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# The Use of Electrical Energy in Brackish Water Desalination

Mahmoud, A. S.; Abdel-Razik, M. H; Ibrahim, M.S.A.; Hussien, H.M.
Public Works Department, Faculty of Engineering, ASU, Cairo, Egypt

**Abstract**— *The objective of this study is to investigate the possibility of producing potable water from brackish water using low cost technique depending on electrical energy. This study was carried out in a batch mode over four months covered spring and winter seasons. The pilot plant consisted of glass tank with a capacity of 6.0 L, aluminum cathode and anode, and direct current supply. The influent water was synthetic water from tap water with TDS concentration of 7000ppm. TDS, temperature, and pH were measured for the influent and effluent waters. The results of this study showed that by using electrical energy with 1.2volt for 1hour, the system managed to achieve high TDS removal efficiency of 87.6% and water recovery of 60%. The energy consumption is 2.3kwh/m$^3$.*

***Keywords***— *Water Treatment, Brackish Water Desalination, Electro-Dialysis, Capacitive Deionization, Electrical Analysis.*

## I. INTRODUCTION

Water scarcity becomes an important issue that extends from personal concerns to national critical issues due to increasing of population growth and increasing in water demand for industrial and agricultural needs. On the other hand, there are uncommonly used sources of water such as sea water and ground water which can meet the future's water needs through desalination. In Egypt brackish water has average salinity between 700 to 3000ppm, therefore it needs a low cost to be desalinated. Desalination is the process of removing salts and minerals from water to produce fresh water. Desalination methods can be divided into four approaches thermal desalination methods, physical or membrane desalination methods, chemical desalination methods, and recently biological desalination methods as shown in Figure 1.

Using electrical energy which is environment friendly energy source in brackish water desalination is a promising technique for producing fresh water. This study is concerned with desalination methods which use electrical energy such as electro-dialysis (ED) and capacitive-deionization (CDI).

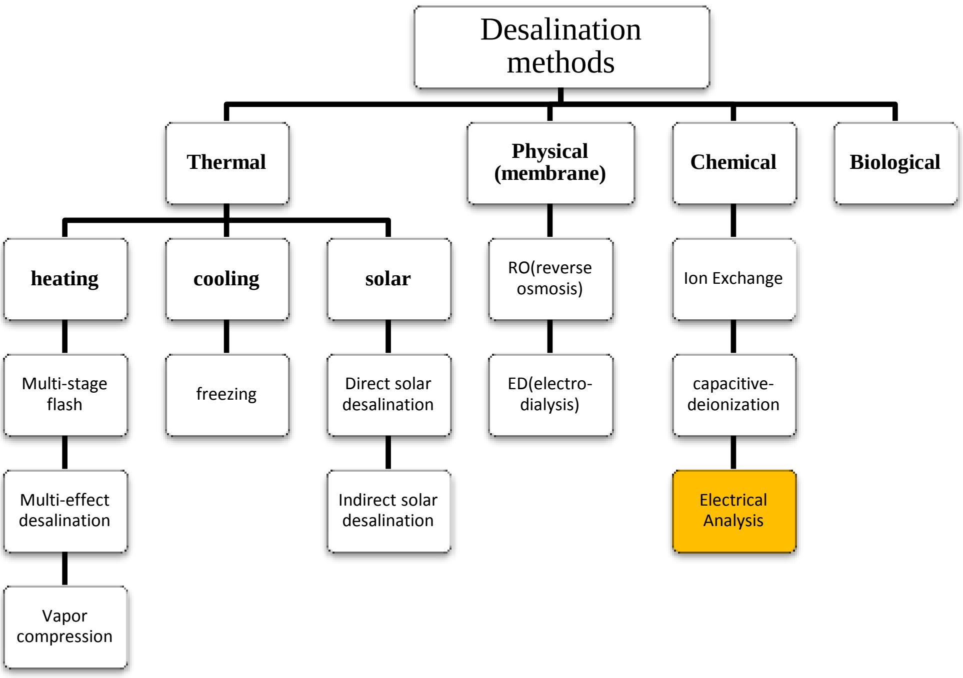


Fig. 1. Desalination Methods

ED appeared in desalination market in the early 1960s. It depends on the fact that most salts in water are ionic and when direct current (DC) passes through a solution, the salts are ionized to positively charged ions (cations) and negatively charged ions (anions). Similar charges repulse and different charges attract, so the ions move towards the electrodes with different charge through a selective membrane as shown in Figure 2.



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This technology is widely used in brackish water desalination that has a TDS concentration is lower than 10.000mg/L.

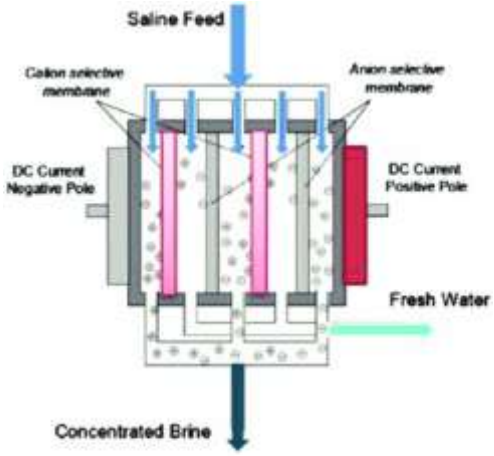


Fig. 2. Sketch of Electro-Dialysis

ED suffers from fouling and scaling problems so; the pre-treatment of feed water is very necessary. A new technique that called (EDR) Electro-Dialysis Reversal was developed to avoid fouling problems. The polarity of membranes has exchanged two or three times per hour and fresh water channels exchanged with brine water channels.

CDI is electrochemical method to desalinate saline water. Electrodes are charged by external DC power supply. This technique consists of two steps, the first is polarization in which anions electro adsorbed on anode (positive charged electrode) and cations electro adsorbed on cathode (negative charged electrode), so the concentration of salts ions in solution decreased. The second step is depolarization in which the voltage is decreased or reversed so the ions on electrodes become free in the waste water as shown in Figure 3. [1]

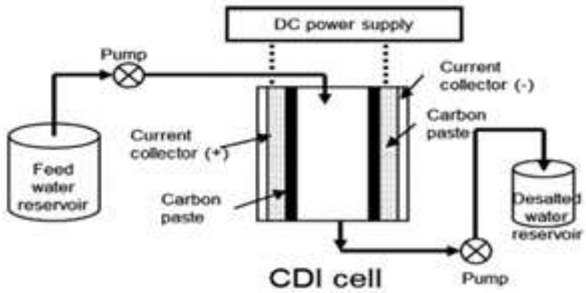


Fig. 3. Capacitive deionization Cell

Recent studies proved the success of desalination methods which depend on electrical energy.

Welgemoed (2005), used a bench scale module consisting of pairs of high-surface area (carbon aerogel) electrodes (400–1100 $m^2/g$) and a very low electrical resistivity (<40 mΩ·cm)to reduce the TDS of brackish water from 1000 to 10 mg/L with energy consumption 0.1 $kWh/m^3$ [2].

Marc (2010), made theoretical calculations for the work required to produce 1 m3 of a solution containing different concentrations of NaCL from 300 to 35000 mg/L with an operating cell voltage of 1.2 V and efficiencies ranging from 70 to 95% [3].

Linchen Han (2015), used a nanopores activated carbon coupled flow-through CDI device to evaluate energy consumption and recovery under various operational conditions. He found that about 30to 45% of the energy consumed during charging could be recovered by charging and discharging the cell at a constant current. Energy consumption for reducing the salinity of brackish water from 3270 to 550ppm by this device could be as low as 0.85 kWh/m3 [4].

Zhao et al. (2014), observed that high level of performance has shown with a cell voltage of 1.57 V, initial NaCl concentration of1000 mg/L and flow rate of 25 mL/min. Under these conditions, the maximum electro sorption capacity obtained was 10.67 mg/g [5].

Alonso Gonzalez (2017), tested ED for the purification of brackish water (TDS = 5482 mg/L) with high concentration of arsenic (2.04 mg/L), Salt removal exceeded 95% and in the majority of tests, the arsenic removal was more than 99.9%, The lowest specific electricity consumption was 2.16 kWh/m3 [6]

## II. MATERIALS AND METHODS

This study was conducted to investigate the possibility of producing potable water from brackish water using low cost technique depending on electrical energy and determination the design criteria of the system. The pilot plant was installed at the Sanitary Engineering Laboratory, Faculty of Engineering, Ain Shams University as shown in Figure 4.

Operation was carried out on batch mode over four months from January 2018 to May 2018 on synthetic water consisting of tap water TDS concentration of 7000 ppm.

The used pilot is illustrated in Figure 4 and consisted of the following:

1. Glass tank with dimensions (15*15*30cm height) which is sufficient to contain 6L of raw water.
2. DC power supply which contain ammeter and voltmeter embedded in it, ammeter ranges from zero to 5.5 ampere and used to measure current intensity and voltmeter ranges from zero to 35 volt and used to measure the voltage.
3. Aluminum cathode and anode to transport electricity from DC power supply to water tank.

The study was done to determine the most economic voltage, retention time and the effective water depth of the system. Several samples were taken at different depths 0, 4, 8, 12, 16 and 20 cm over different retention times up to 70 minutes. The voltages ranged from 0.5 to 10 volt. Each sample was 25ml. TDS, temperature and pH were measured for each sample. Table 1 presents the experimental setting.

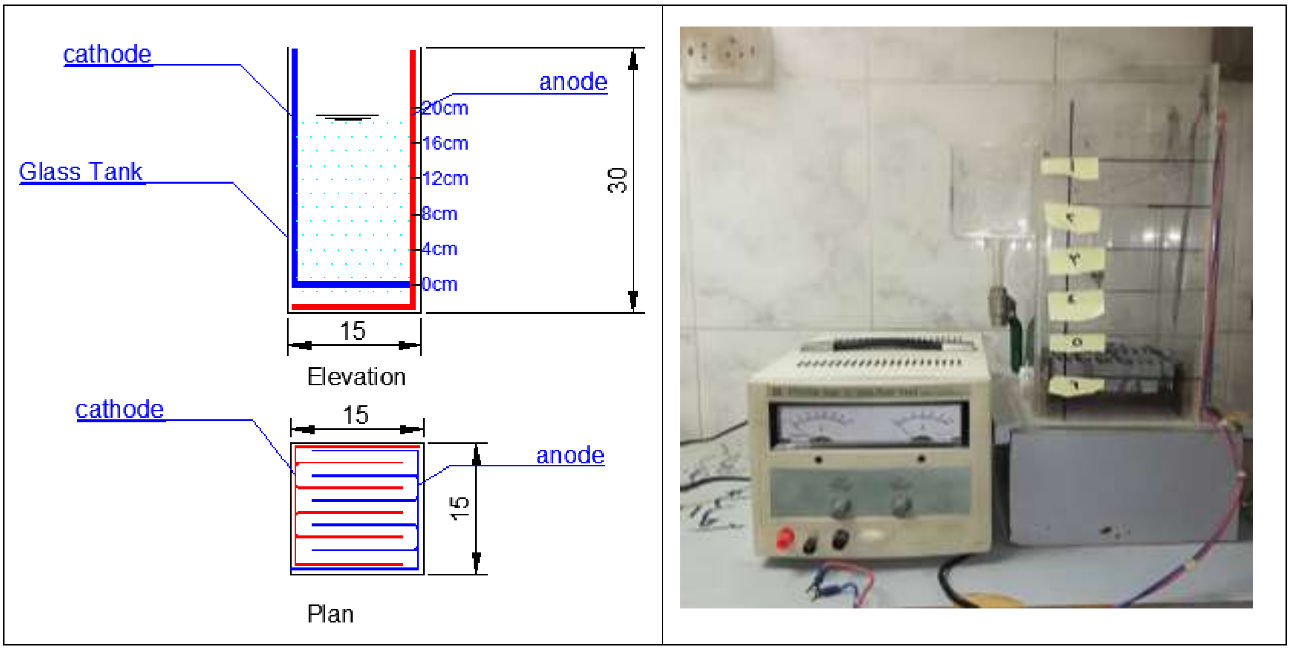


Fig. 4. Pilot Plant

TABLE 1. Experimental Setting

| Run | Date | Voltage(volt) | Retention time(minutes) | Temperature(°c) |
|---|---|---|---|---|
| 1 | April 2018 | 0.5 | 60 | 21.4 |
| 2 | April 2018 | 1.0 | 60 | 21.4 |
| 3 | April 2018 | 1.2 | 60 | 21.4 |
| 4 | February 2018 | 2.5 | 50 | 16.6 |
| 5 | February 2018 | 5.0 | 45 | 16.6 |
| 6 | February 2018 | 10.0 | 40 | 16.5 |

## III. RESULTS AND DISCUSSIONS

Performance of the proposed pilot plant can be evaluated as follows

*TDS*

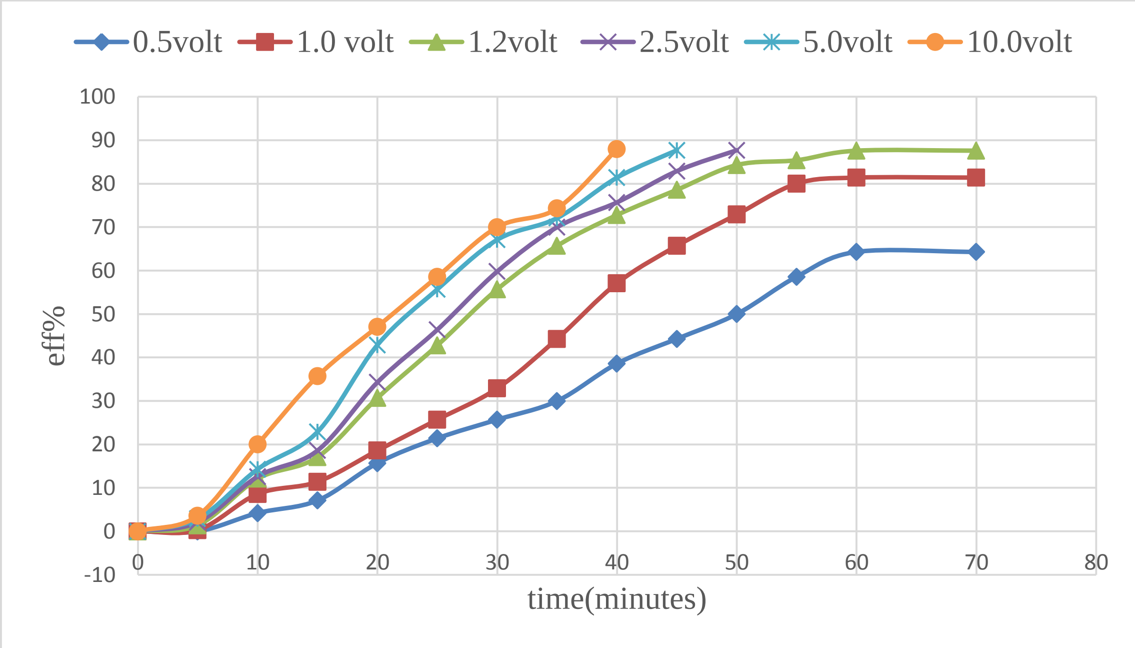


Fig. 5. The relation between TDS removal ratio and time at different used voltages.

From the results illustrated in Figure 5, it is observed that the applied voltage affects TDS removal ratio and corresponding required retention time. TDS removal ratio is directly proportional to applied voltage. The removal ratio was low in case of using voltage less than 1.2 volt and not sufficient to produce potable water for human use. Using voltages more than 1.2 volt achieves removal ratio reaches 90% in 40 minutes.

*pH*

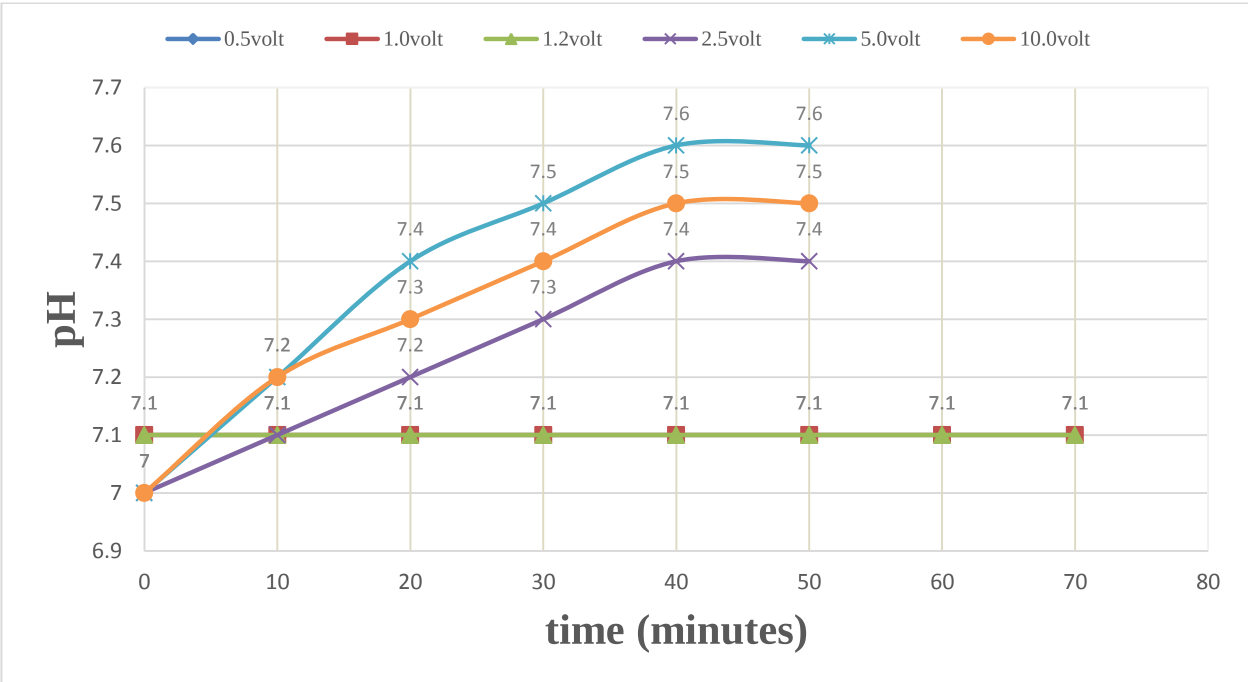


Fig. 6. The relation between pH and time at different applied voltages

On the other From the results are illustrated in Figure 6, it is observed, using voltages less than 1.2 volt does not affect pH values with time hand, pH values change with time when voltages more than 1.2 volt.This phenomena is explained by the equations from 1 to 4.

At anode: $2Cl_{(aq)} \longrightarrow Cl_{2(g)} + 2e^-$ …………………..$E^\circ$=-1.3595V (1)

At cathode: $2H_2O_{(L)} + 2e^- \longrightarrow H_{2(g)} + 2OH^-_{(aq)}$ ……...$E^\circ$=-0.8277V (2)

$Na^+ + e^- \longrightarrow Na$……………………………… ……...$E^\circ$=-2.714V (3)

From equation 2 and 3, it is observed the Na reduction is harder than water molecules in cathode, so the water molecules decompose to their components. Sodium ions remain in water without any changes, so the resultant reaction will be:

$$2H_2O\,(L) + 2(Na^+\,,Cl^-)\,(aq) \longrightarrow H_2(g) + Cl_2(g) + 2(Na^+\,,OH^-)(aq) \quad (4)$$

*Temperature*

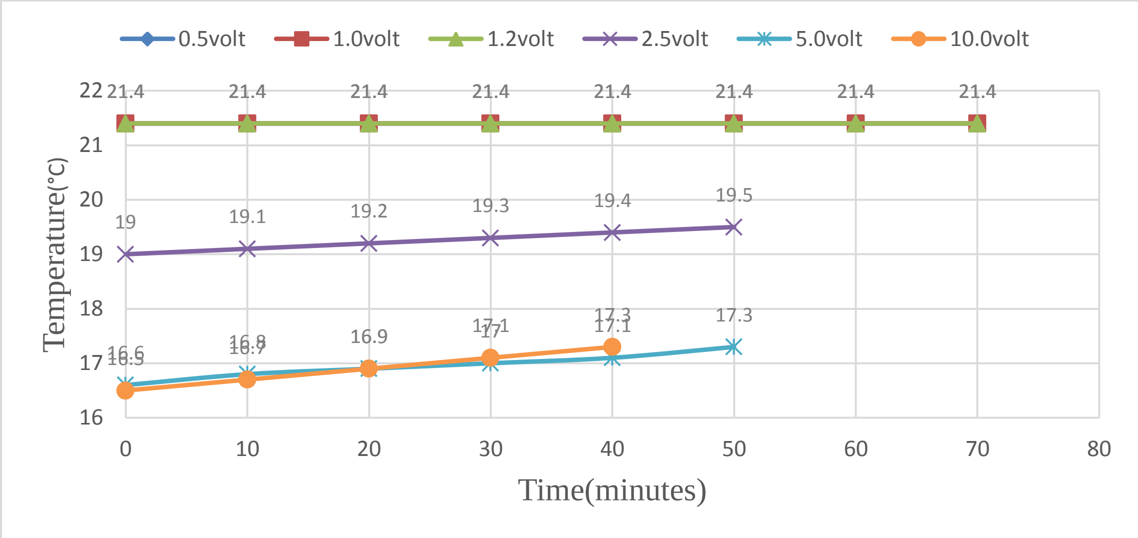


Fig. 7. The relation between temperature and time at different applied voltages

From the results are illustrated in Figure 7, it is observed that the temperature of water is directly proportional to the applied voltage. Temperature changes with time in case of using voltage more than 1.2 volt such as 2.5, 5.0, and 10.0 volt. This is explained by the fact that the temperature of metals and electrolytic solutions increase due to passing electrical current through them.

*Determination the optimum voltage and retention time*

From results discussed and illustrated in Figures 5 to 7, it is can be concluded that the most economic voltage is 1.2 volt for 1 hour. 1.2 volt achieves TDS removal ratio reaches 87.6% and does not affect the temperature or pH values.

*Determination the effective water depth and water recovery*

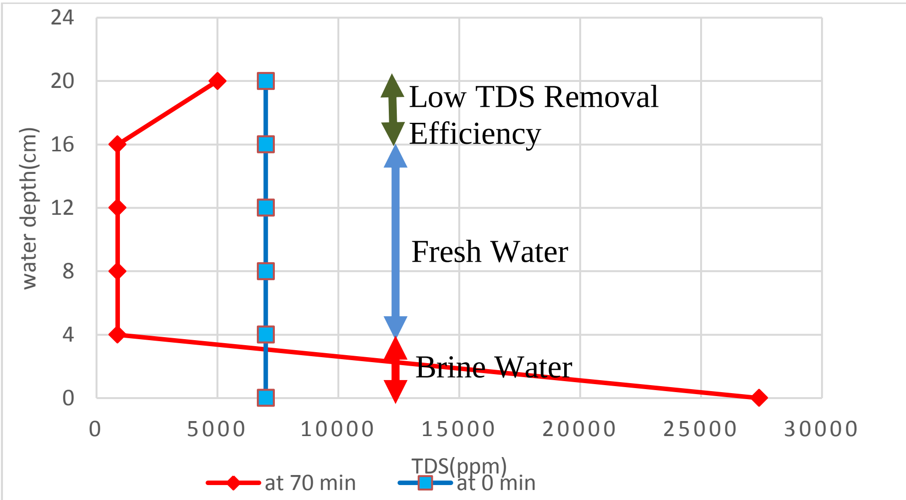


Fig. 8. The relation between TDS and water depth at 1.2 volt

From the results of are illustrated in Figure 8, it is observed that when using 20 cm of raw water, the brine water exists at the bottom of the tank at water depth from 0 to 4 cm where the aluminum cathode and anode accumulate. The fresh water with TDS concentration less than 1000ppm exists at water depth from 4 to 16 cm. When water depth increases more than 16cm the TDS concentration starts to increase again, and the efficiency decreases. The recovery ratio of the system is 12cm/20cm *100 =60%.

Corresponding electrical intensity to 1.2 volt is 5 ampere for 1 hour to desalinate 12cm*15cm*15cm=2700cm3 which equivalent to 6 watt/2700cm3.The energy consumption is 2.3kwh/m3.

## IV. CONCLUSIONS

From the analysis of the results obtained during experimental work, the following can be concluded:

1. The most economic voltage is 1.2volt. Increasing voltage more than 1.2 volt causes change in pH and temperature throughout experimental period due to dissociation of water molecules then formation of NaOH which is one of the components of soap and be harmful to humans.
2. The maximum efficiency of brackish water desalination in case of using 1.2 volt achieved at retention time equal to 60minutes then the removal efficiency became constant.
3. The effective depth of fresh water in case of using 20cm of raw water achieved at the depth between 4cm and 16cm approximately 12cm above brine zone which found at 4cm above cathode and anode, so the water recovery=12cm/20cm*100=60%.
4. The energy consumption to produce 1m$^3$ of fresh water with TDS concentration 865 ppm from raw water with TDS concentration 7000ppm is 2.3kwh.

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