective, are often limited by high energy requirements and operational costs. In response to these challenges, the development of Microbial Desalination Cells (MDCs) represents a promising advancement in the quest for sustainable water treatment solutions.

Microbial Desalination Cells leverage the capabilities of microorganisms to address two major global issues simultaneously: freshwater scarcity and wastewater management. MDCs use microbial electrochemical processes to desalinate water while simultaneously treating wastewater. This dual functionality is achieved through the interaction of microorganisms with electrodes in a specially designed cell, which facilitates both ion removal and pollutant degradation. The core operation of MDCs involves microorganisms that produce bioelectricity as they metabolize organic matter in wastewater This bioelectricity drives the desalination process by generating an electrochemical gradient that removes ions from the water. The result is a reduction in salinity and the production of cleaner, potable water. At the same time, the technology helps in treating wastewater, including challenging contaminants such as black water, thus enhancing environmental sanitation.

MDC have the potential to produce potable water from abundant ocean sources, improving access to clean water in arid and underserved regions. Additionally, the bioelectricity generated by MDCs can provide power to isolated and rural areas where traditional energy infrastructure may be lacking or economically unfeasible. Since the inception of MDC technology, extensive research has been conducted to explore its applications, optimize its performance, and address its limitations.

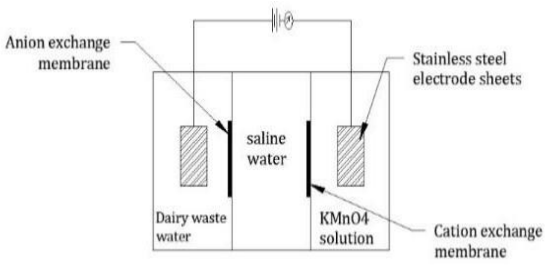

Figure 1: A schematic representation of MDC

III. METHODOLOGY

An MDC was employed to determine the efficiency of desalination and the generation of voltage when using dairy wastewater as the substrate in the anodic chamber with a zinc electrode, and potassium permanganate as the catholyte with a carbon electrode to aid the electrochemical process. The experimental objective was to establish the effects of different dosages of potassium permanganate on the generated voltage over time. Effect of various dosages of activated carbon on generated voltage over time.

Table 1 Constituents of synthetic dairy waste water

Constituents	Concentration (g/l)
glucose	0.18
Yeast	0.02
Milk powder	1.50
Starch	0.03
Magnesium sulphate	0.10
Potassium dihydrogen phosphate	0.025
Dipotassium hydrogen phosphate	0.018
Sodium nitrate	0.05
Sodium acetate	2
Ammonium chloride	0.15
Calcium carbonate	0.15

3.1 Evaluation Of Desalination Efficiency Of MDC

Table 2 Trials using synthetic waste water, KMNO4 (1g,2g,3g), Biochar 3mg/l

Characteristics	**Sample 1**	**Sample 2**	**Sample 3**
pH	7.7	7.33	7.12
Turbidity (NTU)	9.4	8.3	7.6
Conductivity (mS/m)	515	460	325
Chloride (mg/l)	2537	2266.8	1602
Salinity (mg/l)	4583	4081	2893

The observation that the Ph remained close to neutral throughout the experiment suggests that the desalination process did not significantly alter the chemical composition of the seawater. The stability in Ph is crucial, as extreme Ph Fluctuations can be detrimental to the overall efficiency and sustainability of the desalination process. Moreover, the neutral Ph range is conductive to the optimal functioning of the microorganisms present in the system, which play a vital role in removing organic pollutants.

The gradual decrease in conductivity and salinity of the seawater during desalination can be attributed to the migration of ions from the middle compartments. This phenomenon is consistent with the principles of electrodialysis, where ions are transported through ion-exchange membranes under the influence of an electric field. As the ions migrate, the conductivity and salinity of the seawater decrease, resulting in freshwater that is suitable for various applications

3.2 Effectiveness Of Potassium Permanganate In Voltage Generation with Optimum Biochar Dosage

Table 3 Trials using KMNO4 (1g,2g,3g), treatment time (1 hr,2hr,5hr,10hr), biochar 3g

Experiment	Initial wt of KMNO4 (g)	Voltage after 1 hour (V)	Voltage after 2 hour (V)	Voltage after 5 hour (V)	Voltage after 10 hour (V)
Trial 1	1g	1.72	1.74	1.68	---
Trial 2	2g	1.74	1.76	1.82	1.80
Trial 3	3g	1.79	1.83	1.98	2.12

The table demonstrates that increasing the initial weight of potassium permanganate ($KMnO_4$) leads to higher voltage generation over time, with the highest voltage recorded in Trial 3 (3g $KMnO_4$), reaching 2.12V after 10 hours. Voltage generally increases with reaction time, except in Trial 1 (1g $KMnO_4$), where no data is recorded at 10 hours, suggesting a possible depletion of reactants. Trial 2 (2g $KMnO_4$) shows moderate voltage generation, peaking at 1.80V after 10 hours. These results indicate that a higher $KMnO_4$ concentration enhances voltage generation, with 3g being the most effective dosage under the given conditions.

3.3 Effectiveness of Activated carbon in voltage generation with optimum KMNO4 dosage

Table 4: Trials using Biochar(1g,2g,3g), treatment time(1hr,2hr,5hr,10hr), KMNO4 3g

Experiment	Initial wt of Biochar (g)	Voltage after 1 hour (V)	Voltage after 2 hour (V)	Voltage after 5 hour (V)	Voltage after 10 hour (V)
Trial 1	1g	1.2	1.27	1.31	1.36
Trial 2	2g	1.38	1.42	1.49	1.51
Trial 3	3g	1.69	1.71	1.78	1.86

The table shows the effectiveness of activated carbon in voltage generation with a constant $KMnO_4$ dosage of 3g and varying biochar amounts. The results indicate that higher biochar concentrations lead to increased voltage output over time, with Trial 3 (3g biochar) producing the highest voltage of 1.86V after 10 hours. Voltage gradually increases in all trials, but the rate of increase is more significant in higher biochar dosages. Trial 1 (1g biochar) generates the lowest voltage, reaching only 1.36V at 10 hours. This suggests that biochar enhances voltage generation, with 3g being the most effective dosage in this experiment.

3.4 Treatment Efficiency Of MDC On Dairy Waste Water

Table 5:Trials using optimum dosage of KMNO4 and Biochar

Characteristics	Sample 1	Sample 2	Sample 3
pH	6.48	6.56	6.7
Salinity (mg/l)	1470	1356	1240
Conductivity (mS/m)	123	112	102
TDS (mg/l)	586	565	533
Chemical oxygen demand (mg/l)	800	736	712

The table presents the treatment efficiency of MDC on dairy wastewater using an optimal dosage of $KMnO_4$ and activated carbon. The results indicate an improvement in water quality across samples, with increasing pH values (from 6.48 to 6.7), decreased salinity (from 1470 mg/L to 1240 mg/L), and reduced conductivity (from 123 mS/m to 102 mS/m). Additionally, total dissolved solids (TDS) and chemical oxygen demand (COD) show a declining trend, signifying effective removal of contaminants. Sample 3 exhibits the best treatment results, with the lowest salinity, conductivity, TDS, and COD, suggesting that the applied treatment effectively enhances wastewater quality for potential reuse or discharge.

IV. RESULTS AND DISCUSSION

4.1 Treatment efficiency of MDC on dairy waste water on optimum dosages of KMNO4 & Biochar

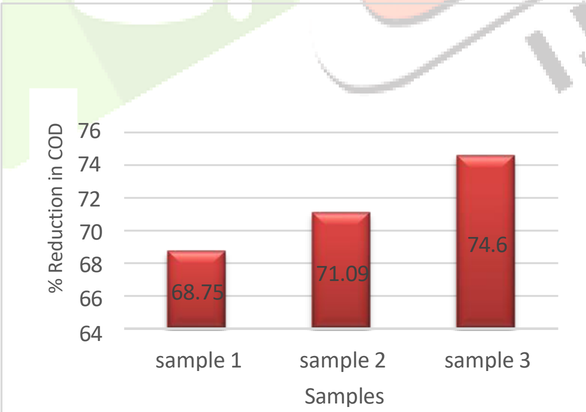

Figure 2: graphical representation for COD removal

The graph illustrates the treatment efficiency of Microbial Desalination Cells (MDCs) in treating dairy wastewater, utilizing optimal dosages of potassium permanganate ($KMnO_4$) and biochar. The data showcases the percentage reduction in Chemical Oxygen Demand (COD) for three different samples, demonstrating the effectiveness of the treatment process in breaking down organic pollutants. Sample 1 achieved a 68.75% reduction in COD, indicating a significant improvement in wastewater quality. Sample 2 exhibited a slightly higher efficiency, reaching 71.09% COD reduction, while Sample 3 showed the highest reduction at 74.6%, reflecting optimal treatment performance under the given conditions. The progressive increase in COD reduction across the samples suggests that the combined use of $KMnO_4$ and biochar enhances the oxidation and adsorption processes, leading to improved organic matter removal. These findings highlight the potential of MDC technology in achieving effective wastewater treatment through optimized operational parameters, making it a sustainable and efficient approach for reducing pollution in dairy effluents.

4.2 Evaluation of Desalination efficiency of MDC using KMNO4 (1g,2g,3g), Biochar optimum concentration

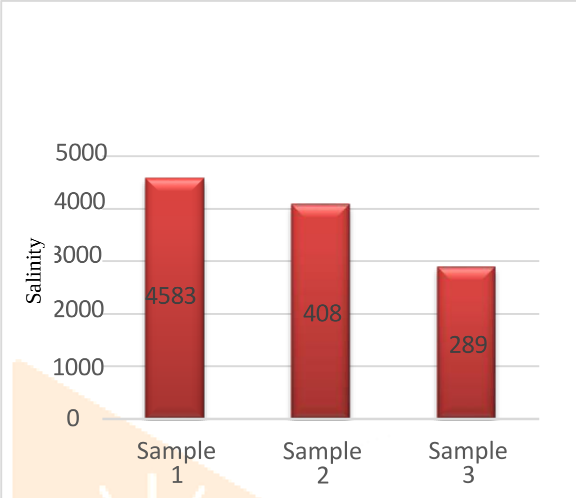

Figure 3:graphical representation for salinity

The graph evaluates the desalination efficiency of Microbial Desalination Cells (MDCs) using potassium permanganate ($KMnO_4$) and biochar at optimal concentrations. The results indicate a significant reduction in salinity levels across the three samples, demonstrating the effectiveness of the treatment process. Sample 1 recorded the highest salinity value at 4583 mg/L, followed by Sample 2at 408 mg/L, and Sample 3 at 289 mg/L, showing a clear trend of decreasing salinity as the treatment conditions were optimized. This suggests that increasing the concentration of $KMnO_4$ and biochar enhances desalination efficiency, possibly by improving ion removal and conductivity reduction. The findings highlight the potential of MDC technology in achieving effective desalination while simultaneously generating energy, making it a promising approach for sustainable water treatment.

4.3 Effectiveness of potassium permanganate in voltage generation with optimum biochar dosage

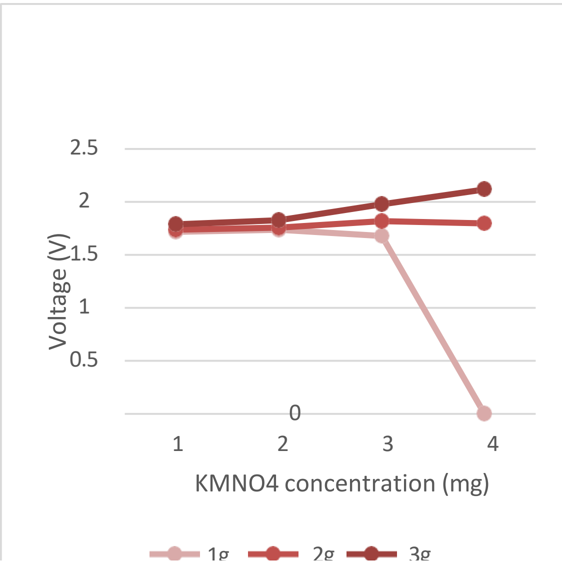

Figure 4: graphical representation of voltage generation on varying KMNO4

The graph evaluates the effectiveness of potassium permanganate ($KMnO_4$) in voltage generation with an optimum biochar dosage, analyzing how different concentrations of $KMnO_4$ (1g, 2g, and 3g) influence the voltage output. Throughout most of the concentration range, the voltage remains relatively stable, fluctuating around 1.5V to 2V, suggesting that $KMnO_4$ enhances electrochemical performance. However, a sharp decline in voltage is observed at 4 mg for the 1g $KMnO_4$ condition, which may indicate a threshold beyond which the system's efficiency drops, possibly due to excess oxidant affecting microbial activity or electron transfer efficiency. This suggests an optimal concentration range for $KMnO_4$, beyond which further addition may negatively impact performance rather than improving voltage generation.

4.4 Effectiveness of Biochar in voltage generation with optimum $KMNO_4$ dosage

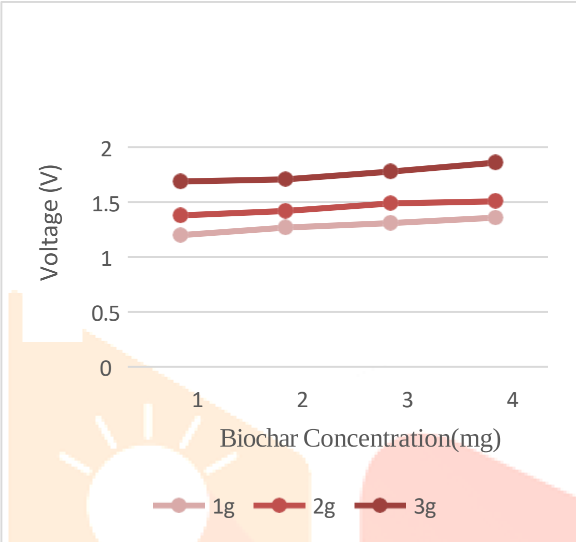

Figure 5: graphical representation of voltage generation on varying biochar concentration

The graph illustrates the effect of varying $KMnO_4$ concentrations (1g, 2g, 3g) on voltage generation with optimum activated carbon dosage. As the concentration increases, the voltage output also improves, indicating enhanced electrochemical activity and better electron transfer efficiency. The highest voltage is observed at 3g $KMnO_4$, suggesting an optimal concentration for maximizing energy generation. Beyond this point, the trend appears to stabilize, implying a saturation effect where further increases may not significantly enhance performance.

V. CONCLUSION

The observation that the pH remained close to neutral throughout the experiment suggests that the desalination process did not significantly alter the chemical composition of the seawater. This stability in pH is crucial, as extreme pH fluctuations can be detrimental to the overall efficiency and sustainability of the desalination process. Moreover, the neutral pH range is conducive to the optimal functioning of the microorganisms present in the system, which play a vital role in removing organic pollutants.

The gradual decrease in conductivity and salinity of the seawater during desalination can be attributed to the migration of ions from the middle compartments. This phenomenon is consistent with the principles of electrodialysis, where ions are transported through ion-exchange membranes under the influence of an electric field. As the ions migrate, the conductivity and salinity of the seawater decrease, resulting in freshwater that is suitable for various applications.

The reduction in Chemical Oxygen Demand (COD) observed in the Microbial Desalination Cells (MDCs) can be attributed to two distinct mechanisms. In the absence of granular coconut shell carbon, the reduction in COD is primarily due to microbial utilization, where microorganisms break down organic pollutants into carbon dioxide and water. In contrast, the presence of granular coconut shell carbon enhances COD removal through adsorption of organic compounds onto the carbon surface, followed by microbial utilization. This synergistic effect highlights the potential of integrating adsorption and biodegradation processes in MDCs to achieve efficient removal of organic pollutants.

VI. Acknowledgment

We would like to express our sincere gratitude to Adi Shankara Institute of Engineering and Technology for providing the resources and facilities necessary for conducting this study. We are deeply thankful to the the Civil Department for their constant support, guidance, and encouragement throughout the duration of this project. Their expertise and thoughtful advice have been invaluable to the successful completion of this work.

References

[1] S. Mishra et al., Enhancing electro-kinetics and desalination efficiency through catalysts and electrode modifications in microbial desalination cells, Journal of Environmental Management, Volume 366,121719(2024).

[2] G. Rangel et al., Comparative analysis of three cathodic electron acceptors, The International Journal of Electrical and Power Engineering, Volume 4(1),114584, (2010).

[3]]S. Zhao et al., Application of biochar in microbial fuel cells: Characteristic performances, electron-transfer mechanism, and environmental and economic assessments, Ecotoxicology and Environmental Safety, Volume 267 ,115643,(2023).

[4] Mostafa M et al., An extended bio-electrochemical model for wastewater treatment and water desalination: Insights into the performance of microbial desalination cells, Desalination, Volume 586 ,117791,(2024).

[5] S. Prakash et al., Enhanced performance of novel microbial desalination cell using sago effluent as an anolyte: A response surface optimization approach, Journal of Water Process Engineering, Volume 59, 105004,(2024)

[6] M. Shatat et al., Water desalination technologies utilizing convectional and renewable energy sources, International journal of low carbon technologies, Volume 9, 102569, (2014)

[7] A. Zarouk et al., Developments in the microbial desalination cell technology: A review, Water-Energy Nexus, Volume 4,112548,(2021)

[8] S.Aber et al., microbial desalination cell for sustainable water treatment: ac critical review ,global challenges, Volume 7, 117540,(2023)

[9] A.Odunlami et al.,microbial desalination cell :technical review, south African journal of chemical engineering ,Volume 46,. 10269185,(2023)

[10] Sabina et al., Optimization of MFC operation for wastewater treatment by ceramic membrane, International journal of hydrogen energy, Volume72, 400411,(2024).

[11] Tawalbeh et.al., Microbial desalination cells for water purification and power generation: A critical review, Energy , Volume 209,118493,(2020) .

[12] Jatoi et.al., A comprehensive review of microbial desalination cells for present and future challenges, Desalination, Volume 535,115808, (2022).

[13] Zhang et.al., Microbial desalination fuel cells: Progress and prospects, Environmental science: water research and technology, volume 8. 115808, (2022).

[14] Tawalbeh, M., et al. (2020). Microbial desalination cells for water purification and power generation: A critical review. *Energy*, *209*, 118493.

[15] Xiaoxin Cao, et al.(2009)*Environmental Science & Technology 43* (18), 7148-7152

[16] Sikder, S., et al. (2024). Efficiency of microbial desalination cells in treating wastewater, desalinating saltwater, and generating bioelectricity in Bangladesh. *RSC Advances*, *14*(52), 38547-38559.

[17] Qu, Y., et al. (2012). Simultaneous water desalination and electricity generation in a microbial desalination cell with electrolyte recirculation for pH control. *Bioresource Technology*, *106*, 89-94.

[18] Zhang, J., et al. (2018). Life cycle assessment of a microbial desalination cell for sustainable wastewater treatment and saline water desalination. *Journal of Cleaner Production*, *200*, 900-910.

[19] Dongre, A., et al. (2022). Effective salt removal from domestic reverse osmosis reject water in a microbial desalination cell. *3 Biotech*, *12*(8), 172.

[20] Tawalbeh, M., et al. (2020). Microbial desalination cells for water purification and power generation: A critical review. *Energy*, *209*, 118493