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Microbial Desalination Cells for Water Desalination and Power Generation

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Abstract
There are several ways to improve the desalination process, one of which is to use various configurations and modify the MDCs' traditional design. This strategy improves a number of variables, including the desalination efficiency, the rate of current production, the rate of removal of COD, and the rate of removal of total dissolved solids (TDS) The purpose of this study is to test the concept that desalination and energy production, two activities that work in tandem during wastewater MDC operation, can enhance system performance overall and increase the system's suitability for large-scale applications. use three chambered microbial desalination cells fed with synthetic wastewater and inoculated with activated sludge and anaerobic aged sludge.MDC was able to eliminate more than 90% of the NaCl in a salt solution with an initial salt concentration of 10000 mg TDS/L over the course of the four months procedure while also producing bioelectricity. Additionally, the desalinated water met the drinking water requirement in terms of TDS concentration, with a TDS concentration of 7.50 g TDS L/1 d/1 (volume of the salt solution). An utmost power density of 314.8 mW/m^3 was generated by the MDC. The predicted results demonstrated acceptable agreement with experimental results with determination coefficients $R^2 > 90$ %.

Keywords: salt removal, total dissolved solids, MDC

الخلاصة: هناك عدة طرق لتحسين عملية التحلية، إحداها استخدام تكوينات مختلفة وتعديل التصميم التقليدي لـــ MDCs. تعمل هذه الإستراتيجية على تحسين عدد من المتغيرات، بما في ذلك كفاءة التحلية، ومعدل الإنتاج الحالي، ومعدل إزالة COD، ومعدل إزالة المواد الصلبة الذائبة الكلية (TDS). الغرض من هذه الدراسة هو اختبار مفهوم تحلية المياه وإنتاج الطاقة، وهما نشاطان يعملان جنبًا إلى جنب أثناء تشغيل MDC لمياه الصرف الصحي، ويمكنهما تحسين أداء النظام بشكل عام وزيادة ملاءمة النظام للتطبيقات واسعة النطاق. استخدم ثلاث خلايا ميكروبية لتحلية المياه مغطاة بمياه الصرف الصناعي وتلقيحها بالحمأة المنشطة والحمأة اللاهوائية القديمة. تمكنت MDC من التخلص من أكثر من 90% في المائة من كلوريد الصوديوم في محلول ملحي بتركيز ملح أولي يبلغ 10000 mg,TDS / لتر على مدار الدورة من الإجراء لمدة 4 أشهر أثناء إنتاج الكهرباء الحيوية أيضًا. بالإضافة إلى ذلك، استوفت المياه المحلاة متطلبات مياه الشرب من حيث تركيز المواد الصلبة الذائبة، بتركيز TDS قدره 7.50 جم TDS لتر / 1 يوم/ 1 (حجم محلول الملح). تم إنشاء كثافة طاقة قصوى باستخدام جهاز تسجيل بيانات وربطه على الحاسوب تبلغ 314.8 ميجاوات / متر مكعب بواسطة MDC. أظهرت النتائج المتوقعة اتفاق مقبول مع النتائج التجريبية مع معاملات التحديد R^2> 90.

1. INTRODUCTION

In our time, as the global population grows, so does the need for water and energy. Drinking water is the most important resource for the entire world's population. However, there are only a limited number of natural resources available, and groundwater is in short supply in many regions of the globe. To decrease the amount of energy needed for wastewater handling and saltwater desalination, there must an advance new technique that can provide better wastewater handling while utilizing less energy. A useful tool for desalinating saltwater is the microbial desalination cell (MDC)[1] . MDCs do not require any additional energy [2]. Although the lab scale proof of concept for MDC for seawater desalination has been accomplished, real-world operational circumstances, unique reactor designs, and process optimization must be evaluated for this technology to become economically feasible. [3].

The integrated architecture of the microbial desalination cell (MDC), also known as MFC(Microbial fuel cell)-powered desalination knowledge, provides a pressure-free treatment of salty water and sewage simultaneously. This method desalinates the water while using microbes to produce output energy from wastewater or biomass. Bacteria supplied with organic matter yield electrons by oxidizing wastewater on the anode of the MFC, which in turn produces power. A team of scholars from Penn State University and Tshinghua University in China was developed this method to desalinate water and generate power in 2009 [2]. In contrast to using an external energy exporter, MDC employs electrical energy produced locally by the bacteria through MFC. to produce drinking water with less energy, the MDC offers a number of advantages, including wastewater treatment; low energy consumption; fewer chemicals used; decreased waste; large retrieval; and a positive social effect. MDC water desalination has the advantage of not requiring external electricity, as does electrodialysis ED, water pressurization, as does reverse osmosis RO, or the use of draw solutions, as does FO (forward osmosis). Furthermore, MDCs can generate 180-231 percent more energy than traditional desalination systems. MDC development is still in its early stages, and more research is needed before it can be developed into a technology that is practical from a business standpoint. The basic concepts of MDCs for water desalination are covered in this research, along with reactor designs, components, regulations for wastewater handling and water desalination, and functional restraints. [4]. when desalinating NaCl solutions between 30 g/L and 5 g/L [5,6].

Alternative desalination procedures, on the other hand, need between 6-and 68-kW hours to desalinate 1 m^3 of seawater. Chlorides and sulphates are transferred from the mid chamber into the anode in the MDC via the anion exchange membrane (AEM). The sodium and calcium ions migrate across the cation exchange membrane (CEM) into the cathode, where they remove nearly all of the salt and provide more energy than the device requires to operate outside [7]. The rate of desalination has the biggest impact on MDC performance. It is based on the desalination sample's initial salt content. MDC performs best when desalinating water with a lot of salt in it. By reducing ohmic resistance and boosting current production, this could accelerate the desalination process (DR). A new method for anode-cathode recirculation has recently been demonstrated to be active in maintaining the pH in equally the anode and the cathode while increasing the desalination rate by 2.52 times and the electron production by 98 % [8]. Since a few years ago, there have been several studies in the literature discussing different elements of MDC, indicating considerable attention in and fast growth of this technology. To scale up MDCs, it is important to comprehend the difficulties that come with various MDC designs and understand their mechanisms. To provide a critical evaluation of various MDC setups, this review article will concentrate on engineering advancements and approaches to resolving operational difficulties [9]. The deletion of salts from the middle chamber while preventing their concentrations in the anode and cathode chambers, which causes an increase in salinity in the anolyte and catholyte, represents one of the primary problems with the MDC technology. While this ion addition helps with conductivity conditioning and it is generally appropriate for wastewater treatment.

2. OBJECTVE AND PURPOSE

The primary goal of this research project is to verify the idea that desalination and energy output, two processes that work alongside to treat wastewater, can enhance system showing overall and increase the system's suitability for a large-scale implementation.

3. MATERIALS AND METHODS

3.1. MDC operation and experimental procedures

Three compartments were present in the cubic MDC reactor that was employed in this study: a serially aligned anode (15 cm in height x 15 cm in length x 20 cm in width); desalination (15 cm in height x 15 cm in length x 10 cm in width); and a cathode (15 cm in height x 15 cm in length x 20 cm in width). Cation exchange membranes (CEM, CMI 7000, Citation Membranes International, NJ) were employed to divide the cathode and anode chambers, while anion exchange membranes (AEM, AMI 7001, Anion Membranes International, NJ) were used to separate the anode and middle desalination chamber.

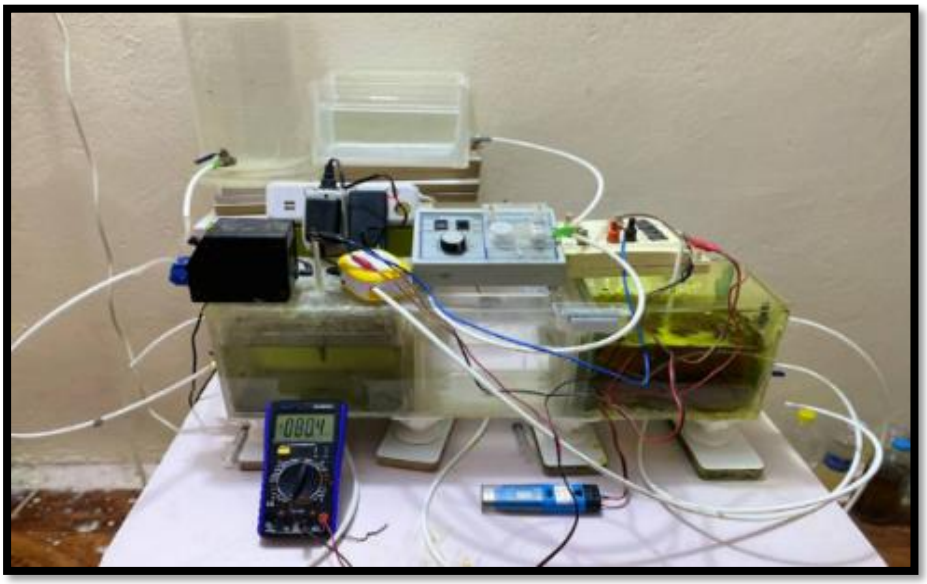

Figure 1. A photograph shows the MDC used in the present study

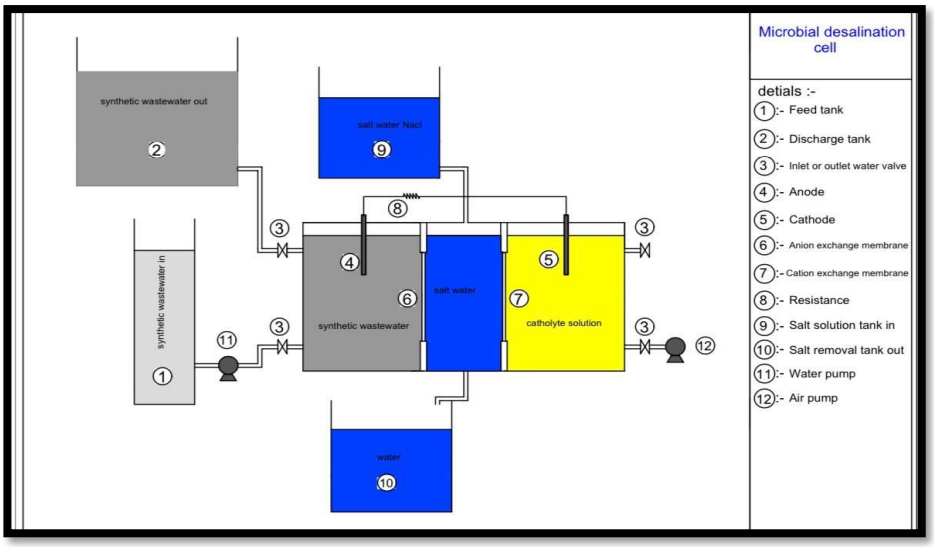

Figure 2. An illustration shows a schematic of the MFC unit showing the parts of the unit

3.2. Mineral salts medium (MSM):

The steps mentioned in were followed to prepare this MSM (Mineral Salts Medium)solution [11]. The media solution was made by dissolving the following substances in distilled water: 0.42 g/L NaHCO3, 0.56 g/L (NH4)2SO4, 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.

3.3. 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 Na2HPO4 as shown in the Figure 3[12].

Figure 3. Catholyte solution

3.4. Electrical measurements

Using the Calm Log USB Voltage Data Logger, voltage values were captured (Figure 4). Direct connection of the voltage logger to a computer allows for online data download. An electronic multimeter of the Best DT9205A type was used to measure the electrical current generated. The external applied resistance was managed by a resistance box.

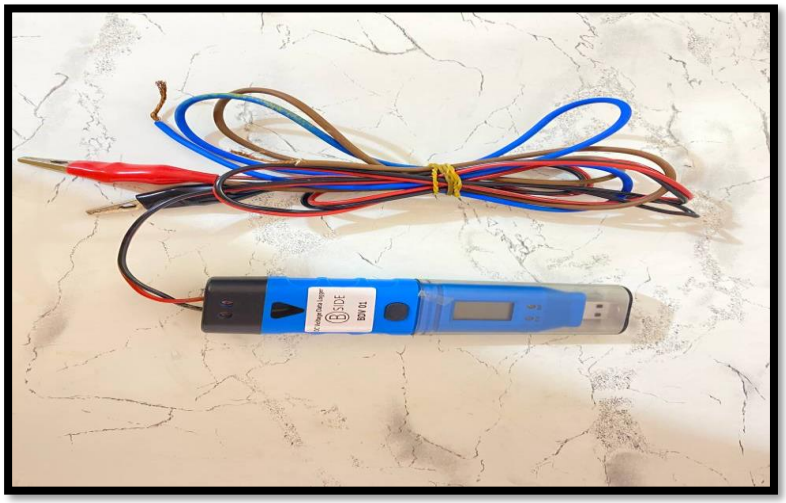

Figure 4. USB voltage data logger

3.5. 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 [12]. 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.

Table (1): The structure of synthetic wastewater

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

3.6. Chemical oxygen demand (COD)

The amount of oxygen that reactions in a measured solution can use is guided by a COD in ecological chemistry. It is often stated as the lump of oxygen used over the size of the solution, which is milligrams per litter (mg/l) in SI units. Although COD concentration has little impact on removal efficiency, it has a substantial impact on electricity generation, and its rise results in a rise in power output [13].

4. METHODOLOGY

The middle chamber of brine is prepared by adding 5000-10000 mg/l of sodium chloride in deionized water and checking the outside on a daily basis to see the removal percentage (TDS).

4.1. Total dissolved solids (TDS)

The dissolved organic matter and inorganic salts in water, most notably sodium, potassium, chloride, calcium, magnesium, and sulphate, are referred as TDS. According to the WHO, an optimal level of TDS in drinking water is 600 mg/L [17]. The acceptable boundary for TDS in India is 500 mg/l, according to the Bureau of Indian Standards [18]. Therefore, it is crucial to remove dissolved particles from saline water [14].

The TDS of rivers ranges from 20 to 2,000 mg/l, although the TDS of groundwater may be higher. Water contaminants at high quantities may have disagreeable flavours and laxative effects. TDS levels are measured because they may render water unsafe for drinking, agriculture irrigation, and aquatic life in rivers if they are high. As a result, some metals may corrode or bubble. Numerous factors, the level of TDS in a body of water is influenced by a number of issues, counting the precipitation that enters the body of water (rainwater is practically clean with less than 10 ppm TDS), human activities, the type of rock and soil that water runs over, and others. The positively charged ions of sodium, calcium, magnesium, potassium, and iron as well as the negatively charged ions of chloride, bicarbonate, carbonate, and sulphate are the main dissolved components in water that could result in the aforementioned issues. Filter paper was used to remove the suspended solid from the sample's 50 ml (V), which was then weighted (W1) and filled with the filtered model. The sample was then dried for three hours at 105 ^{o} C before the cup with the dissolved solid was weighted a second time (W2) Then TDS was determined using:

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

where:

V= volume of sample, (L).

W_1=weight of cup full by filtered sample, (g).

W_2= weight of cup with the dissolved solid, (g).

4.2. Electrical conductivity (EC)

Water's electrical conductivity can be measured using its electrical conductivity (EC). A portable instrument (a conductivity, TDS, and C ° meter) was used to measure the EC, and the instrument indication was converted to electrical conductivity indicators.

Figure 5. Electrical conductivity meter

4.3. Salt removal performance

The showing of the MDC is mostly determined by desalination efficiency, which can be modified by substrate availability and order interior resistance [9]. The total desalination rate (TDR), often known as desalination efficiency, is a measure of salt removal. Efficiency of desalination determines how much saline water's conductivity is reduced [15]. TDR is calculated using the change in influent and effluent NaCl concentrations and the saltwater hydraulic retention time [16]. Higher temperatures are anticipated to increase the permeability of ion reciprocation membranes and the conductivity of electrolytes, which cause increases of desalination's effectiveness. An average substrate concentration is also necessary for the ideal circumstances for optimal desalination effectiveness. Low substrate concentration decreases the effectiveness of desalination and hinders the microbial oxidation process, while low internal resistance and high substrate availability both help the process along [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 three-chamber MDCs, salinity reductions from 5000–10000 mg/l NaCl solutions with conductivities comparable to seawater can exceed 90%. High salinity reductions, however, required a sizable volume of freshwater. MDCs might be more effective for reducing salinity by a partial amount. For instance, wastewater only required two to three times as much desalinated water. These results show that a more feasible application for which MDCs are more likely to be used is fractional salt deletion from saltwater. MDCs can be used to desalinate brackish water as well [5]. The water in the central compartment was effectively desalinated to remove all three of the initial salt concentrations. Based on the change in solution accessibility, the salt deletions at each beginning salt concentration were approximately 88% (5000 mg/l flowrate 10 ml/min), 79% (5000 mg/l flowrate 20 ml/min), and 90% (10000 mg/l flowrate 10 ml/min) (Figure 6). The conductivity of the solution barely altered in the open-circuit control. Their TDS clearance rate would decrease with a long HRT. The wide disparity between their salt result volume and anode volume may be the cause of this benefit, as seen by their lesser TDS deletion rate based on wastewater volume. Furthermore, an IEM(ion-exchange membranes). with a large surface area would enhance ion transference and consequent salt removal. The findings indicate that the amount of salt eliminated rises as the desalination cycle and rate cut short. Osmotic pressure and the impact of the electric field were the primary factors in the desalination chamber's decrease in the salt content. When the electric field was

present, Na^{+1} and Cl^{-1}, respectively, moved to the cathode chamber and anode chamber. There is a change in osmotic pressure amidst the two chambers when the anode chamber's conductivity is lower than the desalination chambers. Now, the electric field and osmosis work together to lower the desalination chamber's salt concentration. When salinity decreases, the osmotic action weakens, salt removal slows down, and the ionic strength and osmotic pressure difference amidst the anode chamber solution and the desalination chamber also diminish.

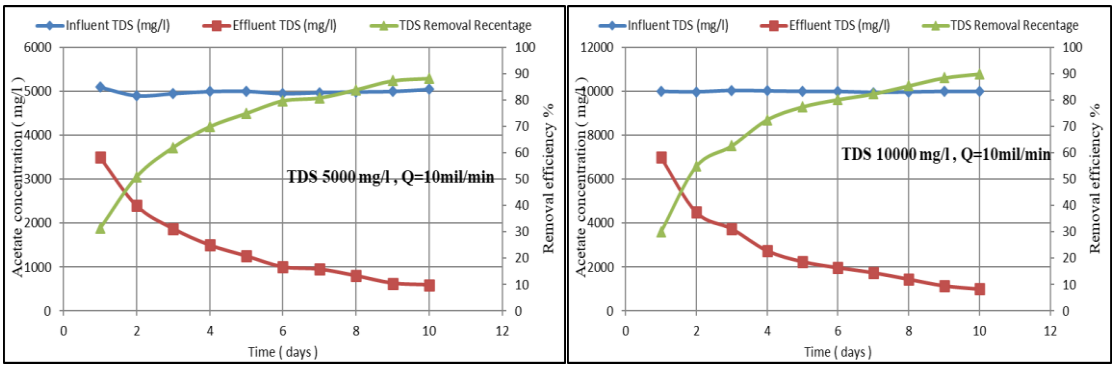

Figure 6. TDS of the MDC with 5000 mg/l,10000 mg/l NaCl for (25℃)

Because of the larger osmotic pressure differences, desalination of the 10 g/l salt solution was marginally greater than that of the 5 g/l solution in the absence of current production by bacteria and at a flowrate of 20 ml/min. The 5 g/l solution's desalination was significantly improved by biotic current generation. It is likely that in the instance of the 10 g/l, the rise in chloride concentration in the anode chamber had a negative impact on the bacteria's ability to generate current.

5.2. Power production from the MDC

Bio-electricity was continually created during the desalination process. According to the polarization curve, an open-circuit potential of 0.532V and an ultimate power density of 314.4 mW/m^3 could be reached for 10 ml/min, while 0.450 V could yield an ultimate power density of 225 mW/m^3. (Figure 7). MDCs offer a wide range of services and goods (electric energy and desalinated water). Focusing on just one product will be better because it will affect the mechanisms of MDCs. If desalination is the main goal for the purpose of producing electricity, to achieve a high desalination efficiency, MDCs can be worked at their ultimate (likely) current. MDCs can operate at their ultimate power output (despite lower desalination efficiency and current generation) but at a lower power output. There may be a trade-off between higher power generation in addition lower desalination efficiency because the electric energy generated by MDCs can be utilized by downstream desalination techniques (such as the RO method).

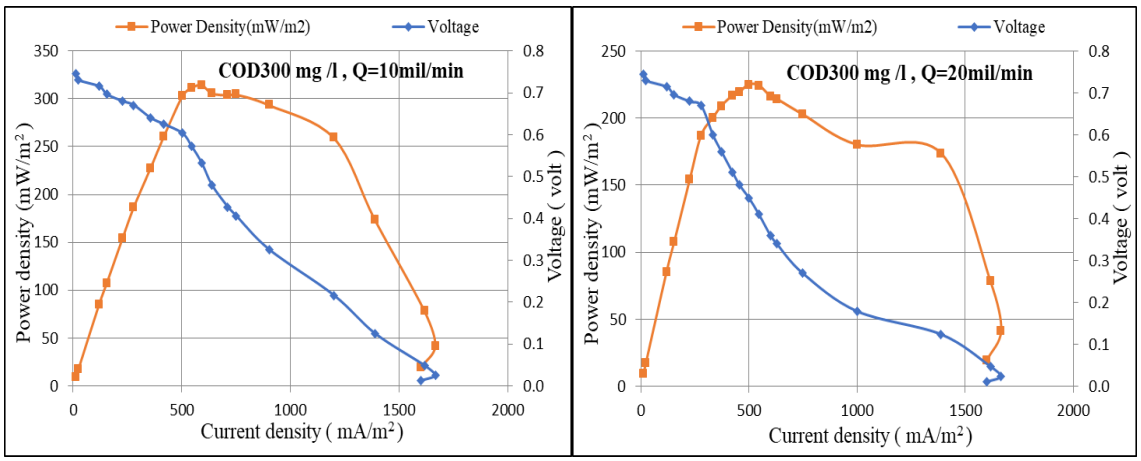

Figure 7. Polarization arch (power density, current density and voltage) of the MDC flow rate of 10 and 20 ml/min.

5.3. The generated current

The maximum current was over 3.55, 9 mA for a flow rate of 10, 20 ml/min, as shown in Figure 9. The current amplified for the first nine days before becoming steady after the ninth day. Under the specified circumstances, the current was maintained steadily for more than 12 days.

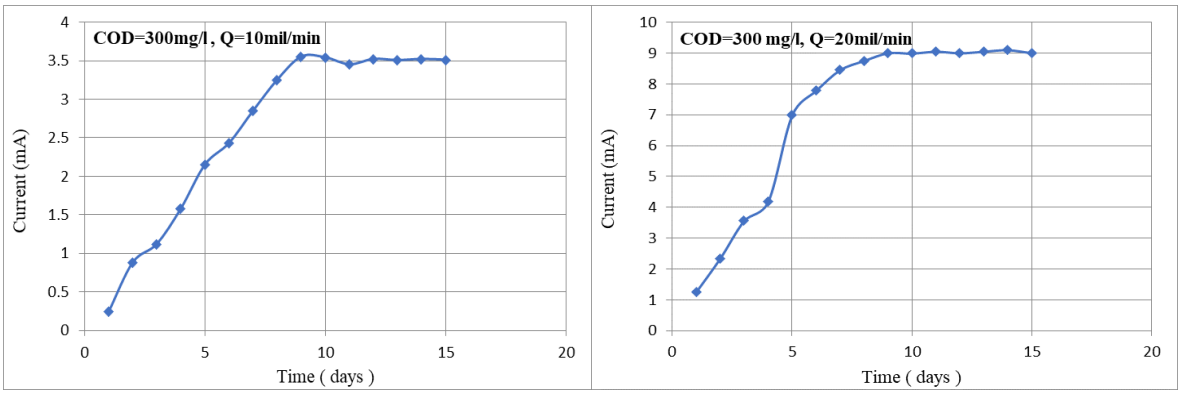

Figure 9. Variation the generated current with time for Q=10,20 ml/min

6.CONCLUSIONS

To produce simultaneously renewable energy, clean wastewater, and satisfy rising energy demands, MDC has appeared as a viable possible technology. With microbial desalination cell, this work shows a breakthrough in the sustainable desalination of salt water. The electrochemical ion adsorption on the electrodes of the MDC reactor allowed it to remove an average of 91% of the salt from the desalination chamber without adding salt to the anode or cathode chamber. A thorough analysis of several MDC modifications, counting their desalination capabilities in addition power output, has been provided. The performance of the MDC in terms of desalination and created coulombic efficiency has been critically examined as a result of a number of operational parameters. In this research, the application of a microbial desalination cell was investigated. At 7.50 g TDS L/d of TDS removal rate, the NaCl (salt result volume) was able to be removed by the MDC in excess of 90%. 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 produced by the MDC was 314.8 mW/m^3. Thanks to the study's findings and lessons learned, this can help to build a more effective desalination and wastewater treatment method. The relatively slight deviation between the experimental and predicted results at the beginning of operation is because of the period of acclimation and membranes saturation

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