International Journal of Research in Biosciences
Vol. 4 Issue 4, pp. (46-53), October 2015
Available online at http://www.ijrbs.in
ISSN 2319-2844

Research Paper

Desalination of diluted seawater and bioelectricity generation by microbial desalination cell using sewage as substrate and source of microorganisms

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(Received January 3, 2015, Accepted August 19, 2014)

Abstract

Shortage of freshwater has led mankind to develop technologies to make seawater usable. The present day desalination technologies are uneconomical for developing countries as these are energy intensive. In the present study, a simple, economical, laboratory scale microbial desalination cell was set up and operated without the input of energy, by using sewage as a source of substrate and microorganisms. In addition to achieving desalination, it also resulted in production of power, though insignificant. On operating the MDC using 0.5% NaCl and diluted seawater separately, the reduction in Na^+ was 45% and 22.5% respectively and reduction in Cl^- was 53% and 7.9% respectively within the first 24 hrs of operation with no further decrease thereafter. The maximum potential difference recorded was 13.1 mV (0.026 mA) with 0.5% NaCl solution, at 24 hrs. Preliminary studies of the microbial community developing on the anodic surface using Scanning Electron Microscopy revealed the presence of slightly curved rod shaped bacteria with thread like appendages. In light of the numerous technical innovations in this area, the present study documents the use of simple basic environment friendly MDC using sewage as a substrate and source of microorganisms to drive the desalination process.

Keywords: biofilm, microbial fuel cell, nanowires, sewage.

Introduction

Water and energy are the two most pressing issues facing the world and are driving the search for sustainable supply of both[1]. One of the solutions to increase fresh water availability is desalination of brackish and sea water. The high energy consumption of the conventional desalination technologies make them unavailable for developing countries. Therefore, feasible innovations in the existing desalination technologies that make them less energy dependent need to be introduced [2]. An alternative would be to develop desalination processes powered by renewable energy, such as solar and wind driven electricity.

A potential answer to above problems lies in bio electrochemical systems (BES) that use bacteria to create renewable energy in the form of electricity, hydrogen and methane. A Microbial Fuel Cell (MFC) is a type of bioreactor that utilizes the bio-chemical reactions occurring in bacteria to degrade organic waste matter and produce bioelectricity[3]. A MFC can be modified to function as a Microbial Desalination Cell (MDC) by placing an additional chamber (middle chamber) in the MFC assembly, which functions as the desalination cell. The three chambers (anode, middle desalination, and cathode) are separated using ion

exchange membranes and clamped together with a water seal between the chambers. The middle chamber is separated from the anode using an Anion Exchange Membrane (AEM) and from the cathode by using a Cation Exchange Membrane (CEM). Bacteria in the anode chamber metabolize organic matter and release electrons and protons into the anodic solution. The electrons are transferred to the anode and move via the external circuit to the cathode where they combine with protons, forming water. The difference in the potential coupled to electron flow produces current. The AEM prevents protons and other positively charged ions from leaving the anode chamber. In order to balance the charge due to electrons efflux, anions (Cl^-) move from the middle chamber through AEM into the anodic chamber. On the other side, protons are depleted in the cathode chamber as they combine with electrons and oxygen to form water, with charge balanced by cations (Na^+) passing from the middle chamber through the CEM into the cathode chamber. As a consequence of these two charge-transfer processes, Na^+ and Cl^- ions in the middle chamber are removed and the water is desalinated[2,4,5].

A number of recent studies have evaluated MDCs to determine the parameters that affect its performance, identify the microorganisms involved, explore innovations in MDC configurations in order to increase the efficiency of its performance and suitability for continuous operations[6,7,8]. The basic aim of the present study was to operate a simple and economical MDC using sewage as substrate and source of microorganisms.

Materials and Methods

Collection of Sewage

Raw sewage sample (outgoing fluid) after the physical treatment process was collected from Love Grove waste water treatment plant, Worli, Mumbai and was divided into 500 ml volumes and refrigerated till use or processed to be used in the MDC. The sewage was left undisturbed for 24 hrs at 4^oC so as to settle the solid particulate contents, 500 ml supernatant was filtered through Whatman filter paper no.1 and taken for setting up a single batch of MDC.

MDC design

The three chambered MDC consisted of three glass bottles (volume-500 cm^3), comprising the anode, cathode and desalination chamber. The lids of the bottles were perforated in order to provide for wire point inputs. The anode and the cathode chamber bottles were provided with an opening (cross sectional area 28.26 sq. cm.) in the side wall in order to facilitate ionic movements between the chambers and the desalination cell via the anion exchange and cation exchange membranes respectively. The side wall openings were clamped in order to assemble the MDC.

Electrodes

Graphite plates were used as electrodes in both anode and cathode chambers.

Membranes

AEM and CEM, (free samples) from Membranes International Inc., N.J., U.S.A., were fitted on the anode and cathode side of the desalination chamber respectively.

Electrolytes

Anode solution (anolyte) used was filtered sewage. 0.1 M phosphate buffered saline (PBS) was used as cathode solution (catholyte).

Desalination chamber solution

NaCl solution (0.5%) or filtered diluted (1:5) sea water was used.

Anode biofilm formation

A graphite electrode was immersed in 0.1 M PBS for 24 hrs and then in filtered sewage for four days to allow biofilm formation on the electrode by sewage microflora. This preformed biofilm was used in the MDC.

MDC assembly and operation

The three glass bottles were rinsed with alcohol thrice, kept in oven for 1 hour at 100^{o}C for sterilization. Graphite electrodes were soaked in distilled water for 24 hours and then rinsed with 0.1M PBS. The anode had preformed biofilm as mentioned above. The three chambers were assembled by placing AEM between the anode chamber and middle chamber and the CEM between the middle chamber and cathode chamber. A Teflon ring was placed on either side of the membrane for leak proof fitting. The anode chamber was covered with a layer of paraffin oil and sealed with parafilm to restrict air passage and provide partially anaerobic conditions. The anode and cathode were connected with an external resistance of 500Ω. The three solutions i.e. anolyte, saline solution, catholyte (500 ml of each) were filled in their respective chambers. The cell was left undisturbed at room temperature for 4-5 days. At intervals of 24 hrs the multimeter reading was noted and aliquots were drawn from the middle chamber for Na^+ and Cl^- ion analysis.

External circuit

The external circuit was completed using a resistance box (500Ω) and a digital multimeter. The voltage output given by the MDC was measured by multimeter.

Power Production

Current (I) was calculated as per Ohm's Law, using the formula

$$I = \frac{V}{R}$$

where, I is the current in milli amperes (mA), V is the voltage in milli volts (mV), and R is the resistance of the conductor in ohms (Ω).

Statistical analysis

All test experiments were repeated thrice and controls, twice. The mean and standard deviation (SD) was calculated.

Analysis of the desalination potential in terms of reduction in Na^+ and Cl^- concentration

In the MDC, the Na^+ from the NaCl solution in the middle chamber would be transported to the cathode chamber. Hence post desalination process, the solution in the middle chamber should show a decrease in the concentration of Na^+. The Na^+ ion concentration of middle chamber solution was estimated by Flame photometry using calibration curve method[9]. The Cl^- from the NaCl solution in middle chamber would be transported to the anode chamber. Hence post desalination the Cl^-concentration in the middle chamber should decrease. Cl^- estimation was performed by Mohr's method[9].

Analysis of the MDC potential to desalinate sea water

The efficiency of the MDC to desalinate naturally saline samples was studied using a sea water sample from the Marve creek, Mumbai. The sample was diluted (1:5) such that the initial Na^+ and Cl^- ion concentrations were within the sensitivity range of the methods used for estimation of the same. The diluted samples were introduced in the middle chamber and the MDC was operated. Aliquots were drawn and the Na^+ and Cl^- ion concentration was estimated.

Analysis of the microbial community developing on the anode as a biofilm

The anode microbial biofilm consists of electrochemically-active bacteria present in sewage and is the most crucial part of the MDC that is responsible for the desalination process and power generation. To confirm that bacteria are responsible for current generation and desalination in MDC, the microbial communities that developed on the anode was examined by Scanning Electron Microscope (SEM). The anodic biofilm was processed (air dried, fixed, dehydrated and sputter coated with gold) and examined under SEM[10,11].

Results and Discussion

The laboratory scale three chambered Microbial Desalination Cell was constructed as shown in Figure 1. It was simple in design as compared to ones reported in the earlier studies[1,2,4,7]. Its efficiency in desalinating a 0.5% NaCl solution and diluted sea water was tested.

The ability of the MDC to desalinate saline solution (0.5% NaCl) was analyzed with respect to Na^+ and Cl^- concentration (Table 1). The anolyte used was sewage. A control MDC was operated using autoclaved sewage in the anode chamber. Since, Na^+ and Cl^- ions are being transported to the cathode and anode chamber respectively, the concentration of these ions should decrease in the middle chamber. As expected, a reduction of Na^+ concentration by 45 % and Cl^- by 53 % was observed after 24 hrs (Table 1 and Figure 2), after which there was no further decrease in either of the ions.

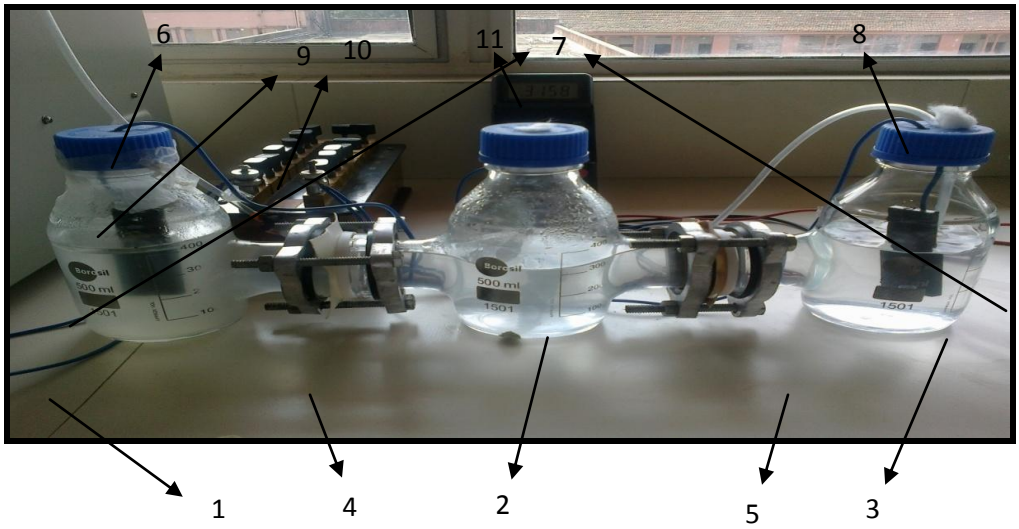

Figure 1: A schematic view of the current study MDC 1: Anode chamber, 2: Middle chamber, 3: Cathode chamber, 4: AEM, 5: CEM, 6: Copper wires for suitable connections 7: Graphite electrodes, 8: Tube to air pump, 9: Parafilm for sealing anode, 10: Resistance box, and 11: Digital multimeter

Table 1: Na^+ and Cl^- concentrations with 0.5% NaCl in the middle chamber.

Time (hrs)	Na^+ concentration in middle chamber (gm/L)				Cl^- concentration in middle chamber(gm/L)			
	Test		Control		Test		Control	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0	2.33	0.2	2.22	0.2	2.96	0.09	3.03	0.12
24	1.29	0.25	2.22	0.2	1.38	0.12	3.03	0.12
48	1.29	0.25	2.22	0.2	1.38	0.12	3.03	0.12

72	1.29	0.25	2.22	0.2	1.38	0.12	3.03	0.12

Table 2: Voltage and current production in the MDC with 0.5% NaCl solution in the middle chamber

Time (hrs)	TEST			CONTROL		
	Voltage (mV)		Current (mA)	Voltage (mV)		Current (mA)
	Mean	SD	Mean	Mean	SD	Mean
0	8.88	0.652	0.018	-1.37	0.275	-0.003
24	13.10	0.772	0.026	-2.23	0.056	-0.005
48	9.56	0.308	0.019	-9.79	0.325	-0.020
72	5.35	0.149	0.010	-42.54	0.275	-0.085

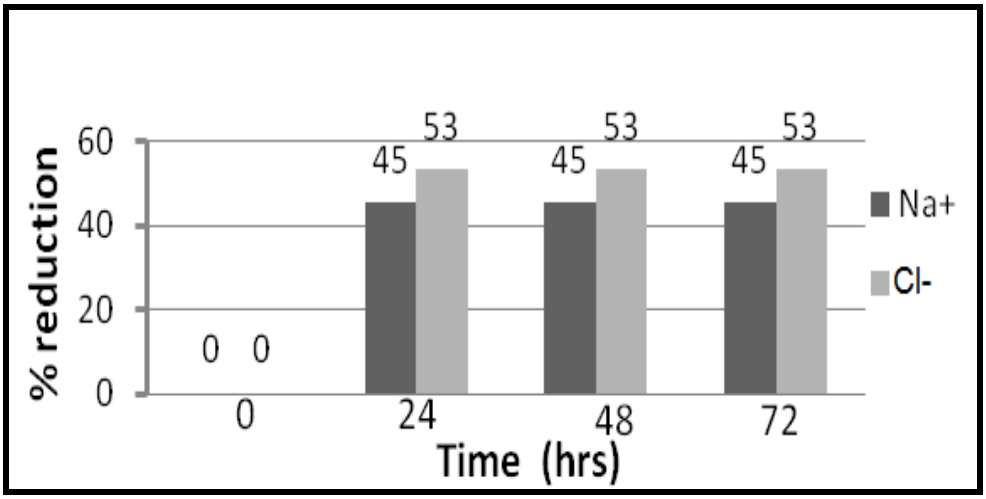

Figure 2: % reduction in Na^+ and Cl^- concentrations with 0.5% NaCl solution in the middle chamber

The maximum voltage generated was 13.1 mV at the end of 24 hrs of operation after which a progressive decline was observed. The decline in voltage generation after 24 hrs, is a consequence of salinity and pH changes in the anolyte due to the migration of anions from the middle chamber, affecting microbial activity in the anode [8,12,13]. Since, an anode with a pre-developed biofilm was used, reasonable voltage (8.88 mV) and current production (0.018 mA, Table 2) was observed, immediately (at 0 hrs), which increased upto 24 hrs. Current production at 24 hrs was 0.026 mA which was the maximum produced, at 48 hrs it was 0.019 mA and thereafter decreased further. Earlier studies have reported a higher open circuit voltage of upto 700mV, but with comparatively sophisticated MDC configuration, complete anaerobiosis in the anode chamber and acetate as substrate[2]. A control MDC was operated with autoclaved sewage in the absence of anode biofilm. As seen from Table 2, negligible voltage and current production was observed, indicating the absence of biotic reaction in the anode chamber and confirming that the anode biofilm was responsible for power production.

The potential of the laboratory scale MDC in desalination of naturally saline samples such as sea water was analyzed. The sea water (middle chamber) was diluted 1:5.

Table 3: Voltage and current production, and Na^+ and Cl^- concentrations using diluted (1:5) sea water sample in the middle chamber

Time (hrs)	Voltage (mV)	Current (mA)	Ionic concentration (gm/L)	
			Na^+	Cl^-
0	9.54	0.019	2.00	2.073
24	11.27	0.023	1.55	1.870

48	9.67	0.019	1.55	1.870
72	5.27	0.011	1.55	1.870

The maximum voltage (11.27 mV) generated and current (0.023 mA) produced using diluted sea water (Table 3) as sample in the middle chamber was marginally less as compared to the desalination cell operated using 0.5 % NaCl solution (13.1 mV and 0.026 mA respectively, Table 2) at the end of 24 hrs. However the % reduction in ionic concentration was much lower i.e. 22.5% in Na^+ and 7.9% in Cl^- concentration (Figure 3), when diluted sea water was used as the sample to be desalinated. The decrease could be probably due to presence of interfering radicals or ions which were not present in the NaCl solution. Presence of divalent cations in the middle chamber have been reported to have negative effects on MDC performance in terms of power generation and desalination[8,13]. Pre-treatment of natural samples to eliminate the interfering ions can be considered prior to introduction of samples in the MDC middle chamber.

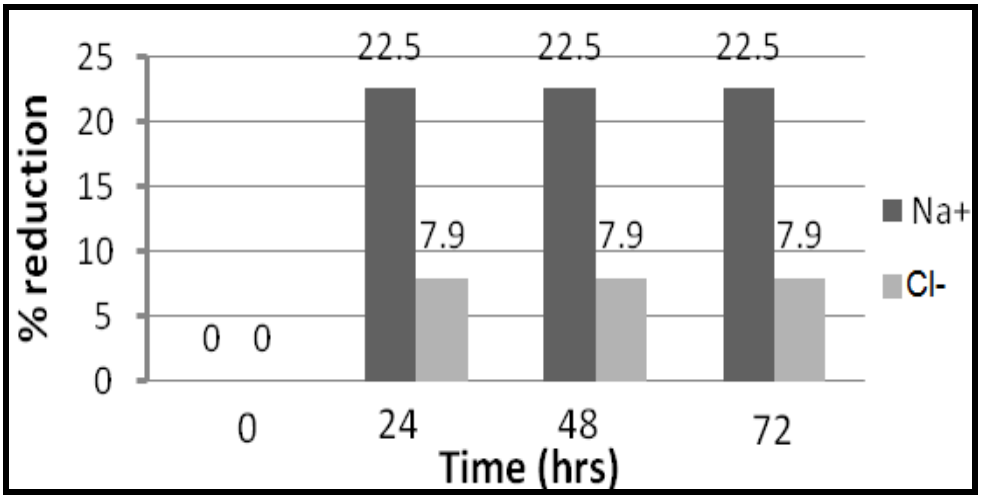

Figure 3: % reduction in Na^+ and Cl^- concentrations with sea water in the middle chamber.

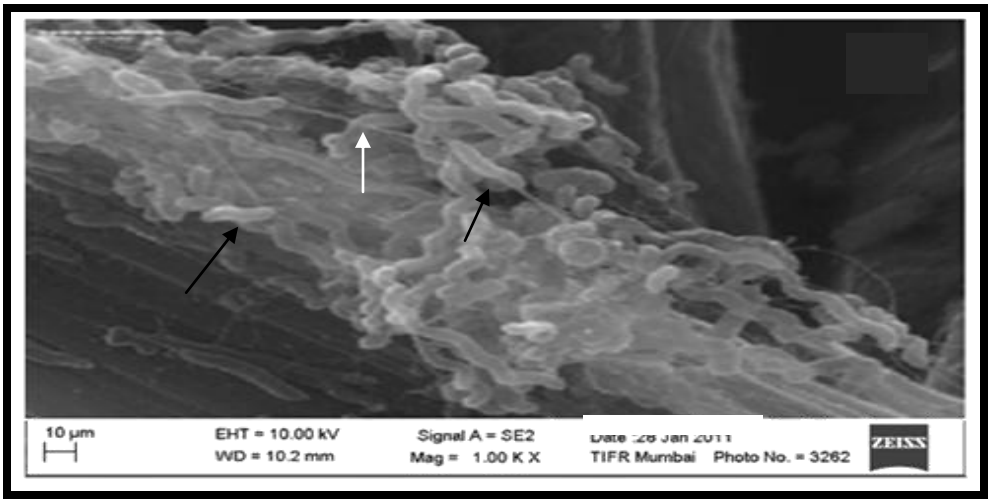

Figure 4: SEM image anode biofilm from MDC using sewage as source of both electricity generating bacteria and substrate. Black arrow marks indicate the microbes attached to the anode surface with nanowires (white arrow mark)

Conclusion

A simple and economical MDC was assembled and operated using sewage as substrate and source of microorganisms. Its ability to remove Na^+ and Cl^- ions was 45 % and 53% respectively from a 0.5% NaCl solution and 22.5 % and 7.9 % respectively when diluted seawater was used in the middle chamber, along with a small amount of voltage and current generation (13.1 mV, 0.026 mA and 11.27, 0.023 mA with 0.5 % NaCl and diluted seawater respectively) after 24 hrs of operation. The interfering ions in the diluted seawater may be responsible for the reduction in removal of Na^+ and Cl^- as compared to the reduction seen with 0.5% NaCl solution. The microbial community that developed comprised of curved rod shaped bacteria with numerous thread like appendages that presumably served as nanowires to transfer the electrons to the anode. Thus, MDCs present an environment friendly sustainable approach to desalination and can be integrated into water desalination plants.

Acknowledgements

We are grateful to the Rotary Club of Bombay Mid-Town for awarding the Smt. Sumitra Devi Jatia Research Award for this research project and Prof. Tanaz Asha, Department of Chemistry, Sophia College, for helping with the ionic estimations. We, also thank Prof. Pushan Ayyub, Dept. of Condensed Matter Physics and Material Science, Tata Institute of Fundamental Research, Mumbai for very graciously helping with the Scanning Electron Microscopy, in his laboratory.

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