Water Desalination Using Microbial Desalination Cells

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Abstract

Using different configurations and modifying the conventional design of MDCs, such as: B. Using three microbial desalination units, whose chambers are injected with synthetic wastewater and inoculated with activated sludge and anaerobic aged sludge, is one way to improve the desalination process. Over the course of four months, the MD C produced bioenergy and was able to remove more than 89% of NaCl from a brine solution with an initial salt concentration of 9000 mg TDS/L. In addition, the TDS content of the desalinated water of 1000 g TDS L/1 d/1 (volume of brine solution) met the drinking water standard. The purpose of this study is to desalinate water using microbial fuel cell technology..

1. INTRODUCTION

These days, as the world's population increases, so does the demand for energy and water. The most vital resource for everyone on the planet is drinking water. But there aren't many natural resources available, and in many parts of the world, there is a shortage of groundwater. An advanced new approach that can provide better wastewater handling while using less energy is required to reduce the amount of energy required for saltwater desalination and wastewater management. The microbial desalination cell (MDC) is a practical device for desalinating saltwater [1]. No more energy is needed for MDCs [2] In order for MDC for seawater desalination to become commercially viable, real-world operational conditions, distinct reactor designs, and process optimization must be assessed, even if the lab-scale proof of concept has been completed [3].

Since water makes up over 75% of the earth's surface, it is one of its most abundant resources. However, many countries, especially in the Middle East and Africa, suffer from a serious shortage of drinkable water. This seeming contradiction results from the fact that 97.5 percent of the water on Earth is contained in the seas, despite the fact that groundwater, lakes, and rivers together provide the majority of the water needed by humans and animals. To solve the issue of water scarcity, better and more affordable techniques for desalinating saltwater are needed**.** To solve the problem of water scarcity, better and more affordable techniques for desalinating saltwater are needed. This page provides a detailed analysis of water desalination systems, which generate fresh water from salt water using either conventional or alternative energy sources [4].The latest developments in seawater desalination techniques, with a focus on membrane-based technologies, as well as identifying chances to advance new, potentially disruptive technologies through advances in material science, procedure engineering, and system integration, as well as step up developments to established technologies[5]. Although there are many different types of desalination technologies, they can be roughly divided into two groups according to their degree of development: Both sophisticated and basic desalination methods Two types of advanced and proven technologies include thermal and membrane desalination [6].

The earliest technique for turning salt water into drinkable water is thermal desalination, which just simulates the natural water cycle. Thermal desalination is sometimes called phase-change desalination since the process entails a phase transition from liquid to vapor and then back again from vapor to liquid. The processes, which are driven by thermal energy, result in some of the feed being evaporated. Water is then produced by condensing the evaporated feed. From the 1950s through the 1970s, thermal desalination was the main desalination technique[7] .Generally speaking, thermal methods are recommended where**:**

1)lowenergycosts
2)Thefeedwater'shighsalinityandtemperature
3) cogeneration, which produces both water and electricity at a power plant's precise site[8] . Thermal desalination (MED) use multi-stage flash (MSF) or multi-effect desalination techniquesSeawater is used as the feed water for 100% of MSF plants and 92% of MED plants [9].

3. MATERIALS AND METHODS

3.1 Mineral salts medium (MSM):

The steps mentioned in were followed to prepare this MSM (Mineral Salts Medium)solution[10] . The media solution was made by dissolving the following substances in distilled water: 0.42 g/L $NaHCO_3$, 0.56 g/L $(NH_4)_2SO_4$, 0.20 g/L $MgSO_4.7H_2O$, 15 mg/L $CaCl_2$, and 1 mg/L $FeCl_3.6H_2O$. The solution was then cooled below
oxygen and autoclaved for 20 minutes at 121 °C.

3.2 Catholyte

In the cathodic chamber of the MDCs, a phosphate buffer solution (PBS) was utilized as a catholyte solution and
an oxidant. The catholyte contains 32.930 g/L of $K_3Fe(CN)_6$, 3.1167 g/L of NaH_2PO_4, and 20.7492 g/L of Na_2HPO_4 [11].

3.3. Synthetic wastewater

By using a carbon exporter with an initial COD concentration of 300 1200 mg/l, acetate-based wastewater was produced artificially. The structure of the synthetic wastewater is shown in Table 1. There are 0.56 g/L of trace mineral salts in the solution. (NH_4) $FeCl_3•6H_2O$, 20 mg $MnSO_4•H_2O$, 0.42 g $NaHCO_3$, $2SO_4$, 0.20 g $MgSO_4•7H_2O$, and 15 mg $CaCl_2$ are all present in the solution [11]. The salt solution was combined with filter sterilized acetate solution after autoclaving at 121 °C and chilling for 15 minutes below oxygen-free nitrogen gas.

Component	Mg/l
Acetate	**300-1500**
$NaHCO_3$	480
NH_4Cl	95.5
K_2HPO_4	10.5
KH_2PO_4	5.25
$CaCl_2.2H_2O$	63.1
$MgSO_4.7H_2O$	19.2

Table (1): The structure of synthetic wastewater[11]

4. METHODOLOGY

6000–9000 mg/l of sodium chloride is added to deionized water to create the middle chamber of brine. The removal percentage (TDS) is measured daily by looking outdoors.

4.1. Total dissolved solids (TDS)

TDS is a term used to describe the dissolved organic and inorganic salts in water, specifically sodium, potassium, chloride, calcium, magnesium and sulfate. The WHO states that 600 mg/l TDS is the ideal level in drinking water [12]. The Bureau of Indian Standards [13] states that the permissible limit for TDS in India is 500 mg/L. Therefore, it is essential to remove dissolved particles from salt water [14]. Although groundwater can have higher TDS, rivers can range from 20 to 2,000 mg/l. Excessive levels of water pollutants can have a laxative effect and cause an unpleasant taste. Total dissolved solids (TDS) levels are measured because, at high concentrations, they can make drinking water, agricultural irrigation and aquatic life in rivers unsafe. As a result, some metals may corrode or form gas bubbles. TDS levels in water bodies are affected by a variety of factors, including rainfall entering the water body (rainwater is actually clean, with a TDS of less than 10 ppm), human activities, the type of rock and soil, where the water flows, and more. Positively charged sodium, calcium, magnesium, potassium and iron ions and negatively charged chloride, bicarbonate, carbonate and sulfate ions are the main dissolved components in water that can cause the above problems. The suspended solids in 50 mL of the sample (V) are removed with filter paper, then weighed (W1) and filled into the filtered mold. The sample is then dried at 105 °C for three hours, and the dissolved solids in the beaker are weighed a second time (W2). The TDS is then measured:

$$T.D.S\ (mg\backslash l) = \frac{W2-W1}{V} * 1000 * 1000 \quad (1)$$

where:
V= volume of sample, (L).
W1=weight of cup full by filtered sample, (g).
W2= weight of cup with the dissolved solid, (g).

4.2. Salt removal performance

The expression of MDC is primarily determined by the desalination efficiency, which can be modified by substrate availability and order internal resistance [9]. Total desalination rate (TDR), commonly referred to as desalination efficiency, is a measure of the amount of salt removed. The efficiency of desalination determines the degree to which the conductivity of the brine is reduced [15]. TDR is calculated based on the change in NaCl concentration at the inlet and outlet and the hydraulic retention time of the brine [16]. Higher temperatures are expected to increase the permeability of ion exchange membranes and the conductivity of electrolytes, thereby improving desalination efficiency. In order to achieve an ideal environment for optimal desalination efficiency, an average substrate concentration is also required. Low substrate concentration reduces the effectiveness of desalination and hinders the microbial oxidation process, while low internal resistance and high substrate availability support the process [17].

$$R = (C_{initial} - C_{end} / C_{initial} * 100\%) \quad (2)$$

where $C_{initial}$ and C_{end} are the initial and the end salt concentrations in one desalination cycle.

5. RESULTS AND DISCUSSION

5.1. Salinity removal

In a three-compartment MDC, salinity reduction of 6000–9000 mg/L NaCl solutions with conductivity comparable to seawater was greater than 90%. However, high salinity reductions require large amounts of fresh water. MDCs may be more efficient in reducing salinity. For example, wastewater requires only two to three times as much desalinated water. These results suggest that a more feasible application for which MDCs are more likely to be used is in fractional desalination from saltwater. MDCs can also be used for brackish water desalination [18]. Water in the middle compartment was effectively desalinated to remove all three initial salt concentrations. Depending on the change in solution accessibility, salt removal at each initial salt concentration was approximately 87% (6000 mg/L flow rate 10 mL/min), 80% (6000 mg/L flow rate 20 mL/min), 89% (9000 mg/L flow rate 10 ml/min), and 84% (9000 mg/L flow rate 20 ml/min) (Figure 6). The conductivity of the solution in the open circuit control barely changes. Your TDS removal will decrease with longer HRT. The large difference between its salt result volume and anode volume may be the reason for its advantage, as can be seen from the lower TDS removal based on the amount of wastewater. In addition, IEM (ion exchange membrane) with a large surface area will improve ion transfer and the resulting salt removal. The results show that the amount of salt removed increases with the shortening of the desalination cycle and speed. Osmotic pressure and electric field effects are the main factors causing the salinity reduction in the desalination chamber.

When the electric field is present, Na+1 and Cl-1 migrate to the cathode chamber and anode chamber respectively. When the conductivity of the anode chamber is lower than that of the desalination chamber, the osmotic pressure between the two chambers changes. Now, the electric field and osmosis work together to reduce the salt concentration in the desalination chamber. As the salt content decreases, the osmotic effect weakens, the desalination slows down, and the ionic strength and osmotic pressure difference between the anode chamber and the desalination chamber solution also decrease.

Due to the large difference in osmotic pressure, the desalination rate of the 9 g/L saline solution was slightly higher than that of the 6 g/L saline solution at a flow rate of 10 mL/min without bacterial electricity production. The desalination effect of the 6 g/L solution was significantly improved by generating bioelectricity. In the case of the 9 g/L solution, the increase in chloride concentration in the anode chamber may have a negative impact on the electricity generation ability of the bacteria.

5.1.1. TDS Removal with Flow rate 10ml/min and TDS=(6000mg/l,9000mg/l) (Salt Removal%)

After 10 days of operation, When the sodium chloride salt concentration was (6000mg/l). the TDS elimination process had reached a steady state. The average TDS content is determined after reaching steady state. The highest TDS reduction efficiency the effluent's average (87%) Effluent TDS (mg/l)(was 780 mg/l).

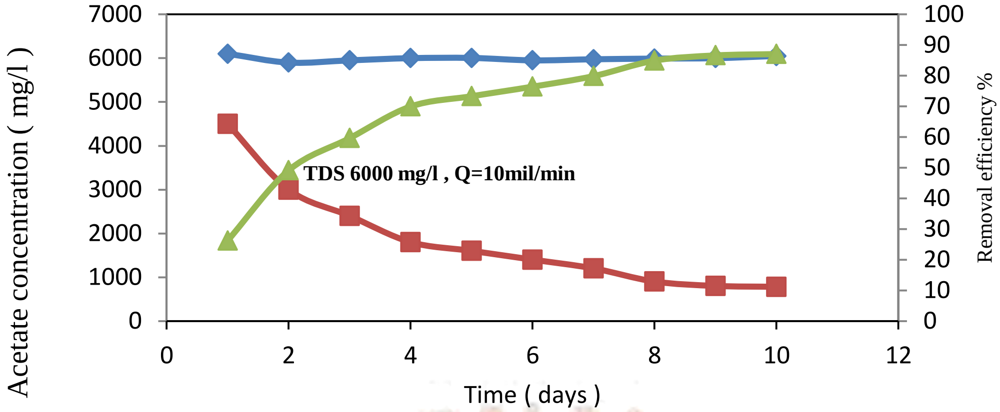

Fig. 1: TDS Removal with Flow rate 10ml/min (Nacl=6000mg/l)

5.1.2. (%Salt Removal)TDS Removal with Flow rate 20ml/min and TDS=6000mg/l

After 14 days of operation, When the sodium chloride salt concentration was 6000mg/l. the TDS elimination process had reached a steady state. The average TDS content is determined after reaching steady state. The highest TDS reduction efficiency the effluent's average 80% Effluent TDS (mg/l) was1188mg/l

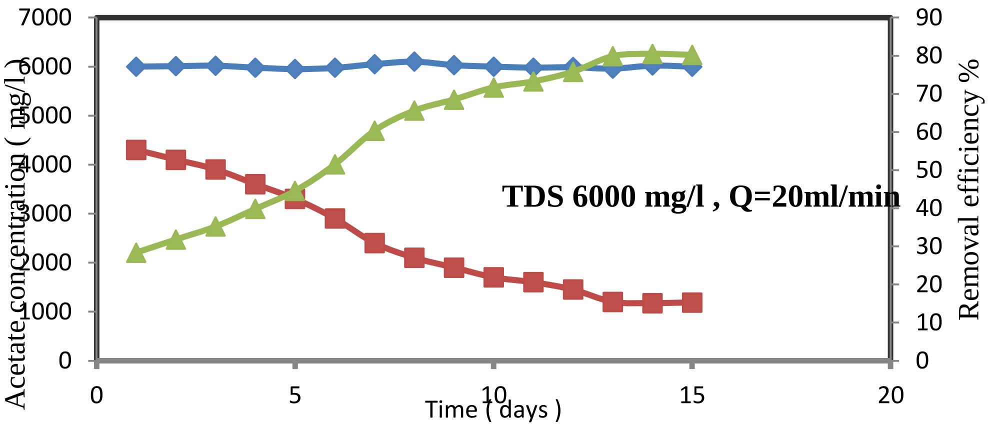

Fig. 2: TDS Removal with Flow rate 20ml/min (Nacl=6000mg/l)

5.1.3. TDS Removal with Flow rate 10ml/min and TDS=9000mg/l (Salt Removal%)

After 10 days of operation, When the sodium chloride salt concentration was 9000mg/l. the TDS elimination process had reached a steady state. The average TDS content is determined after reaching steady state. The highest TDS reduction efficiency the effluent's average 89% Effluent TDS (mg/l) was1000mg/l.

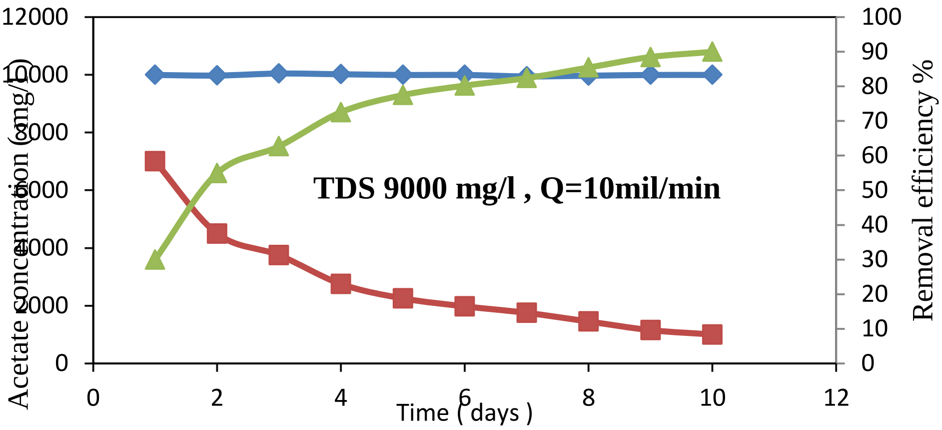

Fig. 3: TDS Removal with Flow rate 10ml/min (Nacl=9000mg/l)

5.1.4 TDS Removal with Flow rate 20ml/min and TDS=9000mg/l (Salt Removal%)

After 15 days of operation, When the sodium chloride salt concentration was 9000mg/l. the TDS elimination process had reached a steady state. The average TDS content is determined after reaching steady state. The highest TDS reduction efficiency the effluent's average 84% Effluent TDS (mg/l) was1400mg/l.

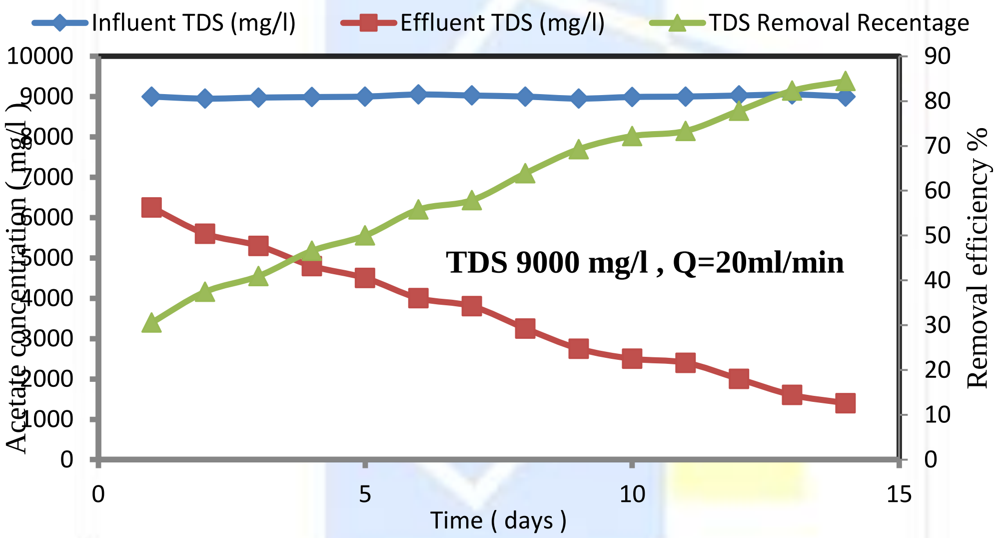

Fig. 4: TDS Removal with Flow rate 20ml/min (Nacl=9000mg/l)

Conclusion

To simultaneously generate renewable energy and clean wastewater and meet the growing energy demand, MDC has been demonstrated to be a viable technology. This work demonstrates a breakthrough in sustainable desalination using microbial desalination cells. Electrochemical ion adsorption on the electrodes of the MDC reactor was able to remove an average of 91% of the salt in the desalination chamber without adding salt to the anode or cathode chambers. Several MDC modifications were thoroughly analyzed considering their desalination capacity and power output. The performance of the MDC in desalination and production of coulombic efficiency was rigorously examined using many operating parameters. In this study, the application of microbial desalination cells was investigated. The MDC was able to remove more than 90% of NaCl (volume of salt results) at a TDS removal rate of 7.50 g TDS L/d. The TDS concentration in the desalinated water was within the acceptable range for drinking water, and the MDC produced the highest power density. The final power density of the MDC was 314.8 mW/m3. As a result of the results and lessons learned from this study, this can help develop more efficient desalination and wastewater treatment methods. This

The relatively small deviation between the experimental results and the predicted results at the beginning of the operation is due to the adaptation phase and the saturation of the membrane.

Due to the large difference in osmotic pressure, the 9 g/L brine solution has a slightly higher desalination rate than the 6 g/L brine solution without electricity production by bacteria and at a flow rate of 10 mL/min. The desalination of the 6 g/L solution is significantly improved by generating a biostream. In the case of 9 g/L, the increased chloride concentration in the anode compartment may have a negative impact on the electricity generation capacity of the bacteria

REFERENCES

[1] S. Sevda and I. M. Abu-Reesh, "Improved petroleum refinery wastewater treatment and seawater desalination performance by combining osmotic microbial fuel cell and up-flow microbial desalination cell," Environ. Technol. (United Kingdom), vol. 40, no. 7, pp. 888–895, 2019, doi: 10.1080/09593330.2017.1410580.

[2] X. Cao et al., "A new method for water desalination using microbial desalination cells," Environ. Sci. Technol., vol. 43, no. 18, pp. 7148–7152, 2009, doi: 10.1021/es901950j.

[3] S. Sevda, H. Yuan, Z. He, and I. M. Abu-Reesh, "Microbial desalination cells as a versatile technology: Functions, optimization and prospective," Desalination, vol. 371, pp. 9–17, 2015, doi: 10.1016/j.desal.2015.05.021

4- Shatat, Mahmoud, and Saffa B. Riffat. 2014. 'Water Desalination Technologies Utilizing Conventional and Renewable Energy Sources'. International Journal of Low-Carbon Technologies 9 (1): 1–19. https://doi.org/10.1093/ijlct/cts025.

5-. Amy, Gary, Noreddine Ghaffour, Zhenyu Li, Lijo Francis, Rodrigo Valladares Linares, Thomas Missimer, and Sabine Lattemann. 2017. 'Membrane-Based Seawater Desalination: Present and Future Prospects'. Desalination 401: 16–21. https://doi.org/10.1016/j.desal.2016.10.002.

6- Elsaid, Khaled, Enas Taha Sayed, Mohammad Ali Abdelkareem, Ahmad Baroutaji, and A. G. Olabi. 2020. 'Environmental Impact of Desalination Processes: Mitigation and Control Strategies'. Science of the Total Environment 740: 140125. https://doi.org/10.1016/j.scitotenv.2020.140125.

[7] Bruggen, Bart Van der, and Carlo Vandecasteele. 2002. 'Distillation vs. Membrane Filtration: Overview of Process Evolutions in Seawater Desalination'. Desalination 143 (3): 207–18. https://doi.org/10.1016/S0011-9164(02)00259-X.

[8] Mabrouk, Abdel Nasser, and Hassan E.S. Fath. 2015. 'Technoeconomic Study of a Novel Integrated Thermal MSF-MED Desalination Technology'. Desalination 371: 115–25. https://doi.org/10.1016/j.desal.2015.05.025.

[9] Jones, Edward, Manzoor Qadir, Michelle T.H. van Vliet, Vladimir Smakhtin, and Seong mu Kang. 2019. 'The State of Desalination and Brine Production: A Global Outlook'. Science of the Total Environment 657: 1343–56. https://doi.org/10.1016/j.scitotenv.2018.12.076.

[10] M. M. Ghangrekar, S. R. Asolekar, and S. G. Joshi, "Characteristics of sludge developed under different loading conditions during UASB reactor start-up and granulation," Water Res., vol. 39, no. 6, pp. 1123–1133, 2005, doi: 10.1016/j.watres.2004.12.018

[11] L. Wei, Z. Yuan, M. Cui, H. Han, and J. Shen, "Study on electricity-generation characteristic of twochambered microbial fuel cell in continuous flow mode," Int. J. Hydrogen Energy, vol. 37, no. 1, pp. 1067–1073, 2012, doi: 10.1016/j.ijhydene.2011.02.120.

[12] M. Ragab, A. Elawwad, and H. Abdel-Halim, "Evaluating the performance of Microbial Desalination Cells subjected to different operating temperatures," Desalination, vol. 462, no. September 2018, pp. 56– 66, 2019, doi: 10.1016/j.desal.2019.04.008.

[13]Organization, W.H., 2017. Guidelines for Drinking-Water Quality, fourth ed. Incorporating the First Addendum, World Health Org (WHO), Geneva (Licence: CC BY-NC-SA 3.0 IGO).

[14] S. A. Rahmaninezhad, N. Mehrdadi, and Z. Mahzari, "Using ultra filtration membrane in photo electrocatalytic desalination cell (UF-PEDC)," Desalination, vol. 486, no. November 2019, p. 114483, 2020, doi: 10.1016/j.desal.2020.114483.

[15] A. Ziaedini, H. Rashedi, E. Alaie, and M. Zeinali, "Performance assessment of the stacked microbial desalination cells with internally parallel and series flow configurations," J. Environ. Chem. Eng., vol. 6, no. 4, pp. 5079–5086, 2018, doi: 10.1016/j.jece.2018.07.051.

[16] A. Morel et al., "Microbial desalination cells packed with ion-exchange resin to enhance water desalination rate," Bioresour. Technol., vol. 118, pp. 243–248, 2012, doi: 10.1016/j.biortech.2012.04.093.

[17] M. Ragab, A. Elawwad, and H. Abdel-Halim, "Evaluating the performance of Microbial Desalination Cells subjected to different operating temperatures," Desalination, vol. 462, no. September 2018, pp. 56– 66, 2019, doi: 10.1016/j.desal.2019.04.008.

[18] H. Luo, P. E. Jenkins, and Z. Ren, "Concurrent desalination and hydrogen generation using microbial electrolysis and desalination cells," Environ. Sci. Technol., vol. 45, no. 1, pp. 340–344, 2011, doi:10.1021/es1022202.