Bioelectrochemical Treatment of Sewage Associated With Desalination of Wetland Saline Water and Bioelectricity Generation in Stacked Microbial Fuel Cell

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Abstract-Microbial desalination cells (MDCs) are considered as a new clean sustainable technology for simultaneous treatment of wastewater, desalination of saline water, and power generation. In this study, the performance of a stacked microbial desalination cell (SMDC) contained three desalination chambers was investigated. This SMDC which designed with three desalination chambers was fed with real domestic wastewater to the anode and actual wetland saline water to the desalination chambers. The results revealed that maximum COD removal efficiency, desalination efficiency, power generation, and coulombic efficiency were 100%, 96.8%, 877mW/m^2, 6.92%, respectively. These promising results indicated the validity of using SMDC for simultaneous desalination of actual wetland saline water, treatment of sewage treatment, and power generation.

Keywords- Stacked microbial desalination cell, , Power generation, Saline water, Biotreatment.

I. INTRODUCTION

The world is increasingly focusing on water and energy conservation. It is estimated that the chemical energy contained in the organic fraction of domestic wastewater is nearly 1.93 kWh/m^3, which is five to ten times the energy required for wastewater treatment using traditional activated sludge processes (0.2–0.4 kWh/m^3 of treated wastewater). However, as organic energy in wastewater is often lost in traditional treatment processes as it is either oxidized to CO_2 (released in the form of heat), or transformed into excess sludge [1]. Microbial desalination cells (MDCs) are MFC-derived technology that offer simultaneous wastewater treatment, power generation, desalination, realizing in-situ utilization of chemical energy of wastewater for salt water desalination. Stacked MDCs were invented to improve the desalination rate and current efficiency [2, 3]. Rodrigo et al. [4] reported that; The desalination performance of MDC can also be increased using multiple pairs of ion-exchange membranes (IEMs), inserted between the anode and cathode chambers, to improve the charge transfer efficiency and allow the saline water to flow through a series of MDCs prompting more salt removal. This configuration is referred to the stack structure MDC system (SMDC). The SMDC consists of alternating AEMs and CEMs which create alternating pairs of desalting and concentrating cells in the desalination chamber, thus increasing the separation of ion pairs from the saltwater for every electron passing through the circuit due to Kim et al [5]. The stacked MDCs are useful as they recover more energy compared to other MDC configurations, and are thus cost-effective. In this case, the organic matter is oxidized by bacteria in the anodic chamber in a stacked set-up, thereby recovering more energy [6]. SMDC configuration is promising, and has shown the advantages in enhancing the total desalination rate (TDR) and the charge transfer efficiency (CTE) [2, 7, 8].
The SMDC scale and using thin desalination cells could benefit the current production [1, 9, 10]. Kim et al. [5] reported that the transport of electron through the electrodes of MDC is responsible for the movement of a pair of

ion across the membranes in each chamber which leads to the enhanced CTE and total rate of the desalination process. Rodrigo et al. [4] found that the insertion of membrane in stacked MDC enhanced the charge transfer capability and salt removal due to the transfer of ions through the pairs of membrane. Stacked configuration works on the mechanism of bio-electrochemical reaction, where varying their setups and operational parameters such as connection of electrodes; either series or parallel and hydraulic flow methods may affect the process of desalination and the desalination chamber number. A remarkable increase in the total desalination rate could be obtained by means of increasing the desalination cell number and reducing the external resistance [2].
This study aimed to assess and evaluate the performance of a stacked microbial fuel cell (SMDC) for simultaneous biotreatment of real sewage, desalination of actual wetland saline water, and power generation.

II. MATERIALS AND METHODS

2.1 Substrate

Real domestic wastewater was freshly collected from the main sewage pipe in Al-Kut city, Iraq. The average quality and characteristics of the collected raw sewage is presented in Table 1. It is obvious that the most critical constituents are the chemical oxygen demand (COD) as well as the oil and grease.

Table 1- Characteristics of the collected real sewage

Constituents	Unit	Average concentration	Allowable* concentration
pH	-	7.2-7.5	6-9.5
COD	mg/l	1500-250	100
TSS	mg/l	60	30
Color	mg/l	Reddish brown	Clear
CL^-	mg/l	195	200
SO_4^{-2}	mg/l	324	200
PO_4^{-2}	mg/l	7.5	3.0
NO_3^-	mg/l	18	50
NH_4^+	mg/l	24	30
TDS	mg/l	1000	-

*According to the Iraqi regulations for rivers and public water reservation.

2.2 Saline water

Actual saline water samples was collected from Hor Al-Dalmaj wetland, Iraq. The average quality and characteristics of the real saline water is presented in Table 2.

Table 2- Characteristics of the actual Al-Dalmaj wetland saline water

Constituent	Unit	Average concentration
TDS	mg/l	15000-3000
TSS	mg/l	1600
SO_4^{-2}	mg/l	576
NO_3^-	mg/l	33
Cl^-	mg/l	1263
PO_4^{-3}	mg/l	Nil
pH	mg/l	7.0-7.4

2.3 Biocatalyst

Activated sludge was freshly collected from the aeration tank of a local wastewater treatment plant in Baghdad. It was exploited as the source of active microorganisms. The qualitative analysis of the collected sludge revealed that the dominant types of microorganisms were *Pseudomonas*, *Bacilli*, and *E-coli*. The activated sludge samples were stored anaerobically in a tightly closed plastic container at 4°C until use.

2.4 catholyte solution

The catholyte solution was prepared according to the procedure reported by Ge et al. [8] .It was composite from phosphate buffer solution (PBS) with initial pH range of 7-7.4 consisted of; 0.7492 g/L Na_2HPO_4, 3.1167 g/L NaH_2PO_4 and 32.930 g/L of $K_3Fe(CN)_6$.The solution was sterilized by an autoclave at 121°C for 20 minutes using steam under approximately 1.2 kg / cm^2 pressure.

2.5 SMDC construction and setup

A quintuple chamber-SMDC made of transparent acrylic material was constructed and setup in this study. The SMDC consisted of anode compartment, 3 desalination compartments, and a cathodic compartment. The anode compartment had dimensions of 10cm x 10cm x 10cm, whereby, the dimensions of the three desalination and cathode compartments were 10cm x 10cm x 5cm. Graphite plain electrodes were used in the SMDC, each had a surface area of 106.4 cm^2. The graphite electrodes were scratched before use to enhance bacterial attachment during biofilm growth. (AEM) and (CEM) membranes were alternately sandwiched in two perforated Perspex sheets and used to separate the compartments from each other Fig.1. Two types of membranes were used; CMI-7000 and AMI-7000, provided by membrane international INC., NJ. The dimensions of membranes were 10cm x 10cm and of the perforated Perspex sheets were 12cm x×12 cm containing 169 pores, each of 5 mm diameters.

2.6 Operating conditions

After designing and constructing the SMDC, all the components were cleaned very well with proper detergent, washed with tap water, and then with distilled water. AEM and CEM membranes were immersed with 5% concentration sodium chloride for 12 h before using them, and then rinsed with deionized water to ensure good conductivity for protons and electrons. SMDC was continuously operated at a room temperature, and continuously fed with 0.56 ml/min actual domestic wastewater from Al-Kut city until obtaining stable power output. The total hydraulic retention time (HRT) was (30h). Table 1 represents the main characteristics of wastewater. The desalination chambers were continuously fed with 0.05 ml/min actual saline water from Al-Dalmaj wetland.

Figure.1 Photo of the SMDC system

2.7 Analysis

The general performance of SMDC was evaluated by the removal efficiency of Chemical oxygen demand (COD), total dissolved solids (TDS) removal efficiency, and power generation. Daily measurements of COD were carried out using COD analyzer (Type: lovibond COD/RD/125), TDS concentration was measured using (WTW Laboratory Multi-parameter Bench top Meters, Multi 9430 IDS), and the voltage was continuously measured by a multimeter with a voltage data logger (EL-USB-3) and converted to power according to the following equation:

$P=I\times V$ …… (1)

Where; P = power, I = current.

According to Ohm's law:

$I= v/\Omega$ ……. (2)

Where;

Ω= resistance and V= voltage.

The power was normalized by the surface area of the anodes to obtain the power density. Columbic efficiency was calculated as the total measured coulombs divided by the moles of COD removed assuming 4 mole of electrons/mole of COD.

III. RESULTS AND DISSCUSION

3.1 COD removal

MDC was continuously operated at stable conditions for 90 days. The Anode chamber was continuously fed with real domestic wastewater and the desalination compartments were fed with actual saline water from Hor Al-Dalmaj wetland. The results demonstrated complete reduction of COD with maximum and average removal efficiency up to 100% and 97.5%, respectively as presented in Fig. 2. This high removal rate of COD was observed after 1 day of the SMDC start up. This could be related to the type of wastewater components which might be favorable to the biomass in the anodic section of SMDC.

These promising results were in a good and agreement and higher than those in the range of (62%–92%) reported in previous studies [6, 10-13] .

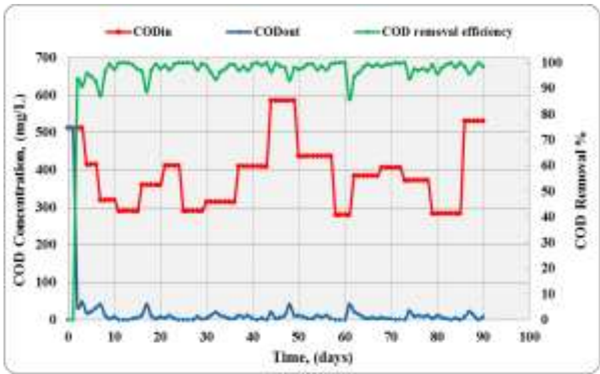

Figure. 2 Profiles of COD removal in SMDC

3.2 Total dissolved solids (TDS) removal

Maximum and average TDS removal efficiency were 96.8 % and 79.5 %, respectively achieved in the desalination chambers of the SMDC after 90 days of continuous operation as given in Fig. 3.

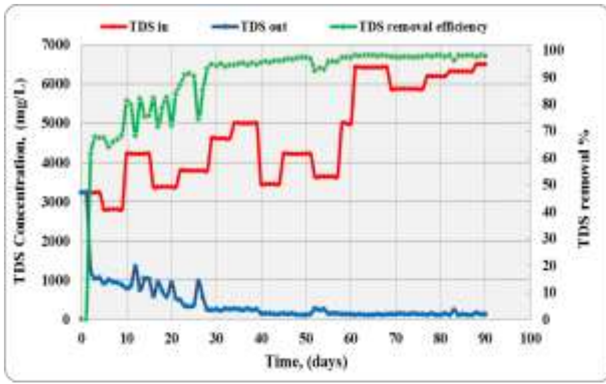

Figure. 3 Profile of TDS removal

In spite of the high fluctuation in the TDS concentration, the TDS removal was significant. This could be due to extra number of ions resulting from the multiplication of real salt water compounds and thus lead to an increase in ion exchange, which in turn leads to high TDS removal. The removal efficiency of TDS exhibited higher values compared to those values previously reported in literatures.

Meng et al.[14] suggested the desalination efficiency of 31.63 ± 1.26% in a two-phase MDC to achieve simultaneous desalination of saline solution and dehydrated sludge after 200 d operation. The results obtained by Cao et al.[15] revealed 90% desalination efficiency in MFC modified to MDC. The desalination efficiency of oilfield produced water was 90% in microbial osmotic fuel cell reported by Ismail and Ibrahim [16].

3.3 Power generation

The profile and variation of generated current and power time in the SMDC is given in Fig. 4. It is obvious that that there was a high fluctuation in the current and power generation during the first 20 days which was well expected till the SMDC achieved its steady state conditions. Than after, almost a stable current and power were observed until the end of the operation period. Maximum current and power generation were 907.9 mA/m^2 and 877 mW/m^2, respectively.

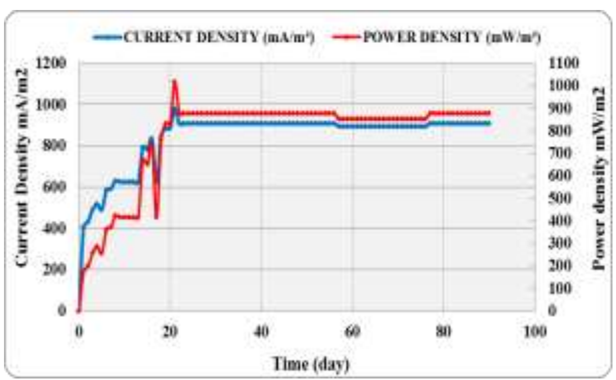

Figure. 4 current and power generation in SMDC

In general, the efficiency of organic matter removal that represented by COD concentrations and saline removal which represented by TDS concentrations associated with power generation had been proved the feasibility of using the SMDC.

3.4 Polarization curve

Polarization curves and power density can reflect the performance of the SMDC. The relationship between the cell voltage and the power densities as a function of the current density is given in Fig. 5. Variable external resistances ranged from 1 to 1000 Ω were applied to demonstrate the data required for the polarization curve of the SMDC. A maximum power density of 373.03 mW/m^2 and current density of 573.1 mA/ m^2 were achieved at an external resistance of 100 Ω.

These results were in accordance with the fact that the maximum power achieved when internal resistance is equal to external resistance (Maximum point $R_{ext}=R_{int}$) [17]. The internal resistance can be estimated as the slope of the linear section of polarization curves [13].

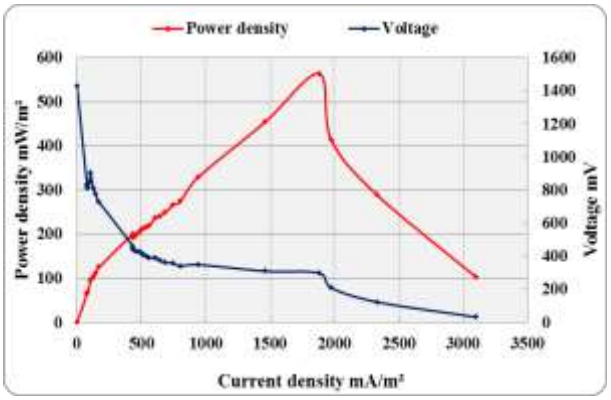

Figure. 5 Polarization curve of SMDC

3.5 Coulombic efficiency

The coulombic efficiency (CE) of a cell indicates a measure of electron recovery from the cell. It is also described as the percentage of total charge transferred to the anode surface over the maximum charge extractable upon complete oxidation of the substrate to electricity [10].Coulombic efficiency (CE) can be calculated as follows [18]:

$$CE = \frac{M*I}{F*b*q*\Delta S} \times 100\% \quad ...(3)$$

Where;

M=32 the molecular weight of oxygen, I is the generated current (Amp), F is Faraday's constant (96485 coulomb/mole), b=4 is the number of electrons exchanged per mole of oxygen, ΔCOD is the change in COD over time, and q is the volumetric influent flow rate. The maximum coulombic efficiency of this MDC under steady conditions is 6.92%.

These results were in a good agreement the coulombic efficiencies values ranged from 1% to 7% previously reported by He et al. [2]. Villasenor et al. [19] reported columbic efficiency values between 0.27% and 0.45%.

IV. CONCLUSION

This study aimed to investigate the performance of a stacked microbial desalination cells (SMDC) for desalination of actual saline wastewater simultaneously with biotreatment of real sewage as well as power generation. The results demonstrated that maximum efficiency of desalination, COD removal, and power generation were 96.8%,100%, and 877mW/m^2, respectively. These results indicated the potential of applying SMDC as a sustainable technology for desalination and biotreatment processes associated with electricity generation.

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