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Enhanced Energy Recovery and Wastewater Treatment Efficiency in Microbial Desalination Cell

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Abstract: *Microbial desalination cells (MDC) is a type of microbial fuel cell (MFC) used for desalination of water. The process is known as a new energy-sustainable method for water treatment. The electric potential gradient created by exoelectrogenic bacteria desalinates water by driving ion transport through a series of ion-exchange membranes (IEMs). In this study, COD removal rate and electricity generation behavior between reactors with and without desalination function were compared. Further studies and deep understanding of the biochemical mechanisms involved indesalinationconcepts were investigated. Result showed that the power output from the MDC was about 2.1 times higher than MFC without desalination function. In addition, the MDC removed 66% of the salts and COD removal was improved by 52%. Desalination in MDCs enhanced wastewater characteristics by increasing the conductivity and stabilizing pH, which has reduced system resistance and maintained microbial activity. The results demonstrated that desalination can significantly beimproved inthe wastewater treatment process, electron transfer and electricity production.*

Keywords: *Microbial desalination cells; Microbial fuel cells; Wastewater treatment; Electricity generation*

1. INTRODUCTION

Current wastewater treatment processes and desalination technologies are highly energy intensive due to the power required for aeration, sludge treatment, high pressure membrane operation, or thermally driven distillation process. Renewable energies, such as solar, wind, hydroelectric and geothermal energies, provide alternative solutions to economical desalination processes and reduce the dependency on fossil fuels[1]. However, at the current stage, desalination powered by renewable energy costs more thanprocesses powered by conventional energy sources; although, in view of long term operation environmental benefits may balance the high costs of renewable sources [2, 3].

In recent years, bioelectrochemical systems (BESs) are mostly known as microbial fuel cells (MFCs), emerged as a promising technology for simultaneous wastewater treatment and energy recovery through direct production of electricity, fuels, or value added products[4, 5].Bioenergy from organic wastes represents a promising energy source that may be used to drive various processes, including desalination. By integrating waste treatment with desalination, we can maximize environmental benefits and extract energy contents from wastes before their being discharged into environment [6-8].

The first conceptual three-chambers MDC as desalination unit was introduced by Cao et al. [9] demonstrated that the desalination ratio reached to 90% after 24 h operation with ferricyanide as catholyte [9]. The conventional threechamberMDCs were modified and enhanced while in desalination chamberthe desalination efficiency was improved [10-13].

The purpose of present work was to investigate and conduct an extensive modification on MFCs while using the generated current fromthe microbial fuel cells (MDCs) for the removal of salts. The primary objectives of this study were COD removal rate and electricity generation behavior between reactors with and without desalination compartmentfor further understandingof the biochemical mechanisms involved in the MDC systems.

2. METHODS

2.1. FABRICATION OF REACTORS

In this study, acubic-shaped MDC and MFC were constructed. MDC was fabricatedsimilar to MFC with an additional chamber between anode and cathode compartments. Fig. 1 shows the schematic diagram and actual image of MFC and MDC. The MDC were consisted of three polycarbonatechambers (anode, desalination in the middleand cathode), separated by an anion exchange membrane (AEM) and a cation exchange membrane (CEM)supplied by Mega (Czech Republic). MFC were made of two anode and cathode compartments which were separated by a CEM. The volume of anode and cathode chambersin both reactors were 200mL, and the volume of desalination chamber in MDC was 120 mL.The electrode

material in the anode and the cathode of both reactors were consisted of carbon felt. The both reactors were operated in a same condition. In a closedcircuit, the external resistance was set at 1000 Ω to achieve a high currentgeneration; no external resistance was applied to an open circuit.

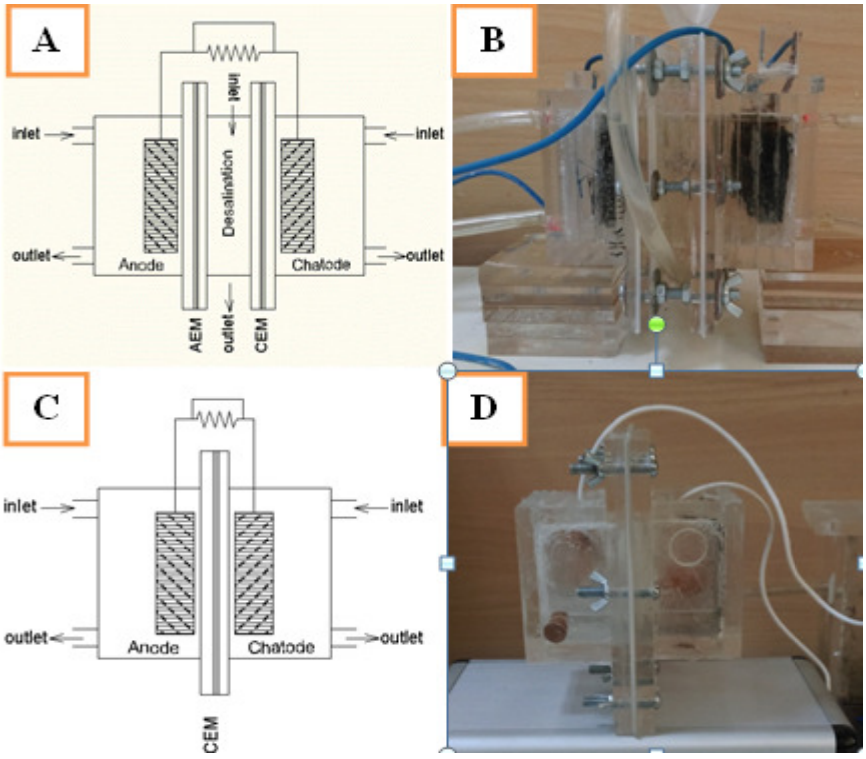

Fig. 1. Fabricated MDC and MFC: (A)Schematic diagram of MDC, (B) photograph image of MDC, (C) Schematic diagram of MFC and (D)photograph image of MFC

2.2. MEDIUM

The anode chamber of the MFC and MDC were fed with a same phosphate buffered sodium acetate solution, which contains (per liter of deionized water) 1.64 g CH_3COONa, 4.4 g KH_2PO_4, 3.4 g $K_2HPO_4•3H_2O$, 1.5 g NH_4Cl, 0.1 g $MgCl_2•6H_2O$, 0.1 g $CaCl_2•2H_2O$, 0.1 g KCl, and 10 mL of trace mineral metals solution. The trace-element stock solution was prepared by adding: 50 g $FeCl_2•4H_2O$, 1.25 g $ZnCl_2$, 12.5 g $MnCl_2•4H_2O$, 1.25 g $(NH_4)_6Mo_9O_{24}.4H_2O$, 3.75 g $CoCl_2•6H_2O$, 2.5 g $NiCl_2•6H_2O$, 0.75 g $CuCl_2•2H_2O$, and 1.25 g H_3BO_3into one literdeionized water.The anodicmedium solution was inoculatedwith anaerobic sludge from Babolwastewater treatmentplant (Babol, Iran).

The cathode chamber in both reactors was fed with a phosphate buffersolution containing (per liter in deionized water): 9.0 g KH_2PO_4, 8.0 g $K_2HPO_4•3H_2O$. The middle chamber in MDC was filled with saline solution as the water should be desalinated withNaClconcentrations of 30 g/L.

2.3. ANALYSES

Cell voltage (E) across an external resistor (R) was recorded using a data acquisition system (AEP-DG40- Iran). The current density (I, A) through the electrical circuit was determined while measuring voltage (E, V) according to given equation I = E/R.

The COD was measured using standard methodsfor the centrifuged sample. The supernatant of centrifuged samples were used in order to remove biomass[14]. The pH was measured using a pH meter (Hanna instruments, Italy).Salt concentration was evaluated by conductivity and TDSmeasurement using a conductivity meter (Hanna instruments, Italy). Thepercentage of desalination was calculated in terms of electrical conductivityof saltwater stated as follows:

$$\%\ Desalination = \frac{Initialconductivity - Finalconductivity}{Initialconductivity} \times 100 \quad (1)$$

3. RESULTS AND DISCUSSION

Synthetic wastewater withtotal COD value of 2000 mg/L was used as substrate in both MFC and MDC reactors. Fig. 2shows typical open circuit voltage profiles from the MFC and MDC. As comparing OCVs of both systems, the electricity production in the MDC was more reproducible and stable than MFC; in addition, MDC had longer batch cycle duration compared to MFC.

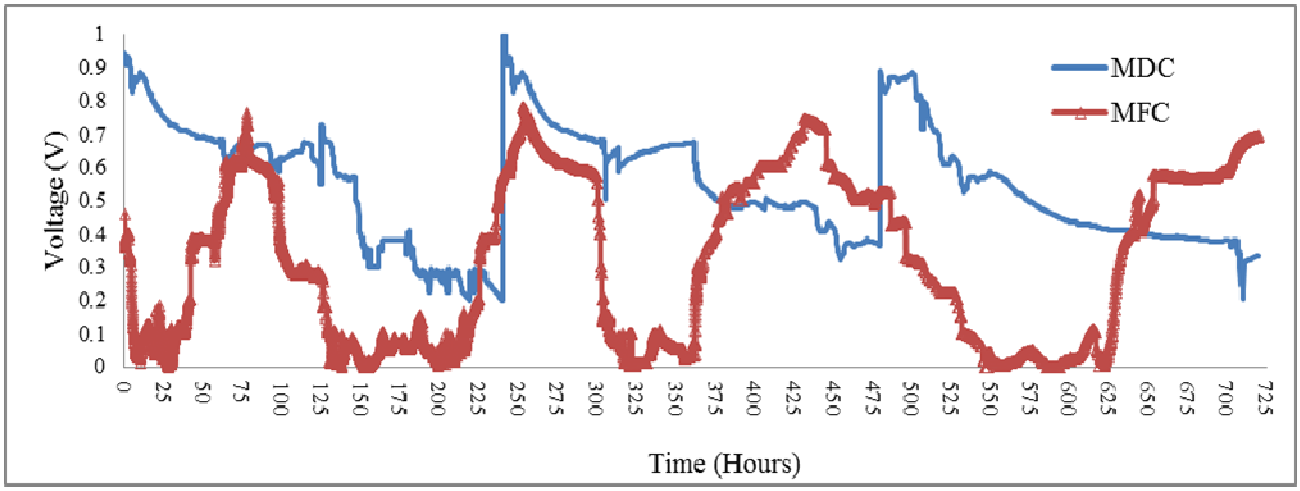

Fig. 2. Voltage generated from synthetic wastewater over batch cycles in MFC and MDC

Although the electricity was generated in the MFC reactor, the voltage fluctuated among batch cycles, presumably due to the complexity of the substrate utilized by microbial activities. The maximum output voltage of about 860 mV under a 1 KΩ external resistor was recorded during the operation of MDC while580 mV was obtained for MFC. The duration of one typical batch cycle was around 240 h.

A gradual decline of the output voltage was observed for each cycle in the MDC, which was mainly attributed to an increase in the internal resistance during desalination and the consumption of the electron acceptor[15]. Previous studies reported that such decline could be reduced by employing narrower desalination chambers or using air-cathode system [4].

Maximum power density of 0.137 W/m^2 (based on cross sectional area of 49 cm^2) and 3.43 W/m^3 (based on anode or cathode volume of 200 mL) were obtained for MDC which were 2.1 times higher than the power generation in the MFC.

The decrease in power and current production in MFC when compared to MDC may be due to the fact that desalination can improve electron transfer and enhanced bioelectricity production. The obtained data for a batch cycle in the MDC showed a COD removal 13% higher than the MFC (Fig. 3).

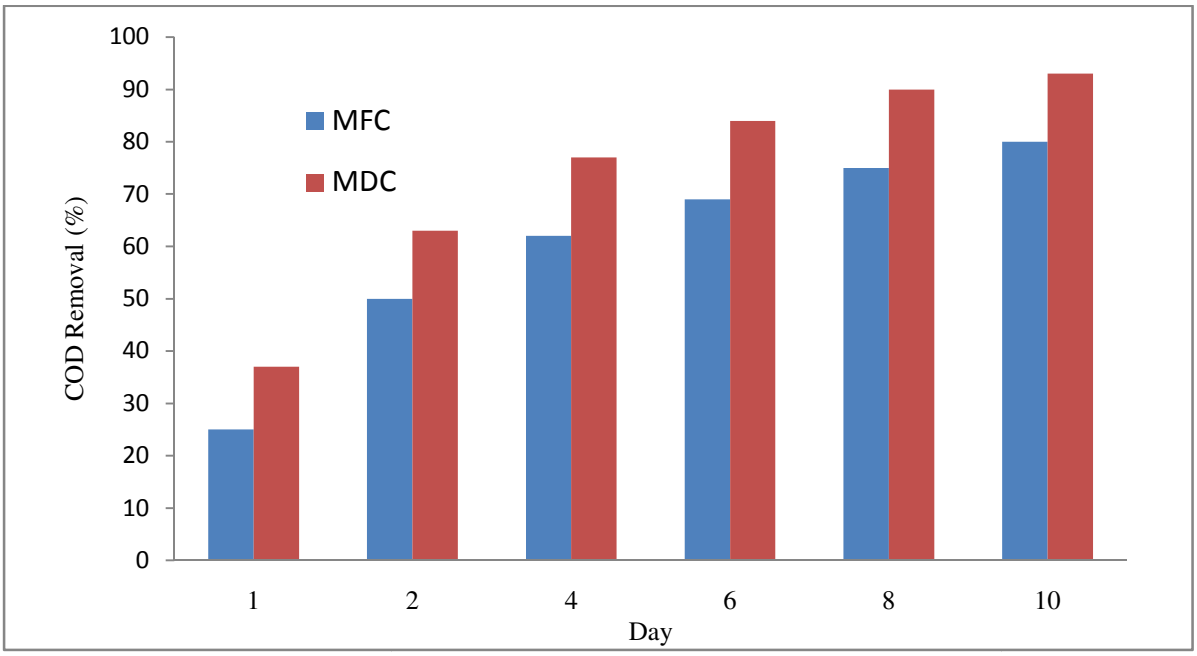

Fig. 3. COD Removal efficiency in the anode chamber of MFC and MDC

During one batch cycle, the averaged COD removals in the anode chambers of MDC were 37.1 ± 6.0, 62.6 ± 4.4, and 77 ± 5.7%, for the four first days. The corresponding COD removals for MFC reactorwere25.1 ± 3.8, 50.5 ± 4.4 and 62.2 ± 3.1%, respectively. The relatively higher COD Removal in MDC reactor was due to the fact that desalination can improve organic matter removal.

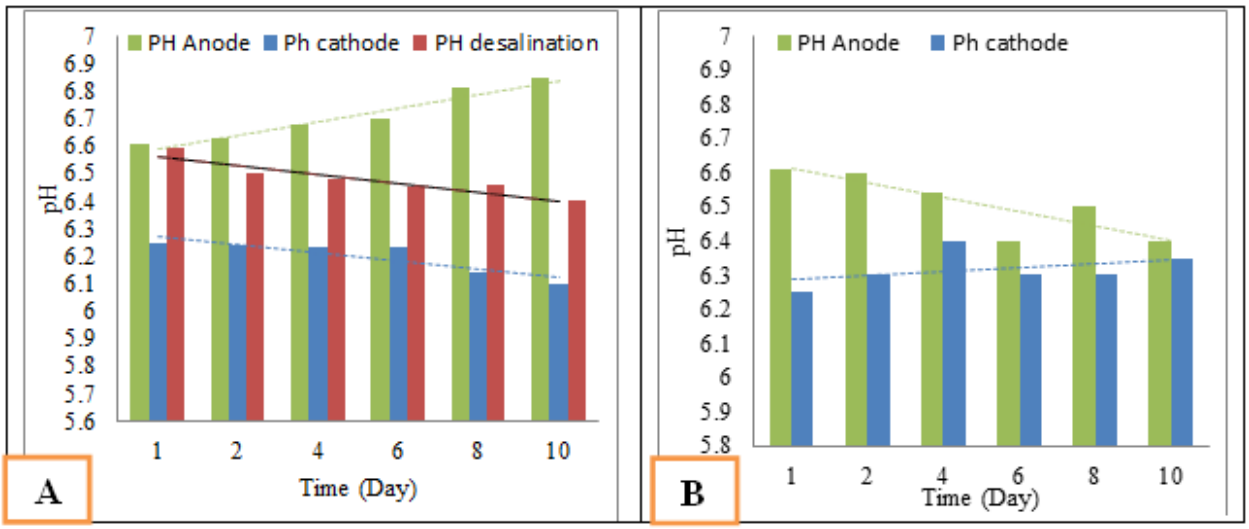

Fig. 4. Electrolyte pH variations over a batch cycle in the MDC (A) and the MFC (B).

The variation of pH in both reactors is shown in Fig.4. Anolyte solution of MDC shows a slightly increasein pH during batch cycles which is beneficial for anodic microbial metabolism. However, the pH of the cathode and desalination solutionsdecreasedgradually during every cycle of operation. The pH of the anolyte in MFC lastly decreased to 6.4 ± 0.2 after 10 days (Fig.4B). Therefore, the MDC has an advantage over MFC, with more stable with pH fluctuation.

In addition to electricity production and wastewater treatment, the MDC removed more than 70% of the salt from the middle chamber during one batch cycle. The total NaCl removal at initial salt concentration of 30 g/L is shown in Fig.5.

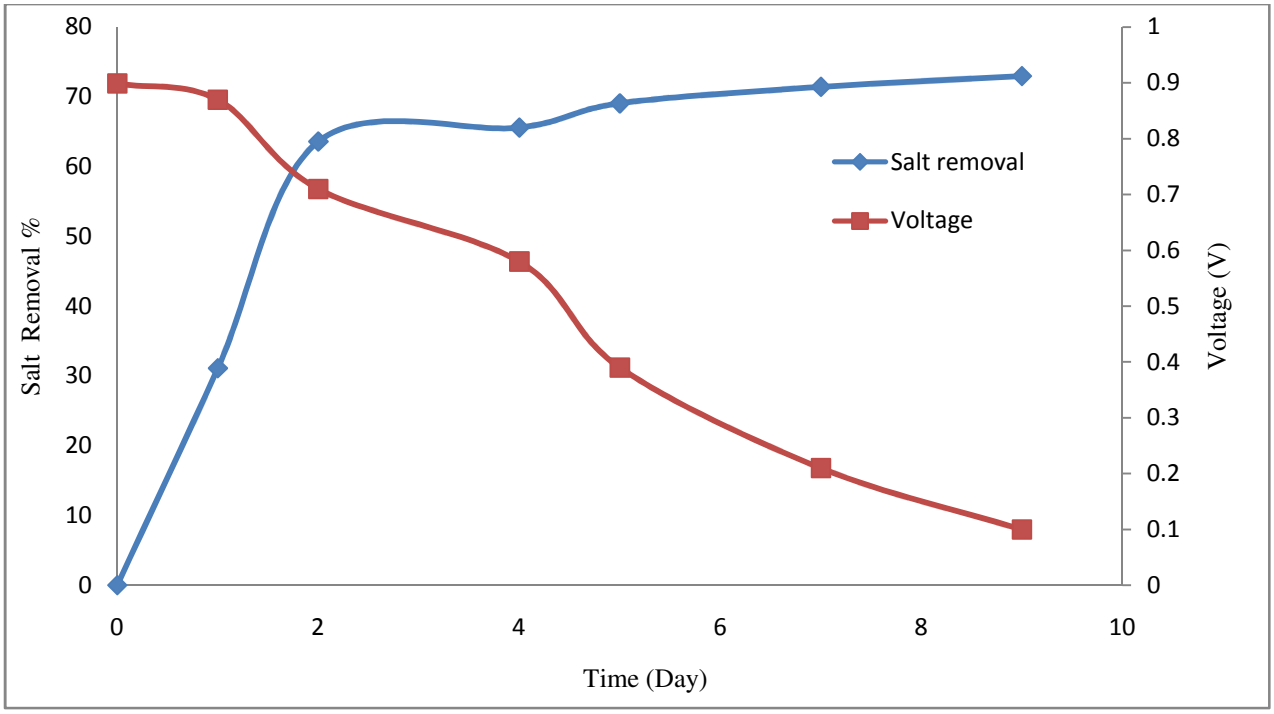

Fig. 5. Salt removal during stable operation period with an initial salt concentrations of 30 g/L

It is clear that the salt removal increased rapidly to 63% during 2 first days, and then rose slightly again to just 73% in the end of cycle. On the other hand, produced voltage decreased continuously over the cycle.

4. CONCLUSIONS

The energy recovery and wastewater treatment efficiency weresignificantly improved by adding the desalination function in MDCreactors as compared with traditional MFCs. The desalination improved output voltage, stabilized the anolyte pH, resulting in an increase of power density by 2.1 times and COD removal by 90%. The results demonstrated that desalination can improve wastewater treatment, electron transfer and electricity generation.

REFERENCES

[1] Kim Y.; Logan B.E., Microbial desalination cells for energy production and desalination, Desalination. 2012.

[2] Mehanna M.; Saito T.; Yan J.; Hickner M.; Cao X.; Huang X.; Logan B.E., Using microbial desalination cells to reduce water salinity prior to reverse osmosis, Energy & Environmental Science. 2010, 3 (8), 1114-1120.

[3] Elimelech M.; Phillip W.A., The future of seawater desalination: energy, technology, and the environment, Science. 2011, 333 (6043), 712-717.

[4] Kim Y.; Logan B.E., Series assembly of microbial desalination cells containing stacked electrodialysis cells for partial or complete seawater desalination, Environmental science & technology. 2011, 45 (13), 5840-5845.

[5] Keller J.; Rabaey K., Experiences from MFC pilot plant operation in MFC Symposium. 2008.

[6] Logan B.E.; Hamelers B.; Rozendal R.; Schröder U.; Keller J.; Freguia S.; Aelterman P.; Verstraete W.; Rabaey K.; Microbial fuel cells: methodology and technology, Environmental science & technology. 2006, 40 (17), 5181-5192.

[7] Saeed H.M.; Husseini G.A.; Yousef S.; Saif J.; Al-Asheh S.; Fara A.A.; Azzam S.; Khawaga R.; Aidan A., Microbial desalination cell technology: A review and a case study, Desalination. 2015, 359, 1-13.

[8] Sevda S.; Yuan H.; He Z.; Abu-Reesh I.M., Microbial desalination cells as a versatile technology: Functions, optimization and prospective, Desalination. 2015, 371, 9-17.

[9] Cao X.; Huang X.; Liang P.; Xiao K.; Zhou Y.; Zhang X.; Logan B.E., A new method for water desalination using microbial desalination cells, Environmental science & technology. 2009, 43 (18), 7148-7152.

[10] Brastad K.S.; He Z.; Water softening using microbial desalination cell technology, Desalination. 2013, 309, 32-37.

[11] Chen X.; Xia X.; Liang P.; Cao X.; Sun H.; Huang X., Stacked microbial desalination cells to enhance water desalination efficiency, Environmental science & technology. 2011, 45 (6), 2465-2470.

[12] Chen X.; Liang P.; Wei Z.; Zhang X.; Huang X., Sustainable water desalination and electricity generation in a separator coupled stacked microbial desalination cell with buffer free electrolyte circulation, Bioresource Technology. 2012, 119, 88-93.

[13] Jacobson K.S.; Drew D.M.; He Z., Use of a liter-scale microbial desalination cell as a platform to study bioelectrochemical desalination with salt solution or artificial seawater, Environmental science & technology. 2011, 45 (10), 4652-4657.

[14] Association A.P.H.; Association A.W.W.; Federation W.P.C.; Federation W.E., *Standard methods for the examination of water and wastewater*, Place, 1955.

[15] Luo H., Xu P.; Roane T.M.; Jenkins P.E.; Ren Z., Microbial desalination cells for improved performance in wastewater treatment, electricity production, and desalination, Bioresource Technology. 2012, 105, 60-66.