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IMPROVING THE DESALINATION CAPACITY OF MICROBIAL DESALINATION CELL

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ABSTRACT

Microbial desalination cell(MDC) hold great promise for drinking water production because of potential energy saving during the desalination process. MDCs reported in literature have used expensive catalyst such as Pt or catholyte (such as ferricyanide) can make the MDC costly, environment un-friendly and non-sustainable. In an effort to improve desalination efficiency, to lower the cost, and make it greener, this study examined the role of granular activated carbon anode compartment of the MDC. The present study aims at evaluating desalination potential of MDC using Dairy waste as substrate and activated carbon in the anode chamber and potassium permanganate solution as oxidising agent in the cathode chambers respectively. This study only involved primary research on desalination of water and power output in the presence and absence of granular carbon. From these results it can be concluded that MDC with activated carbon showed a maximum removal efficiency of 32% and the control showed 21%, however much higher removal efficiencies are required to produce drinking water standards. The study clearly proved that the performance of MDC was better in terms of desalination and current production when the anode chamber was loaded with granular carbon prepared from coconut shell.

Keywords: Bio-electrochemical system, Exoelectrogenic bacteria, Granular activated carbon, Microbial desalination, Salinity removal.

I. INTRODUCTION

In the 21st century, the most crucial problem afflicting people around the world is global water scarcity. About three billion people around the world have no access to clean drinking water. According to the World Water Council, by 2020, the world will be about 17% short of the fresh water needed to sustain the world population. Moreover, about 1.76 billion people live in areas already facing a high degree of lacking fresh water. As a result, the present surface water resources will no longer be sufficient to meet the future needs for mankind. The need for fresh water is at the top of the international agenda of critical problems, at least as firmly as climate change [1]. Increasing amounts of fresh water will be required in the future as a result of the rise in population rates and enhanced living standards, together with the expansion of industrial and agricultural activities. Available fresh-water resources from rivers and groundwater are presently limited and are being increasingly depleted at an alarming rate in many places. Therefore, alternative sources of water such as wastewater, brackish water and seawater will gain importance compared to the more traditional water sources. By removing salt from the virtually unlimited supply of seawater, desalination has emerged as an important source of fresh water. Numerous researches were conducted in an effort to develop more sustainable technological solutions that

would meet increasing water consumption. Of the technologies developed, desalting seawater to produce clean water for drinking, irrigation, industrial and urban development emerged as the most sustainable approach [2].

Desalination is one option for producing potable water from brackish water and seawater in many parts of the world, but most water desalination technologies are energy and capital intensive. The main desalination technologies currently used are reverse osmosis, electro dialysis, and distillation. Continual improvements in desalination processes, particularly in the past decade, have made these systems more reliable and have reduced capital costs, but high energy requirements remain a concern in many parts of the world [3]. Microbial desalination cell (MDC) is a newly-developed technology which integrates the microbial fuel cell (MFC) process and electro-dialysis for water desalination along with production of bio-electricity [4]. The recent emerging microbial desalination cells have a great potential as a low cost and energy saving desalination process with significant environmental benefits, having such advantages as operation under room temperature and normal pressure. A microbial fuel cell was modified by placing two membranes between the anode and cathode, creating a middle chamber for water desalination between the membranes. An anion exchange membrane was placed adjacent to the anode, and a cation exchange membrane was positioned next to the cathode [5]. Exoelectrogenic bacteria oxidizing the organics in the anode chamber promotes the electron transfer and results in the migration of anions and cations from the middle chamber to the anode and cathode chambers, desalinating the water in the middle chamber. The movement of ionic species from the middle chamber results in water desalination without any use of external energy. Instead, electricity is produced while the water is desalinated [6].

In an effort to improve desalination efficiency, to lower the cost, and make it greener, we examined the role of coconut shell based carbon loaded in the anode compartment of the MDC. Performance of the MDC was evaluated in terms of changes in voltage and NaCl concentrations. In this study, the mutual effects of desalination, electricity production and the role of coconut shell based granular carbon in the anode compartment of an MDC were explored. The large surface area of the coconut shell carbon was anticipated to provide surface for bacterial growth, thereby leading to the formation of stronger microbial cultures through the formation of bio-films. In addition, the carbonaceous material offers good biocompatibility, good chemical stability and relatively low cost. The effectiveness of variation in pH, concentration of catholyte, anolyte and salt solution in improving the capacity of desalination from base model of a MDC is the main objective of the present study.

II. MATERIALS AND METHODS

2.1 Experimental Setup

Microbial desalination cell is a modification of microbial fuel cell having three chambers, anode, cathode and desalination chamber separated by anion exchange membrane and cation exchange membrane. Schematic representation and Experimental set up of three chambered MDC is shown in Fig.1 and Fig. 2. The MDC was fabricated using acrylic and held together using silicon glue. Three chambers of dimensions 10cm x 10cm x 10cm were joined and sealed together with anion and cation exchange membrane in between. One as anode chamber (1L), one as cathode chamber (1L) and one chamber for salt solution (1L) where used. The central chamber consists of 6cm hole on either side for the transfer of ions through the membrane. Anion exchange

membrane (AMI-7001S, Sainergy Chennai) and cation exchange membranes (CMI-7000S, Sainergy Chennai) are placed in between two washer sheets. The anode and cathode were Aluminum sheets (7cm x 4cm) with a fixed electrode distance of 20cm. The anode chamber is filled with medium spiked with synthetic dairy waste water and sodium acetate. The cathode chamber is filled with Potassium permanganate diluted in distilled water. A LED light was soldered onto the wires of electrode and the cell voltage and current was measured across the LED. Experiments are run in triplicates under the same conditions continuously for 5days.

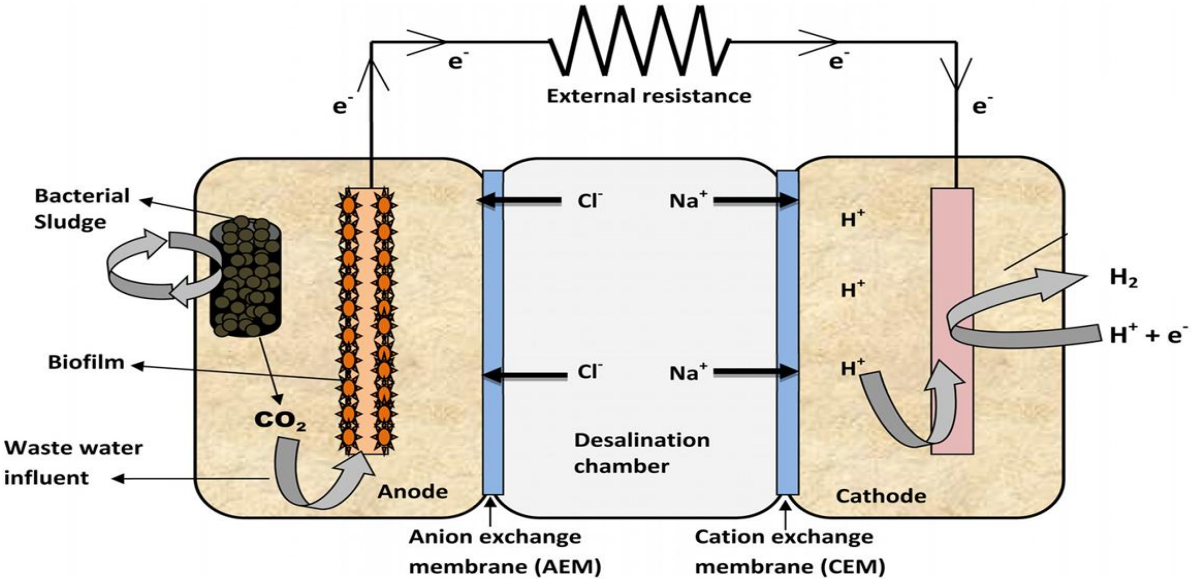

Fig. 1. Schematic representation of ionic flow in microbial desalination cell (MDC).

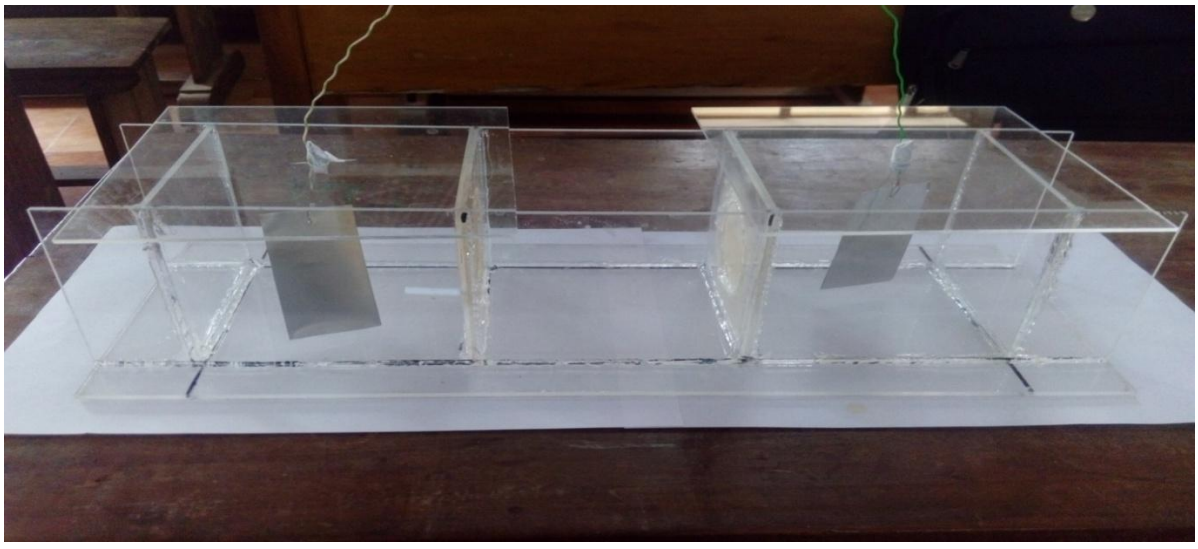

Figure 2 Experimental set up of MDC

2.2. Preparation of Activated Carbon derived from coconut shell

The coconut shells were first washed to remove dirt and then dried overnight in an air oven at 105°C. The dried shell was broken to 5–10 mm size. This material was then immersed (1:2 ratio) in concentrated H_2SO_4 (6N) for 24 h. The material was later washed several times to neutral pH. Carbonization was carried out in a muffle

furnace by ramping the temperature from room temperature to 250°C and held for 2 h. The resultant carbon was ground to 0.6–1 mm size and a pre-weighed amount was loaded to the anode chamber [6].

2.3. Preparation of synthetic waste water

The dairy waste water was collected from MILMA Dairy plant, Ramavarmapuram, Thrissur. The samples were collected in 1L plastic containers and tested for different waste water characteristics as per the standard methods. The sampling was done twice in two consecutive weeks and the synthetic waste water is prepared by taking the average values obtained for the samples. Synthetic waste water was prepared based on the characteristics of dairy waste water. The amount of constituents was found by trial and error method to obtain the actual characteristics of diary waste water. Composition and characteristics of the synthetic wastewater are given in Table 1 and Table 2.

Table 1: Composition of synthetic Dairy wastewater.

Constituents	Concentration (g/L)
Glucose	0.18
Yeast	0.02
Milk powder	1.5
Starch	0.03
Ammonium chloride	0.15
Calcium carbonate	0.15
Magnesium sulphate	0.1
Potassium dihydrogen phosphate	0.025
Dipottasium hydrogen phosphate	0.018
Sodium nitrate	0.05
Sodium acetate	2

Table 2: Characteristics of real and synthetic Dairy wastewater.

Parameters	Value (Real waste)	Value (synthetic waste)
pH	6.7	6.57
BOD (mg/L)	3400	3100
COD (mg/L)	4000	4000
Nitrate (mg/L)	636	557
Phosphate (mg/L)	231	153
TDS (mg/L)	541	533
Turbidity(NTU)	570	470
Conductivity (mS/cm)	1.05	1.02

2.4. Preparation of synthetic Sea water

The chemical composition of artificial sea water was fixed according to the IS: 8770- 1978. The chemical composition of sea water was varied to obtain salinity of 3000mg/L. Composition of artificial sea water for 3000mg/L are given in Table 3.

Table 3. Composition of Synthetic Sea Water

Constituents	3000 mg/L
	Concentration (mg/L)
Sodium chloride	2.25
Magnesium chloride	0.4
Sodium sulphate	0.35
Calcium chloride	0.1
Potassium chloride	0.06
Sodium bicarbonate	0.02
Potassium Bromide	0.01
Boric acid	0.002
Sodium Fluoride	0.0003

III. RESULTS AND DISCUSSION

3.1 MDC having different concentration of activated carbon

The batch was run to fix the activated carbon dosage, 2 and 4g/L of activated carbon was added to the anode chamber of MDC units and one MDC unit was run without any activated carbon. Potassium permanganate of concentration 1500mg/l is used as catholyte [7]. The artificial sea water having a salinity of 3000mg/l, conductivity of 5.13mS/cm and TDS of 2580mg/L, pH 6.5 was analyzed in the middle chamber. The prepared anolyte, catholyte and salt water are filled into the respective chambers with membranes placed in between them. The corresponding changes in pH, conductivity, salinity, TDS, voltage and current monitored during the experiment cycle are shown bellow.

3.1.1 Effect of activated carbon dosage on pH

pH of the solutions in the desalination compartment are presented in Fig. 3. It was observed that the pH remained close to neutral during the experiment in the desalination compartments. In the control experiments (without activated carbon) the pH in the middle (desalination) chamber varied, from 6.66 to 7.73. However, in the experimental MDC (with carbon) pH slightly varied from 6.63 to 7.37 and from 6.7 to 7.53 for 2g/L and 4 g/L respectively. The marginal variation in pH found in the anode and desalination compartments suggests the migration of ions from the middle chamber to the anode chamber during desalination.

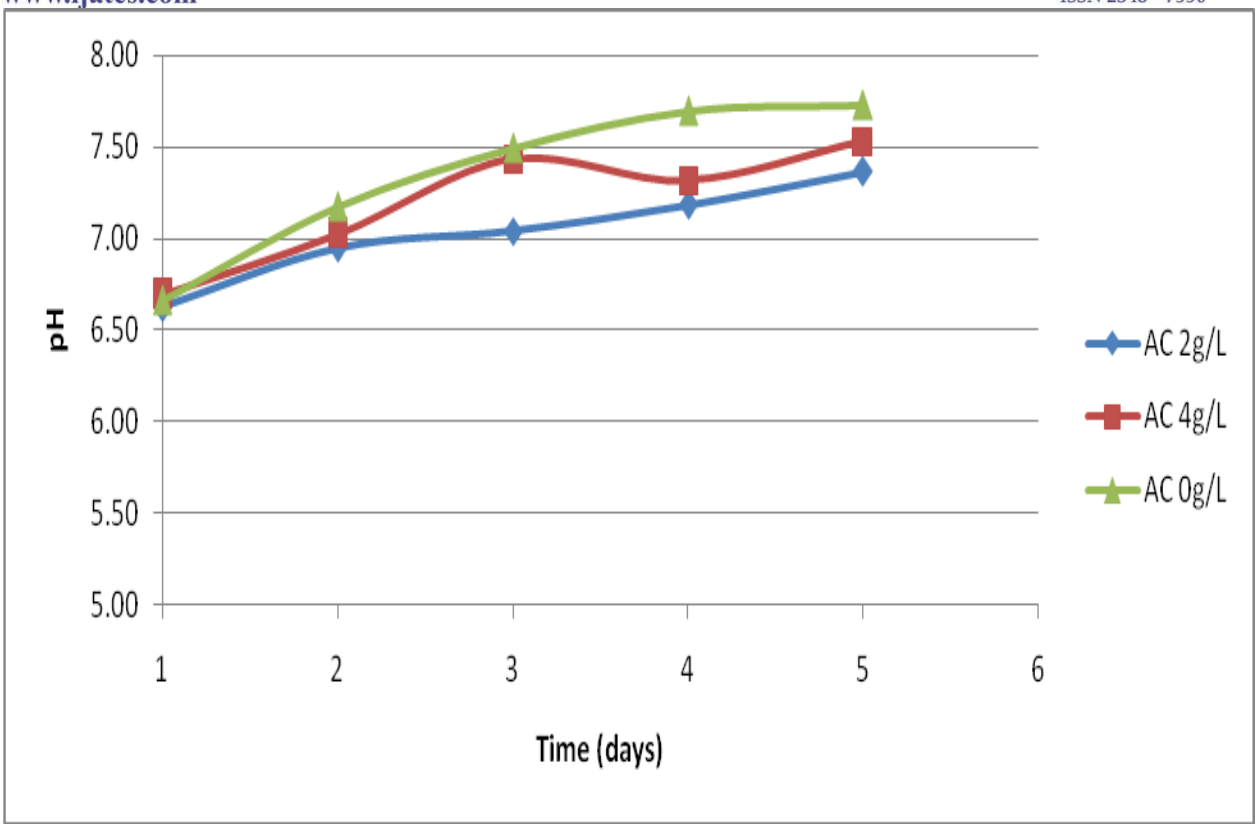

Fig . 3, pH variation in the desalination chamber

3.1.2 Effect of activated carbon dosage on Salinity and Conductivity

The variations in conductivity measured in the desalination chamber are represented in Table 4, Figure 4 and figure 5. In the control experiments (without carbon) the conductivity in the middle (desalination) chamber decreased, from 5.13 mS/cm to 3.65 mS/cm and in activated carbon with 2g/L and 4g/L the conductivity reduced to 3.35 mS/cm and 3.09 mS/cm. The conductivity in the middle chamber decreased about 29% in the control while 40% and 35% in the MFC with 4g/L and 2g/L. Similarly higher salinity removal of 32% was shown by 4g/L activated carbon. The gradual decrease in the conductivity and salinity of the sea water during desalination may be attributed to the migration of chloride anions from middle compartment to the anode compartment.

Table 4. Effect of activated carbon on conductivity and salinity

concentration of activated carbon	2mg/L		4mg/L		Blank	
	Salinity (mg/L)	Conductivity (ms/cm)	Salinity (mg/L)	Conductivity (ms/cm)	Salinity (mg/L)	Conductivity (ms/cm)
Day 1	2980	5.11	2990	5.12	2985	5.12
Day 2	2684.5	4.08	2655	4.00	2860	4.65
Day 3	2422.5	3.69	2442.5	3.65	2675	4.30
Day 4	2350	3.64	2277.5	3.39	2515	3.85
Day 5	2227.5	3.35	2040	3.09	2360	3.65

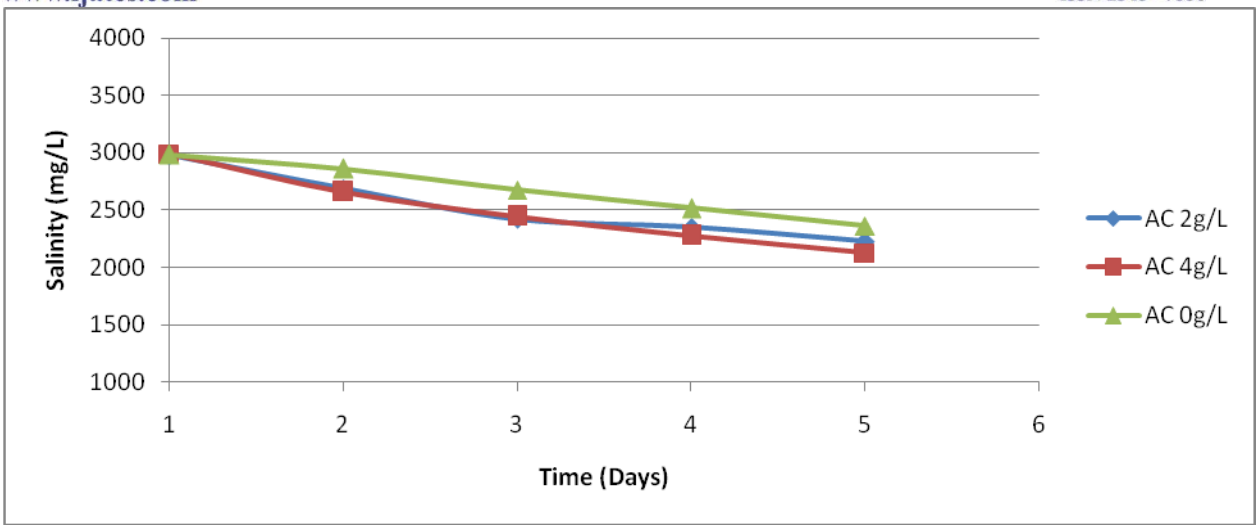

Fig 4, Salinity variation in the desalination chamber

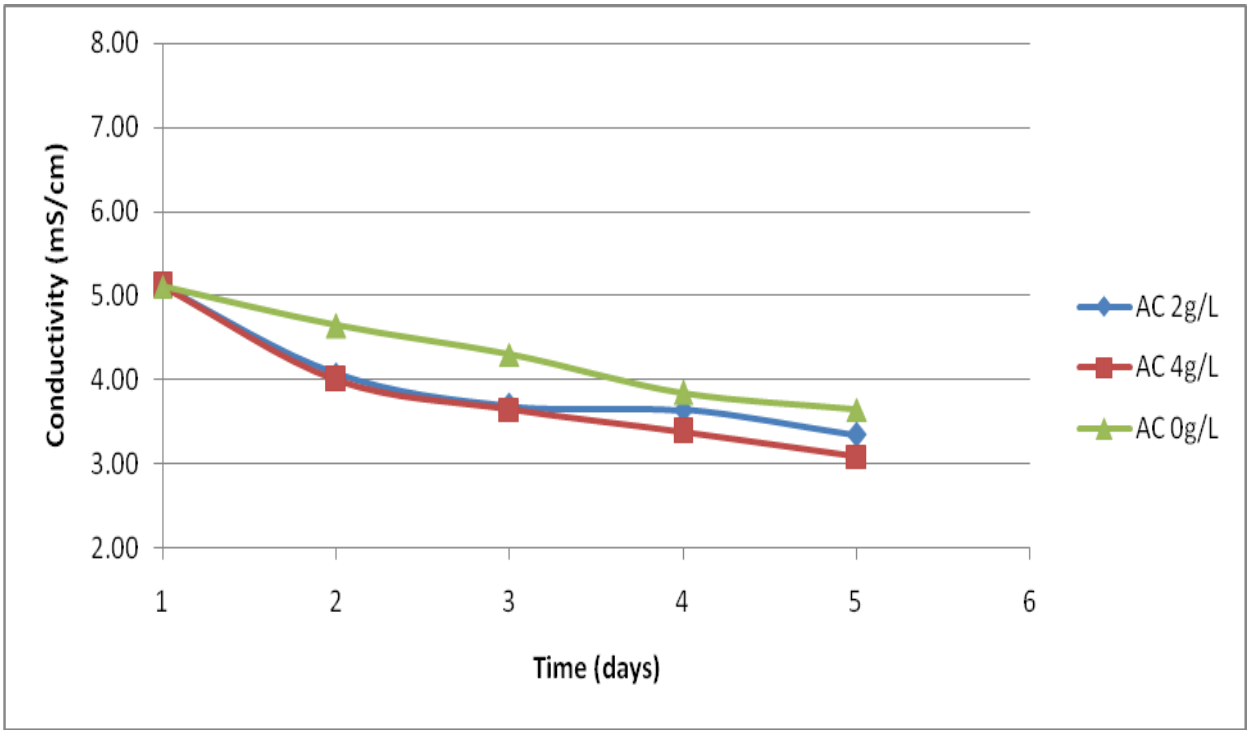

Fig. 5, Conductivity variation in the desalination chamber

3.1.3 Effect of activated carbon dosage on Voltage and Current

The voltage readings obtained during desalination experiments are presented in Table 5 and Fig. 6. Maximum voltage of 920 mV and 910 mV was obtained for activated carbon dosage of 2 and 4g/L and 600 mV were produced in control. The voltage and the current values were seen to fluctuate largely during the experimental runs, presumably due to the complexity of the substrate and microbial activities [8]. The anolyte solution was spiked with a prefixed concentration of acetate when the voltage readings dipped close to 150 mV to avoid substrate limitations for bacteria on the anode or changes in pH. When the anolyte was spiked there was a hike seen in the voltage, demonstrating the power generation was affected by acetate levels.

Table 5. Effect of activated carbon dosage on Voltage and current

concentration of activated carbon	2g/L		4g/L		Blank	
	Voltage (mV)	Current (mA)	Voltage (mV)	Current (mA)	Voltage (mV)	Current (mA)
Day 1	150	0.075	200	0.04	162.5	0.07
Day 2	584.25	0.15	613	0.1775	364.5	0.1175
Day 3	1072.5	0.5175	1175	0.435	601.25	0.1775
Day 4	795.5	0.3375	703.25	0.315	478.5	0.0825
Day 5	443.25	0.14	528.25	0.06	351	0.09

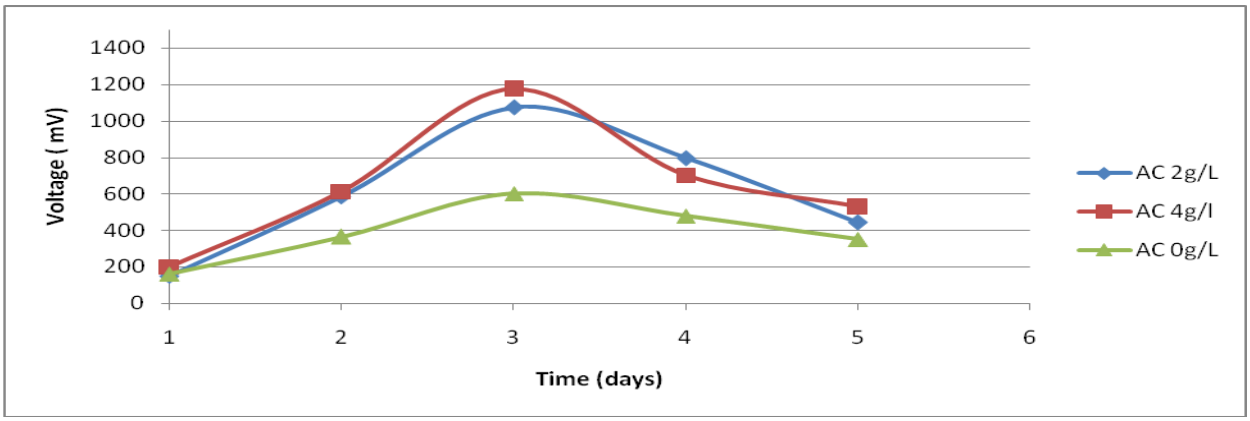

Fig 6. Voltage variation in the MDC

3.1.4 Effect of activated carbon dosage on COD removal efficiency

The final COD after 5 days of MDC operation was reduced by 55% in the control MDC's and by 75% and 80% for MDC with granular coconut shell carbon. The reduction of COD in the MDCs without granular coconut shell carbon may be largely due to microbial utilization and the reason behind removal of COD in MDC with granular coconut shell carbon may be due to adsorption of organics to the carbon and later microbial utilization [9].

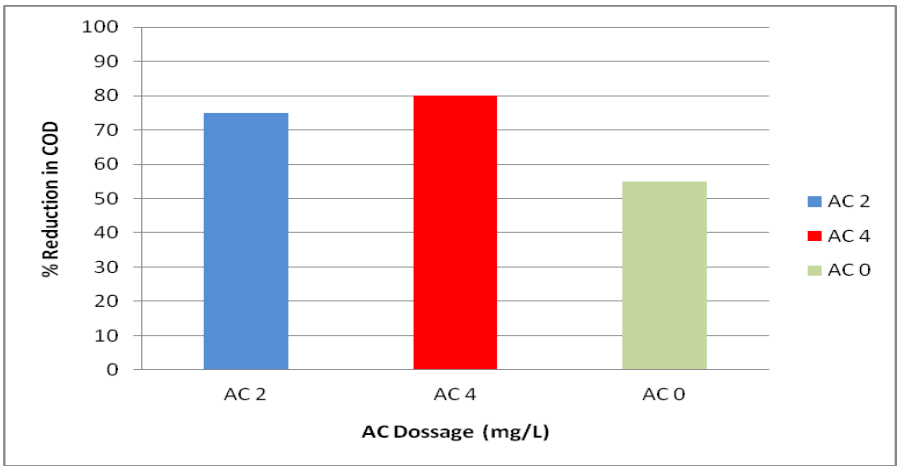

Fig.7. Effect of activated carbon dosage on COD removal efficiency

VI. CONCLUSIONS

Microbial desalination cell is an emerging bio-electrical system and is considered as one of the promising technologies for clean water and energy production. This study clearly proved that the performance of MDC was better in terms of desalination and current production when the anode chamber was loaded with granular carbon prepared from coconut shell. Coconut shell is a widely available biomass in India. It is highly economical. Hence this study tries to explore the use of coconut shell carbon as an electrode material. Further research is required in this area to understand the mechanism and role of this carbon in a MFC. Experiments with different types of carbon from biomass sources might lead to a high performance and techno-economically feasible designs for MFC reactors that can be practically applied for desalination and electricity generation. From these results it can be concluded that MDC with activated carbon showed a maximum removal efficiency of 32% and the control showed 21%, however much higher removal efficiencies are required to produce drinking water standards. The reduced efficiency is due to the deposition of manganese oxide on electrode material. These results show that MDC treatment could be used to substantially reduce salt concentrations and thus energy demands for downstream RO processing or as pre-desalination unit, while at the same time producing electrical power.

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