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Energy Production in Microbial Desalination Cells and Its Effects on Desalination

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ABSTRACT

Microbial desalination cell (MDC) is a newly developed technology for energy-efficient saltwater desalination and wastewater treatment. It has been observed that energy production and maximizing desalination efficiency may have a contradictory relationship. To further understand the interaction between energy production and desalination efficiency, herein we have investigated energy production and desalination efficiency in aMDC affected by salt concentrations/composition (5-20 g/L NaCl and actual seawater) and external resistances (10k to 0.1 &!).Themaximum energy production with respect to total desalinated water was 0.234, 0.3113, 0.3660 and 0.4113 kWh/m^3(desalinated water) operated with 5 g/L, 10 g/L, 20 g/L NaCl, and real seawater, respectively.The highest energy produced with respect to kg COD removal was0.1059, 0.1194, 0.1164 and 0.2245 kWh/kg COD operated with 5 g/L, 10 g/L, 20 g/L NaCl, and real seawater, respectively.As expected, COD removal and the desalination performance were all directly influenced by the external resistance. Significantly, higher COD removal was obtained when UMDCs operated under higher external resistance (100-1000 Ω), and higher desalination performance obtained under lower external resistance (0.1 to 1 Ω).These results demonstrated the linkage between energy production, desalination and COD removal in UMDC.

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1. Introduction

Due to the continuous world development, the net amount of wastewater generated increased tremendously from both domestic user and industries. The conventional wastewater treatment methods are very energy intensive and also produce greenhouse gases that further adversely affect the environment (Oh et al.2010). At the same time, shortage of fresh water is increasing day by day due to the rapid increase in human population. Shortage of freshwater and energy crises are still the two big challenges in this world (Pham et al.2006; Kelly et al.2014). In recent years, bio electrochemical systems are emerged for sustainable energy production from wastewater (Mohan et al.2009). Depending on its origin, various types of bioelectrochemical systems have been developed for treating wastewater along with bioelectricity generation. This produced energy can be stored and used for other applications such as in biosensors. Microbial fuel cells (MFC) have been developed for treating wastewater while generating bioelectricity generation (Sevda et al. 2015; Du et al. 2007; Pant et al. 2010; Sleutels et al. 2012; Li et al. 2014).

Recently, microbial desalination cell (MDC) was developed from MFCs concept, in this device; desalination and wastewater treatment are conducted in one system. MDC has an enormous potential as a low-cost desalination process with wastewater treatment and other benefits. MDC is a new technique in that saltwater can be desalinated without using any external energy source. The exoelectrogenic-bacteria are used in MDC reactor to oxidize biodegradable substrate in the anodic chamber and transfer the electron to the anode electrode (Sevda et al.2015; Cao et al.2009; Luo et al. 2012; Luo et al 2012a; Wang et al. 2013; Chen et al.2012; Sevda et al.2014). Various MDC designs were developed for salt removal and wastewater treatment in recent years. These new developments include air cathode MDC (Wen et al.2012), stacked MDC (Chen et al.2011; Zuo et al.2014), up flow-MDC (Jacobson et al.2011), recirculated MDC (Qu et al.2012), microbial electrodialysis cell (Mehanna et al. 2010), submerged microbial desalination-denitrification cell (Zhang et al.2013), microbial capacitive desalination cell (Forrestal et al.2012) and osmotic MDC (Zhang et al. 2012; Lu et al.2015). The performance of MDCs can be expressed as desalination efficiency, % COD removal, and power generation. In the literature, data shows that at maximum power generation conditions, higher% COD removal were achieved and at higher current generation conditions (lower external resistance), higher % salt removal were obtained in MDCs (Jacobson et al.2011; Jacobson et al.2011a; Zhang et al.2012a). Still, the overall energy productions in MDCs are not well understood. There is also a need to explain the relationship between the energy production and desalination rate in MDCs.

Previousstudiesraised the issue of energy storage and its used during MDC process for achieving maximum desalination efficiency in the

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bioelectrochemical system. The energy produced during MDC process was stored in arechargeablebattery, and it was used in electrodialysis (Zhang et al.2012a). When UMDC used as a pre-desalination unit before electrodialysis, it can reduce 45.30% of energy consumption. The storage of energy during the MDC process and it's used still are the principal concern. When MDCs achieve their maximum desalination efficiency, energy production is low and vice versa (Zhang et al. 2012; Zhang et al. 2012a).Therefore, it is necessary to examine the interaction between desalination efficiency, COD reduction and energy production and the major factor affecting these.

The key objective of this study was to understand the relationship between energy production, desalination rate and COD removal in UMDC operated with different external resistances and saltwater concentrations. The effect of different external resistancesof (0.1Ω, 1Ω, 10Ω, and 100Ω, 1 KΩ, 5 KΩ and 10 KΩ) on the UMDC performancewas studied along with various salt concentrations inthe desalination chamber.Various salt concentrations of 5g/l, 10 g/l, 20 g/L and real seawater were used in the desalination chamber of UMDC. All the UMDCs experimentswerecarried outin batch operationmode.

2. Materials and methods

2.1. Design and operation of air-cathode UMDC

A schematic view and areal picture of the UMDC are shown in Figure 1. The UMDC reactor was constructed by using tubular ion exchange membranes. AEM (AMI-7001, membrane International, USA) and CEM (CMI-7000, membrane International, USA) were used as an inner and outer membrane respectively.Carbon brush electrode (2.5 cm diameter x 3.0 cm length) was used as the anode electrode (Gordon Brush Mfg. Co., Inc). Carbon cloth (10 cm x 20 cm) was used as the cathode electrode (Zoltech Companies, Inc, USA). A titanium wire was used to connect carbon cloth to the external circuit. This carbon cloth works both as cathode electrode and current collector.

Anaerobic sludge used as inoculum source in the anodic chamber was collected from a local wastewater treatment plant (Doha, Qatar). The anaerobic sludge was acclimatized for one month in 3 L batch reactor at room temperature with nutrient medium (Sevda et al.2012). The anode chamber was inoculatedwith this acclimatized anaerobic inoculum. Anodic chamber medium was flushed with nitrogen gas for 30 minutes after inoculation. The working volume of anodic chamber and desalination chamber were 300 and 100 mL, respectively.

The anode of UMDC was fed with synthetic wastewater. The desalination chamber of UMDCs was fed with four different saltwater concentrations (5 g/L, 10 g/L, 20 g/L and real seawater). The UMDC swere operated using the external resistance of 10 KΩ, 5 KΩ, 1 KΩ, 100Ω, 10Ω, 1Ω and 0.1Ω. All UMDC sexperiments werecarried out at room temperature (25 ± 2p C).

2.2. Substrate and saltwater composition

The synthetic wastewater contained 1 g/L CH_3COONa; 0.5 g/L NaCl; 0.015 g/L $MgSO_4$; 0.53 g/L KH_2PO_4; 1.07 g/L K_2HPO_4, 0.02 g/L $CaCl_2$, 0.1 g/L yeast extract and 1 ml/L trace element solution(Sevda et al. 2012). The salt solution was prepared by dissolving NaCl (5 g/L, 10 g/L and 20 g/L) in tap water. Seawater (42 g/L salts) samples were collected from the Corniche, Doha. The UMDCs operated with different salt concentrations of 5 g/L, 10 g/L, 20 g/L and seawater are referred to in this work as UMDC-1,2,3 and 4 respectively. The catholyte (phosphate buffer solution) was used to rinse the cathode electrode from the top to the bottom at a flow rate of 3 mL/min. All the UMDCs were operated with different external resistances in batch mode.

2.3. Analytical measurement and calculation

The cell voltage across the external resistance was recorded every 20 minutes by a digital multimeter (Fluke-289). Polarization curves were made by changing the external resistance from 10 KΩ to 1Ω in a decade resistance box (Microteknik). The corresponding cell potential evolutions across different external resistance were measured. The power measurement was determinedby measuring current (I) and the voltage (V) across a fixed external resistance as described previously (Sevda et al.2012).The maximum volumetric power density was calculated based on the volume of the anodic chamber (300 mL). The maximum power density was calculated based on the surface area of the cathode electrode (50 cm^2). The conductivity, pH and total dissolved solids (TDS) were measured by benchtop pH/conductivity meter (Orion star A215, Thermo Scientific). The COD was determined according to the Standard Methods (APHA. 1998).Also, the volumetric power density was calculated as per water desalinated during the process. Energy production was determined on the basis of COD removal (kWh/kg COD removal) and water desalinated (kWh/m^3 desalinated water) in the anodic chamber and the desalination chamber of UMDC respectively.

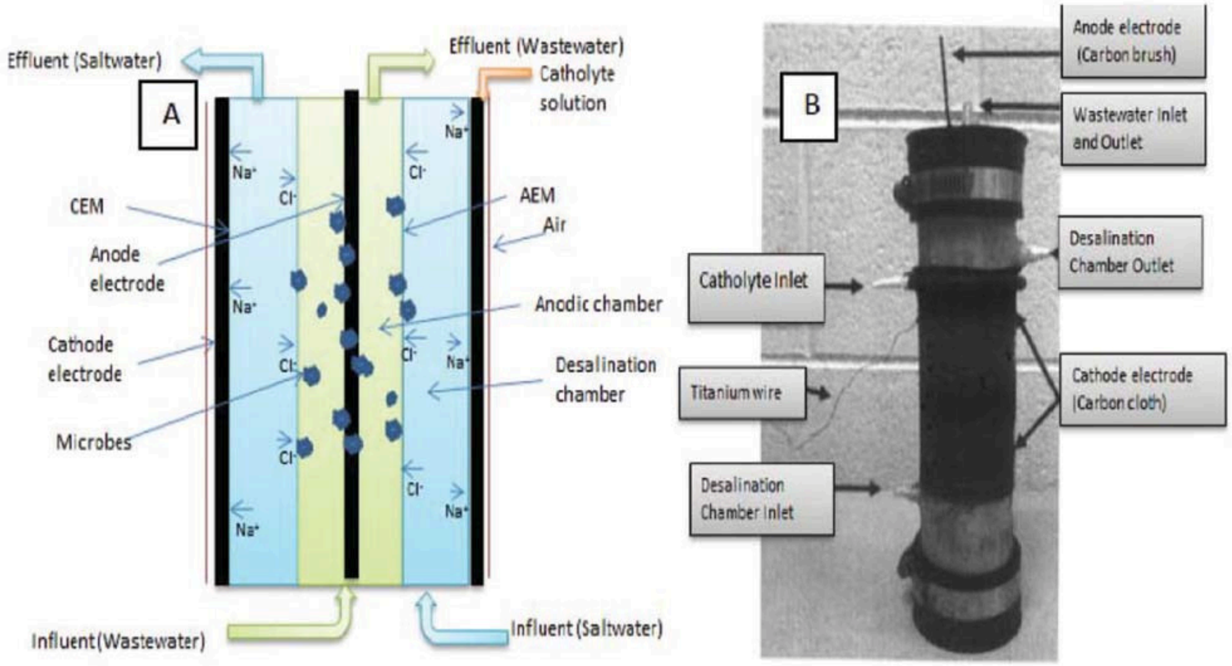

Fig. 1. Schematic view (A) and photograph (B) of used UMDC

3. Results and discussion

3.1. Cell voltage evolution profile of UMDCs

The salt concentration in the desalination chamber was changed from 5 g/L to higher concentrations to determine the effect of salt concentrations on UMDC performance. Initially, all the UMDCs were operated with open circuit mode. After that, the UMDC were operatedwith external resistance, and theexternal resistancewas gradually decreased from higher to lower values. This experiment demonstrated the two important factors affecting the performance of UMDCs, the external resistance and the initial salt concentration in the desalination chamber.

Figure 2 shows the evolution of cell potential in UMDCs operated with different external resistances and salt concentrations. The maximum cell potential across 10 KΩ external resistances decreased from 612 mV with seawater to 532 mV with 5 g/L NaCl. At lower external resistances, similar trends of decrease in cell voltage were obtained as salt concentration increased in the desalination chamber of the UMDCs, which was consistent with previous studies (Jacobson et al.2011)· Figure 2 also shows the cell potential evolution difference in UMDC operated with higher and lower range external resistances. Due to the diffusion of anions and cations from the salt chamber to the anode and cathode, electrolyte conductivity increased, this initially helps toexoelectrogenicmicrobes overall system performance was enhanced. On the other hand, anion, e.g. Cl^- increased over time and thus the activity of exoelectrogenic microorganisms was inhibited and hence theUMDC performance started to decrease (Luo et al. 2012; Jacobson et al. 2011; Davis et al.2013)·

At lower external resistance conditions,UMDCwork near the short-circuit conditions, atthese conditions, UMDCs achieved maximum bioelectricity production but power production decreased.The higher salt concentration (seawater) operated UMDC showed higher power production compared to other low salt concentrations. In multiple batch cycles, the drop in current generation increases as salt concentration increased in desalination chamber (Yang et al.2014)·

In the MDCs, it is imperative to find the suitable operating conditions for maximum power, salt removal, and COD reduction. In comparison to MFCs, where maximum COD reduction occurred at the maximum power conditions, more salt removal achieved in MDCs at higher current generation conditions(Jacobson et al.2011a; Yang et al.2014)·

3.2. COD and salt removal performance in UMDCs

Figure 3A shows the % COD removal in the anodic chamber of UMDCs operated with different external resistances and salt

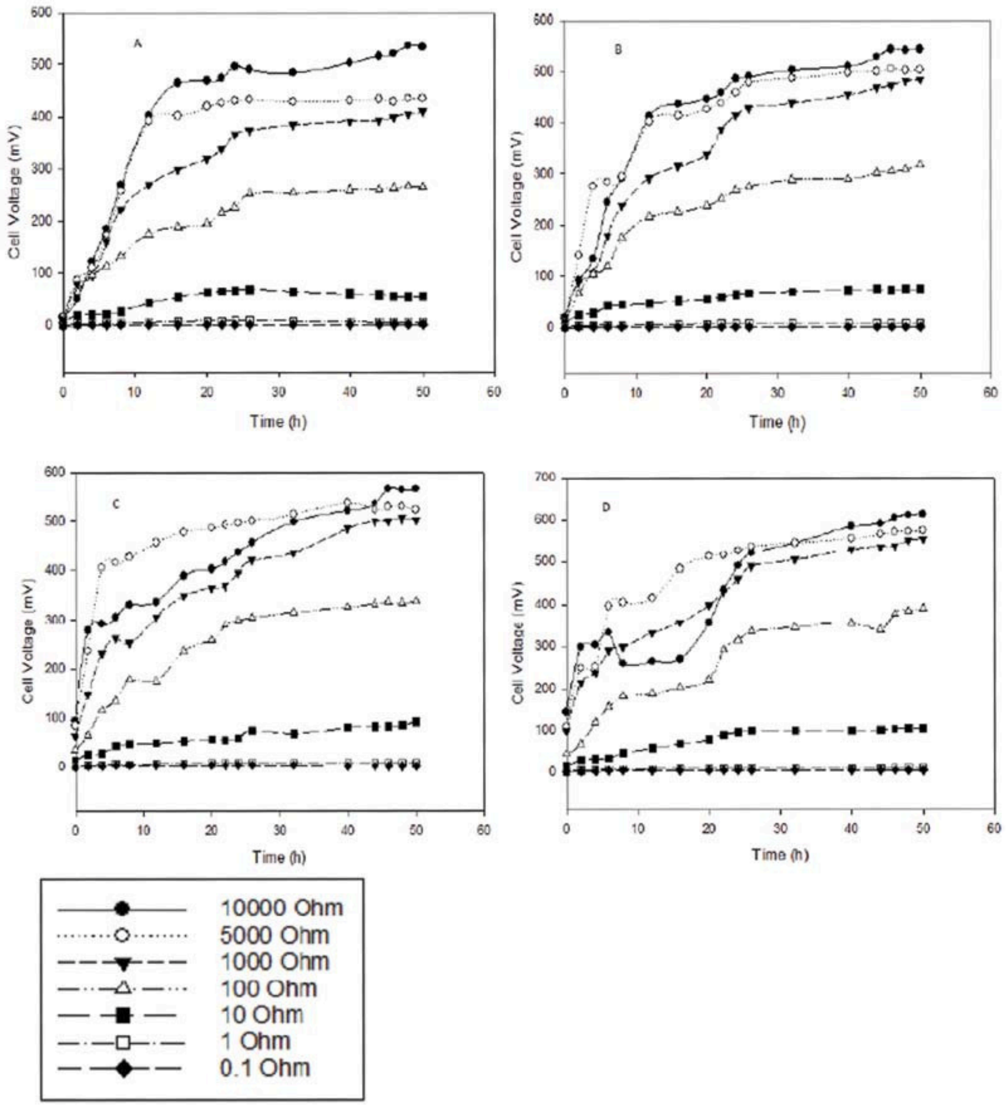

Fig. 2. The profile of cell potential evolution in UMDC operated with various external resistances of 10KΩ, 5KΩ, 1KΩ, 100Ω and 10Ω, 1Ω and 0.1Ω and various saltwater concentration. A, B, C and D shows the cell profile at salt concentration of 5 g/L, 10g, 20g/L and seawater in the desalination chamber respectively.

concentrations. The % COD reduction was mainly affected by the external resistance value. At high external resistance conditions,flow of electrons wereless, and UMDC behave near to the open circuit conditions. Hence, the % COD removal waslow in all the UMDCs.

The % COD reduction obtained in the UMDCs operated in open circuit conditions were 10.4, 12.2, 17.8 and 7.6 in UMDC-1, 2, 3 and 4 respectively. The % COD reduction of 11.6, 32.1, 27 and 27.5 were obtained in UMDC-1, 2, 3 and 4 respectively at 10 KΩ of external resistance condition. In the UMDCs operated with the lower external resistance of 0.1Ω, the % COD removal of 44.1, 59.1, 47.6 and 30.6 were achieved in UMDC-1, 2, 3 and 4 respectively.

The highest % COD removal of 64.1, 82.1, 84.5 and 60.5 were

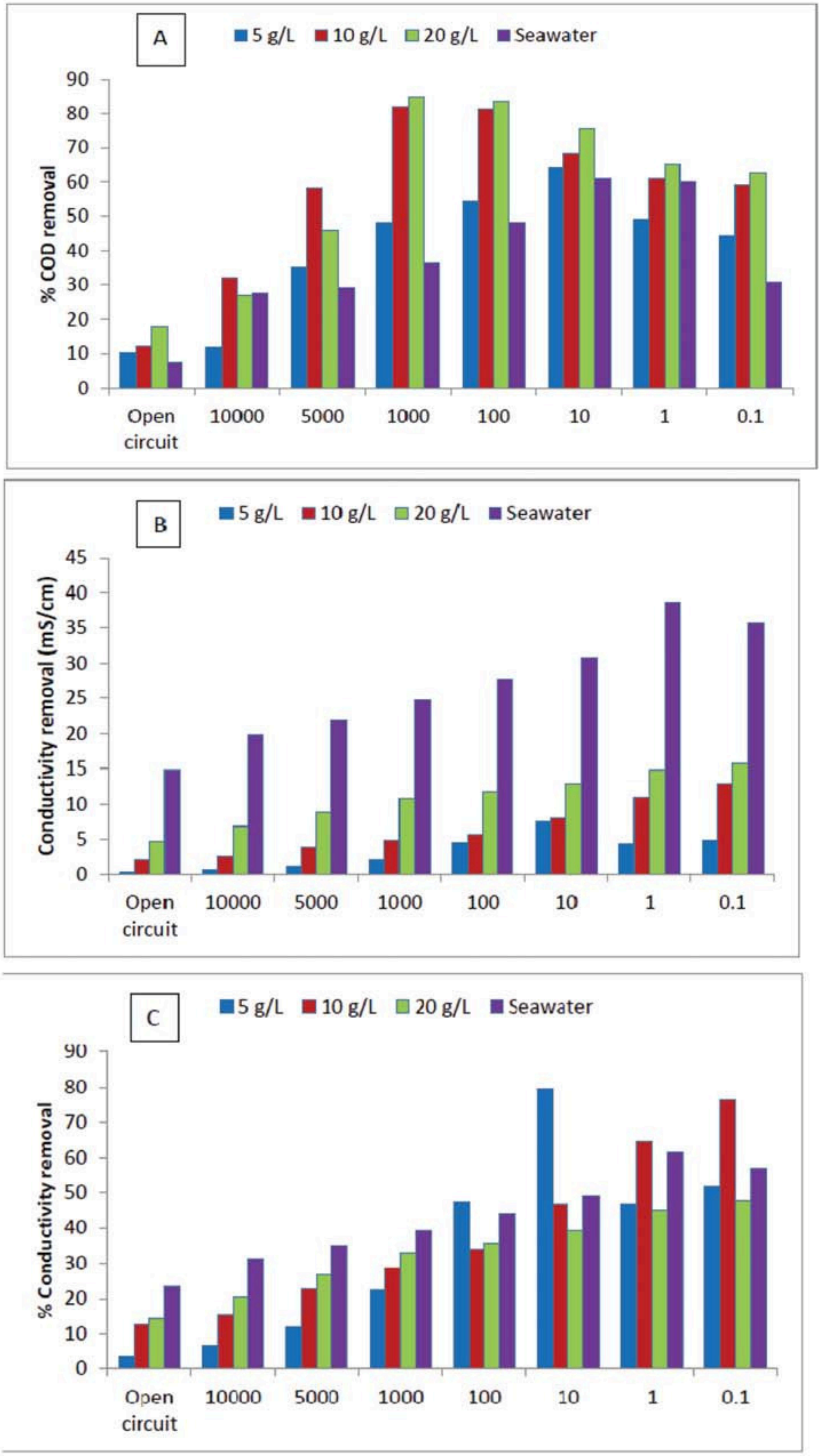

Fig. 3. The performance of UMDCs as determined by % COD removal (A) conductivity removal (B) and % conductivity removal (C) at different external resistances and slat concentrations

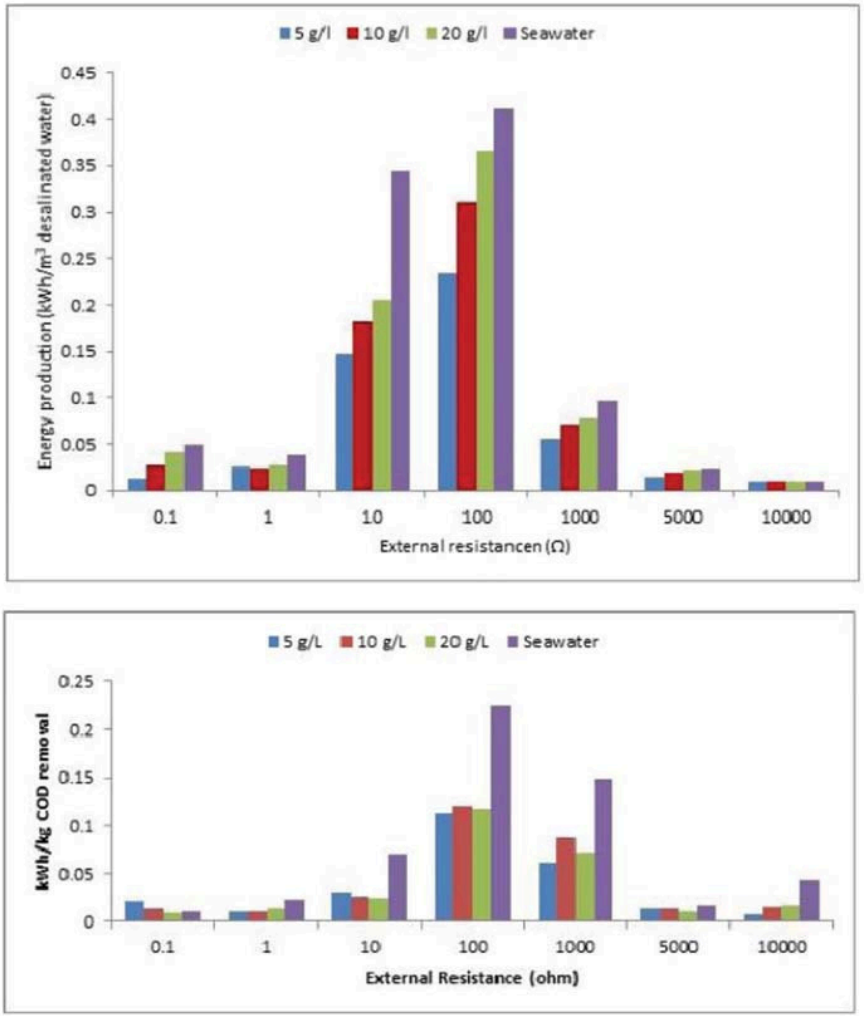

Fig. 4. Energy production with respect to desalinated water volume (A); energy production per Kg COD removal (B) in UMDC operated with different external resistances and salt concentrations (■ 5 g/l ■ 10 g/l ■ 20 g/l ■ Seawater)

achieved in UMDC-1, 2, 3 and 4 respectively. The highest % COD removal were obtained across an external resistance of 10 &!, 1 KΩ, 1 KΩ and 10Ω in UMDC-1, 2, 3 and 4 respectively. In this range of external resistance, UMDCs produced maximum power, and it contributed to more COD reduction.These COD reduction data explain the effect of the external resistance for UMDC performance. The salt concentration increase in desalination chamber also affected the COD removal performance. Still at lower external resistance values, COD reduction did not show much difference along with changing the salt concentration in UMDCs. At higher salt concentration conditions, as the process started, conductivity of anolyte increased and it benefits to a certain limit the microbes, but when the initial salt concentration increased, it hada negative influence on metabolism of electroactive microbesin the long time experiment.

Figure 3B and C show the decrease in conductivity and % decrease in conductivity during the UMDC process. The desalination efficiency of UMDC defined as the percentage conductivity removal from the desalination chamber of UMDC. Conductivity removal from desalination chamber occurred due to the anodic and cathodic overall reaction in UMDC that generate bioelectricity in the system. Figure 3B shows the overall conductivity removal in various UMDCs. In UMDC-1, conductivity removal of 0.62, 1.34, 2.14, 4.45,7.51,4.44 and 4.92 mS/cm occurred using external resistance of 10 KΩ, 5 KΩ, 1 KΩ, 100Ω, 10Ω, 1Ω and 0.1Ω respectively. These obtained results showed the effect of external resistance on conductivity removal rate in UMDC-1. One important observation noticedin this study was that,at low salt concentration condition, maximum salt removal rate and maximum % COD removal occurred at 10Ω external resistance.One possible explanation forthese UMDC behavioursthat at lower salt concentration transfer of ions increased the anolyte conductivity. This increase in anolyte conductivity helps in stabilizing the pH of the system and this small increase in conductivity did not decrease the microbial activity, hence,the overall power production effiecences was increased(Luo et al.2012)·In UMDC-2, conductivity removal of 2.58, 3.83, 4.87, 5.73, 7.94, 10.95 and 12.95 mS/cm were obtained at external resistance of 10 KΩ, 5 KΩ, 1 KΩ, 100Ω, 10Ω, 1Ω and 0.1Ω respectively. This trend was observed in all the UMDCs, and it proved that at low external resistance condition, higher saltswere removed from the desalination chamber due to high current generation conditions.

In UMDC-3, the conductivity removal of 6.7, 8.8, 10.8, 11.7, 12.9, 14.8 and 15.7 mS/cm were achieved at the external resistance of 10 KΩ, 5 KΩ, 1 KΩ, 100Ω, 10Ω, 1Ω and 0.1Ω respectively. These results showed that initial salt concentration also affect the overall salt removal rate. At initial high salt concentrations, higher conductivity removal obtained at the lower external resistance conditions. In UMDC-4, conductivity removal of 13.3, 15.1, 17.2, 18.9, 20.4, 26.1 and 23.9 mS/cm were achieved at external resistance of 10 KΩ, 5 KΩ, 1 KΩ, 100Ω, 10Ω, 1Ω and 0.1Ω respectively.

In the open circuit condition, conductivity removal of 0.3, 2.1, 4.7 and 10.2 mS/cm were achieved in UMDC-1, 2, 3 and 4 respectively. Figure 3C showed the % conductivity removal in UMDCs operated with different external resistances and salt concentrations. Higher desalination efficiency wasobserved in the lower external resistance conditions in all UMDCs. This confirms that salt removal in desalination chamber depended on the current generated in UMDCs (Jacobson et al.2011a)·The external resistance of 10Ω, 1Ω, and 0.1Ω gives better results in terms of salt removal in all the initial salt concentrations. The maximum desalination efficiency of 79.1%, 76.4%, 47.6% and 60.9% were obtained in UMDC-1, 2, 3 and 4 respectively. These results reflect that MDCs will be a better solution for combined brackish water desalination and wastewater treatment.

3.3. *Energy production profile in UMDCs*

In the bioelectrochemical system, the net energy output can be expressed in terms of power density or current density, which is commonly normalized to the electrode area or the volume of electrolyte. In mostcases, the highest obtained power density is reported. However, for the overall energy structure, the total energy production and consumption of the system need to be determined. This energy balance data will help in the scale-up studies of MDCs. Because this study was conducted in batch mode, and no recirculation was used, we assume negligible energy consumption for operating the UMDC process. The energy production was normalized per total desalinated water volume and per kg COD removal to obtainaclear picture of the energy structure in the operated UMDCs. Figure 4 shows the energy production profile with respect to desalinated water volume in various UMDCs. The total energy produced at 0.1 Ω and 10 KΩ was noticeably lower than that at other resistances. Meanwhile, the UMDCs at 100 Ω achieved the highest power production. This is probably because the internal resistance of the UMDCs were in the range of several hundreds of ohms and according to the Ohm's law and the equation $P = VI$, the power reaches the maximum when the external and internal resistance are equal. Interestingly, the UMDCs with seawater showed the highest power generation regardless of the external resistance, which was in agreement with the previous results of the polarization curves. The reason is unknown and warrants further investigations.

Figure 4B shows the energy production profile per kg COD removal in the anodic chamber of UMDCs operated with various external resistances and salt concentrations. Similar to the volumetric energy production, the total power per unit COD removal was the highest at 100Ω and decreased at lower or higher resistance. The UMDC with seawater again outperformed other UMDCs with lower salt concentration. In theory, conventional anaerobic wastewater treatment need energy of 1.2 kWh/kg COD for wastewater treatment[34] and membrane desalination consume energy in the range of 3-5 kWh/m^3 for water desalination[35].The highestenergy produced at 100Ω external resistance conditions was 0.1492 kWh/ (kg COD removal), meaning that wastewater treatment with MDCs consumes approximately 15.3% less energy than conventional anaerobic digesters. Furthermore, the energy efficiency can be greater when desalination is takeninto account. This is an implication that the UMDCs may be a promising technology for sustainable wastewater treatment and desalination in future.

4. Conclusions

The present study demonstratesthe linkage between energy production, desalination and COD removal in UMDCs operated with various external resistances and salt concentrations. The obtained results expressed the importance of optimum external resistance and salt concentration in the UMDC performance. Low salt and COD removal were obtained at higher external resistance conditions due to the lower bioelectricity generation. The achieved desalination efficiency was higher in UMDC operated at the lower external resistance of (0.1Ω-10Ω) while the COD reduction rates were high at higher power production condition (external resistance: 100-1000Ω). However, the total energy production during the UMDC process with respect to the desalinated water volume and kg COD removal follows the same trend with respect to the operating external resistance. This study has shown the relationship between the energy production and desalination in the batch mode operated UMDCs.

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References

[1]. Angenent, L. Development of anaerobic migrating blanket reactor (AMBR), a novel anaerobic treatment system. *Water Res.***35,** 1739–1747 (2001).

[2]. APHA. *Standard Methods for the Examination of Water and Wastewater*. (20th ed. Washington DC/ :American Public Health Association/American water works Association/Water environment federation, 1998).

[3]. Cao, X. *et al.* A new method for water desalination using microbial desalination cells. *Environ. Sci. Technol.***43,** 7148–52 (2009).

[4]. 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. *Bioresour. Technol.***119,** 88–93 (2012).

[5]. Chen, X. *et al.* Stacked microbial desalination cells to enhance water desalination efficiency. *Environ. Sci. Technol.***45,** 2465–70 (2011).

[6]. Davis, R. J., Kim, Y. & Logan, B. E. Increasing Desalination by Mitigating Anolyte pH Imbalance Using Catholyte Effluent Addition in a Multi-Anode Bench Scale Microbial Desalination Cell. *ACS Sustain. Chem. Eng.***1,** 1200–1206 (2013).

[7]. Du, Z., Li, H. & Gu, T. A state of the art review on microbial fuel cells: A promising technology for wastewater treatment and bioenergy. *Biotechnol. Adv.***25,** 464–82 (2007)

[8]. 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. *Environ. Sci. Technol.***45,** 4652–7 (2011).

[9]. Jacobson, K. S., Drew, D. M. & He, Z. Efficient salt removal in a continuously operated upflow microbial desalination cell with an air cathode. *Bioresour. Technol.***102,** 376–80 (2011)a.

[10]. Forrestal, C., Xu, P., Jenkins, P. E. & Ren, Z. Microbial desalination cell with capacitive adsorption for ion migration control. *Bioresour. Technol.***120,** 332–336 (2012).

[11]. He, Z., Huang, Y., Manohar, A. K. & Mansfeld, F. Effect of electrolyte pH on the rate of the anodic and cathodic reactions in an air-cathode microbial fuel cell. *Bioelectrochemistry***74,** 78–82 (2008).

[12]. Kelly, P. T. & He, Z. Nutrients removal and recovery in bioelectrochemical systems: A review. *Bioresour. Technol.***153,** 351–60 (2014).

[13]. Li, W.-W., Yu, H.-Q. & He, Z. Towards sustainable wastewater treatment by using microbial fuel cells-centered technologies. *Energy Environ. Sci.***7,** 911–924 (2014).

[14]. 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. *Bioresour. Technol.***105,** 60–6 (2012).

[15]. Lu, Y., Qin, M., Yuan, H., Abu-Reesh, I. M. & He, Z. When Bioelectrochemical Systems Meet Forward Osmosis: Accomplishing Wastewater Treatment and Reuse through Synergy. *Water***7,** 38–50 (2015).

[16]. Luo, H., Xu, P. & Ren, Z. Long-term performance and characterization of microbial desalination cells in treating domestic wastewater. *Bioresour. Technol.***120,** 187–93 (2012)a.

[17]. McCarty, P. L., Bae, J. & Kim, J. Domestic wastewater treatment as a net energy producer-can this be achieved? *Environ. Sci. Technol.***45,** 7100–7106 (2011).

[18]. Mehanna, M., Kiely, P. D., Call, D. F. & Logan, B. E. Microbial electrodialysis cell for simultaneous water desalination and hydrogen gas production. *Environ. Sci. Technol.***44,** 9578–83 (2010).

[19]. Mohan, S. V., Raghavulu, S. V., Peri, D. & Sarma, P. N. Integrated function of microbial fuel cell (MFC) as bio-electrochemical treatment system associated with bioelectricity generation under higher substrate load. *Biosens. Bioelectron.***24,** 2021–7 (2009).

[20]. Oh, S. T. *et al.* Sustainable wastewater treatment: how might microbial fuel cells contribute. *Biotechnol. Adv.***28,** 871–81 (2010).

[21]. Pham, T. H. *et al.* Microbial Fuel Cells in Relation to Conventional Anaerobic Digestion Technology. *Eng. Life Sci.***6,** 285–292 (2006).

[22]. Pant, D., Bogaert, G. Van, Diels, L. & Vanbroekhoven, K. Bioresource Technology A review of the substrates used in microbial fuel cells (MFCs) for sustainable energy production. *Bioresour. Technol.***101,** 1533–1543 (2010).

[23]. Qu, Y. *et al.* Simultaneous water desalination and electricity generation in a microbial desalination cell with electrolyte recirculation for pH control. *Bioresour. Technol.***106,** 89–94 (2012).

[24]. Sevda, S., Yuan, H., He, Z. & Abu-Reesh, I. M. Microbial Desalination Cells as a Versatile Technology: Functions, Optimization and Prospective. *Desalination* xxxxx (2015).

[25]. Sevda, S., He, Z. & Abureesh, I. Microbial desalination cell: a sustainable approach for brackish water desalination and wastewater treatment with bioelectricity generation. *Qatar Found. Annu. Res. Conf.* 401 (2014). doi:10.5339/qfarc.2014.EEOP0401.

[26]. Sevda, S. & Sreekrishnan, T. R. Effect of salt concentration and mediators in salt bridge microbial fuel cell for electricity generation from synthetic wastewater. *J. Environ. Sci. Heal. Part A Toxichazardous Subst. Environ. Eng.***47,** 878–886 (2012).

[27]. Shannon, M. A. *et al.* Science and technology for water purification in the coming decades. *Nature***452,** 301–310 (2008).

[28]. Sleutels, T. H. J. A., Ter Heijne, A., Buisman, C. J. N. & Hamelers, H. V. M. Bioelectrochemical systems: an outlook for practical applications. *ChemSusChem***5,** 1012–9 (2012).

[29]. Wang, H. & Ren, Z. J. A comprehensive review of microbial electrochemical systems as a platform technology. *Biotechnol. Adv.***31,** 1796–807 (2013).

[30]. Wen, Q. *et al.* Using bacterial catalyst in the cathode of microbial desalination cell to improve wastewater treatment and desalination. *Bioresour. Technol.***125,** 108–13 (2012).

[31]. Yang, E., Choi, M.-J., Kim, K.-Y., Chae, K.-J. & Kim, I. S. Effect of initial salt concentrations on cell performance and distribution of internal resistance in microbial desalination cells. *Environ. Technol.***36,** 852–860 (2014).

[32]. Zhang, Y. & Angelidaki, I. A new method for in situ nitrate removal from groundwater using submerged microbial desalination-denitrification cell (SMDDC). *Water Res.***47,** 1827–36 (2013).

[33]. Zhang, B. & He, Z. Integrated salinity reduction and water recovery in an osmotic microbial desalination cell. *RSC Adv.***2,** 3265–3269 (2012).

[34]. Zhang, B. & He, Z. Energy production, use and saving in a bioelectrochemical desalination system. *RSC Adv.***2,** 10673 (2012)a.

[35]. Zuo, K. *et al.* A ten liter stacked microbial desalination cell packed with mixed ion-exchange resins for secondary effluent desalination. *Environ. Sci. Technol.***48,** 9917–9924 (2014).