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Design and Development ofWater Treatment System using ElectrochemicalWater Desalination

KukKiam-Pin[1], Muhammad Suhaimi Sulong[2], Ariffuddin Joret[1], Mohd Safiee Idris[2], and Syed Ahmad Firdaus Syed Fadzil[2]
[1]Faculty of Electrical and Electronic Engineering,UniversitiTun Hussein Onn Malaysia
[2]Faculty of Technical and Vocational Education, UniversitiTun Hussein Onn Malaysia

Abstract: Seawater for example has a variety of mineral salts and it cannot be consumed easily. It has to go through a refined process to make it a source of drinking. There are various processes and methods of filtration including electrochemical water desalination are used. This paper demonstrates the water treatment system using electrochemical water desalination method and it focused on developing cost-effective ways of providing fresh water. Electrochemical water desalination method can produce fresh water by using voltage potential difference between electrodes to absorb the salt ions in saltwater compartment and release the stored ions from electrodes in another saltwater compartment once voltage potential difference removed. Electrochemical water desalination method was demonstrated in hardware prototype and its concentration of saltwater was measured by using TDS meter, at last its result was analyzed. Factors of salt transport are determined; there are number of battery supply, number of graphite pair, dipping time, surface area of graphite rod, and volume of saltwater. Electrochemical water desalination method will be more affordable by replacing those current desalination methods which required high energy consumption, high maintenance cost, and components costly.

Keywords: *Electrochemical desalination, TDS meter, Electrodialysis*

INTRODUCTION

Nowadays, desalination is an important technique to desalinate the salt water. Over the years, a number of desalination methods have been developed among which distillation, reverse osmosis, and electrodialysis are the most commonly known and widespread technologies [1]. The purpose of the desalination is used to remove some amount of salts and other minerals from the saltwater. Saltwater is desalinated to produce fresh water suitable for human consumption or irrigation. Therefore, most of the modern interest in desalination is focused on developing cost-effective ways of providing fresh water [2].

In this project, water treatment system using electrochemical water desalination method was developed, which the desalination process implemented under the influence of voltage potential difference between electrodes. The desalination process use a number of graphite pair as electrodes to adsorption and desorption. The process absorption is to absorb the ions and stores inside the electrodes while the process desorption is to release stored ions from the electrodes.

Once the voltage potential difference applied between electrodes, the process adsorption will implement by graphite rods dipped in a saltwater compartment. After some contact time, the graphite pair will lift manually brings to another saltwater compartment. Then, the process desorption will implement upon the voltage potential difference removed. At the end of process, a dilute compartment and brine compartment will obtain. The concentration of both compartments will measure based on value of total dissolved solids (TDS) by using TDS meter.

LITERATURE REVIEWS

In table 1 there are two major types of desalination technologies being used currently by most countries. The energy sources using by both desalination technologies are difference. Thermal technology is using thermal and electrical as energy sources to run the desalination process while

Corresponding Author: Kuk Kiam Pin, FKEE, UTHM Parit Raja 86400 Johor, +6074537000

membrane technology is only using electrical energy to run the desalination process. With the different type of energy used will give different quality and productivity of fresh water. Because of highly productivity there are two processes which are multi-stage flash (MSF) and reverse osmosis (RO) have been widely used. Although both are main desalination process been used but they still have some weakness.

Table 1 Desalination Technologies and Process [3]

Thermal Technology	**Membrane Technology**
Multi-StageFlash Distillation(MSF)	Electrodialysis(ED)
Multi Effect Distillation(MED)	Electrodialysis Reversal(EDR)
Vapor Compression Distillation(VCD)	Reverse Osmosis(RO)

Table 2 showed the comparison between two types of main desalination method with project which electrochemical water desalination method based on energy consumption, maintenance cost, and component cost. MSF is desalination method that requires high energy consumption, followed by RO and then project is lowest energy consumption needed. This is because MSF requires large amount of heat as energy to keep boiler at boiling point for evaporation process. RO requires moderate energy in driving hydrostatic pressure difference for flowing process while the project uses only small amount of energy which are some batteries to apply voltage potential difference between electrodes.

Table 2 Comparison between Desalination Methods

	Desalination Methods		
	Multi-Stage Flash Distillation (MSF)	Reverse Osmosis (RO)	Electro-chemical Water Desalination
Energy Consumption	High	Medium	Low
MaintenanceC ost	Medium	High	Low
Component Cost	High	Medium	Low

Next, RO requires high maintenance cost among three desalination methods, followed by MSF and then project is lowest maintenance cost needed. This is because RO need to replace expensive membrane technology after certain period of time by keeping desalination running smoothly. MSF also need to replace some parts of equipment for process evaporation and condensation after certain period of time by keeping operation effectively while project is using sustainable components for desalination. Besides that, MSF need high component cost to build up for desalination process if comparing with RO only need purchase some expensive components to operate desalination process. For project, it only used cheaper components to run the desalination process [2].

In addition, capacitive deionization (CDI) is one of the desalination method also mainly used for water purification technology. CDI is only used small amount of electrical potential difference as energy source over two porous electrodes to run the desalination process. In the project, the concept of electrochemical water desalination method will be developed is similar with CDI desalination method.

METHODOLOGY

This chapter described the processes developed in designed water treatment system using electrochemical water desalination method. The processes development of electrochemical water desalination was represented by a flow chart as shown if figure 1. In addition, the fabrication and analyze process of prototype as well as prototype experimental also was explained in this part.

A. Flow Chart of Project Development

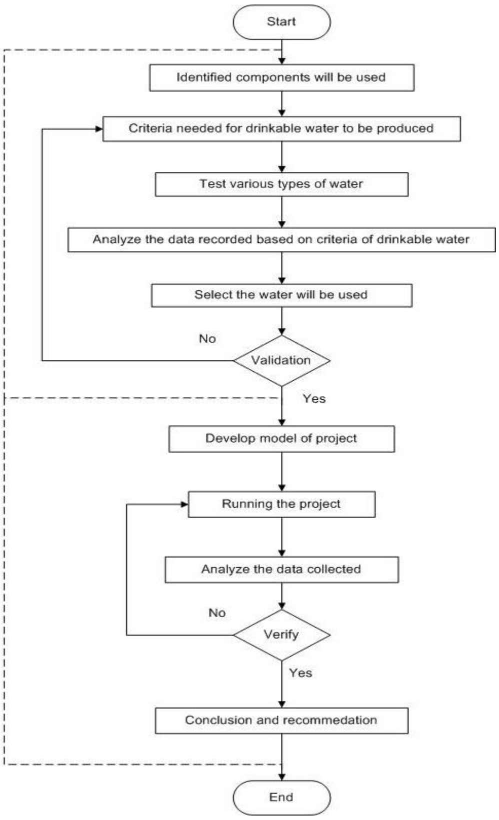

Figure 1 Project Development Flow Chart

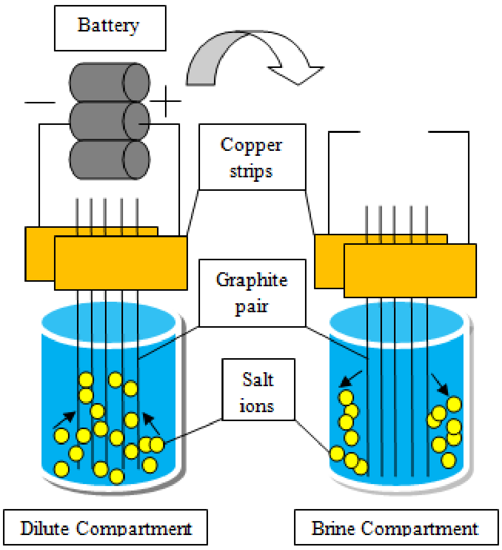

Figure 2 Schematic Design

B. Setup System of Water Treatment System

Figure 3 showed the setup system of water treatment system using electrochemical water desalination method. The components used are battery holder, battery, crocodile clip, copper strip, rubber bracelet, graphite rod (anode and cathode), and plastic bottle (dilute and brine compartment). For dilute and brine compartment, 500ml of saltwater with 600ppm concentration was filled inside. Two pairs of 15cm graphite rod act as anode and cathode respectively and were dipped in the dilute compartment. Three batteries with total 3.6V were used as an external power source.

Figure 3 A Setup System of Water Treatment System

C. System Analysis

The setup system was analyzed based on concentration which total dissolved solids (TDS) of two compartments obtained at the end of desalination process. The TDS value can be measured by using TDS meter. At the end of desalination process, a dilute compartment and brine compartment was obtained. The dilute compartment will provide low level of TDS value while the brine compartment will provide high level of TDS value. Both the low and high level of TDS value was recorded. From there, the water with low level of TDS value which below 500 parts per million (ppm) was verified as a fresh water to be produced [4]. The TDS values recorded from two compartments will be compared each other to observe the difference after desalination method.

D. Experiment Procedures

a. Environment temperature is set at room temperature 23°C to 27°C.
b. Two compartments are filled with 500ml saltwater with 600ppm concentration.
c. The initially concentration which TDS values of both saltwater are recorded by using TDS meter.
d. Two graphite pair with anode and cathode is dipped into dilute compartment.
e. Upon applying external power source, process absorption start.
f. After 10 minutes, the graphite pairs are lift manually bring to another saltwater compartment.
g. Upon removing external power source, process desorption start.
h. After 10 minutes, the concentration which TDS values of both compartments will be recorded again.
i. The cycle will repeat until the TDS value of at least below 500 parts per million (ppm) obtained and the number of cycles also will be recorded.

RESULT AND ANALYSIS

A. Results

Experiments with three different concentrations of saltwater were conducted in order to examine the output of the project. Table 3 showed the result experiment of saltwater concentration 600ppm, 800ppm, and 1000ppm in the period of 50 cycles, 150 cycles and 250 cycles. The saltwater concentration was measured by using a TDS meter. The reading was recorded in every 25 cycles. From the table 4.1, 600ppm concentration of saltwater was obtaining 500ppm and 700ppm within 50 cycles in dilute compartment (DC) and brine compartment (BC) respectively. For the 800ppm concentration of saltwater was obtaining 500ppm in DC then 900ppm in BC within 150 cycles. Lastly, 1000ppm concentration of saltwater was obtaining 500ppm and 1100ppm within 250 cycles for DC and BC respectively. In order to discover the factor that affect to the salt transport in the process desalination, several set of experiment method with different parameter was observed and recorded. Table 4 showed the parameter for each experiment.

Table 3 Result Experiment

Time /Cycles	Saltwater Concentration 600ppm (ppm)		Saltwater Concentration 800ppm (ppm)		Saltwater Concentration 1000ppm (ppm)	
	DC	BC	DC	BC	DC	BC
0	600	600	800	800	1000	1000
1-25	550	650	750	850	950	1050
26-50	500	700	700	900	900	1100
51-75			650	950	850	1150
76-100			600	1000	800	1200
101-125			550	1050	750	1250
126-150			500	1100	700	1300
151-175					650	1350
176-200					600	1400
201-225					550	1450
226-250					500	1500

Table 4 Parameter of Each Experiment

E	C.O.S (ppm)	Battery (1.2V)	Graphite pair	V.O.S (ml)	surface area of graphite rod (cm)	Dipping time (mins)
1	600	3(3.6V)	2	500	8.8	10
2	600	**6(7.2V)**	2	500	8.8	10
3	600	3(3.6V)	**4**	500	8.8	10
4	600	3(3.6V)	2	**220**	8.8	10
5	600	3(3.6V)	2	500	**4.4**	10
6	600	3(3.6V)	2	500	8.8	**20**

Abbreviation:

- E – Experiment
- C.O.S – Concentration of Saltwater
- V.O.S – Volume of Saltwater

Table 5 Salt Transport in 5 Cycles

Time/Cycles	1	2	3	4	5
Salt Transport Experiment 1 (ppm)	2	2	2	2	2
Salt Transport Experiment 2 (ppm)	4	4	4	4	4
Salt Transport Experiment 3 (ppm)	4	4	4	4	4
Salt Transport Experiment 4 (ppm)	4	4	4	4	4
Salt Transport Experiment 5 (ppm)	1	1	1	1	1
Salt Transport Experiment 6 (ppm)	4	4	4	4	4

Once experiments with different parameters have been constructed, each experiment was observed their salt transport was recorded within 5 cycles. Table 5 showed the salt transport of each experiment in the period of 5 cycles. The reading for every cycle was recorded in the table form. The result was recorded in TDS value.

B. Analysis

Figure 4 showed the graph plotted based on result experiment obtained from table 3. From the graph, all the process absorption was conducted steadily until 500ppm which expected saltwater concentration is obtained for each DC. Meanwhile, each BC had obtained 700ppm, 1100ppm and 1500ppm respectively due to process desorption caused a rise of TDS value which representing concentration of saltwater. For 600ppm concentration of saltwater, concentration of DC goes down from 600ppm to 500ppm and then concentration of BC rises from 600ppm to 700ppm within 50 cycles. This is because the 100ppm of salt ion transfers from DC to BC through desalination process. For 800ppm concentration of saltwater, BC receives 300ppm from DC then concentration from 800ppm become 1100ppm while causing a lack of TDS value of concentration of DC that from 800ppm to 500ppm within 150cycles. For 1000ppm concentration of saltwater, concentration of DC drops from 1000ppm to 500ppm followed by concentration of BC grows from 1000ppm to 1500ppm within 250 cycles. This is because 500ppm of salt ion transfers from DC to BC through desalination process.

From there, the higher the saltwater concentration, the longer time needed to reach expected saltwater concentration level through process desalination can be observed. This is because higher saltwater concentration produces large amount of salt ion, required more time or cycles for both processes adsorption and desorption in the process desalination. In addition, the time required for process desalination also depends on chosen value of expected level of saltwater concentration. The lower value of expected level of saltwater concentration chosen, the extra time or cycles needed to conduct the process desalination [5].

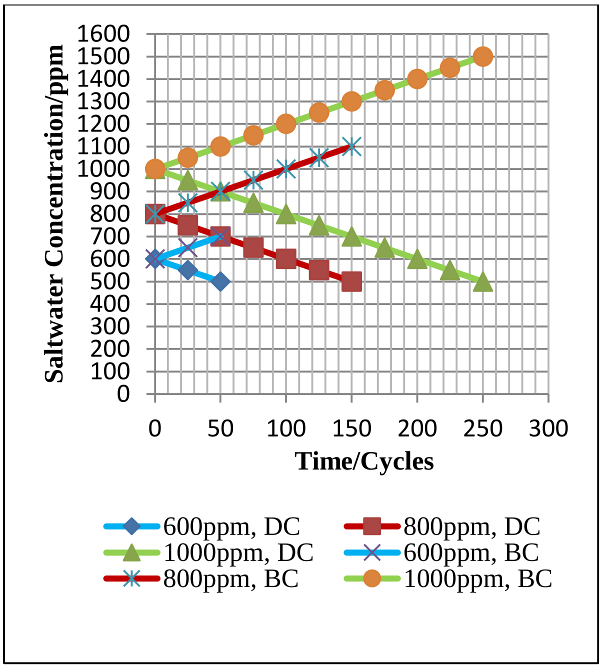

Figure 4 Result Experiment

From the table 5 and figure 5, the result obtained for experiment 1 was 2ppm for every cycle. This is because experiment 1 is the standard setup for electrochemical water desalination, under condition without the factors that affect result of experiment. Therefore, the result of experiment 1 will be used to compare the result from other experiments that setup with different parameters. Comparing between experiments 2 with experiment 1 had clearly show that experiment 2 had higher salt transport each cycle due to its greater number of battery supply which leads to high salt transport. Similarly for experiment 3 and 4 which have greater number of graphite pair and lower volume of saltwater that will lead to high salt transport. In other hand, experiment 5 has only obtained 1ppm each cycle due to lower surface area of graphite rod which leads to low salt transport. Experiment 6 has obtained 4ppm each cycle due to its longer dipping time which leads to high salt transport.

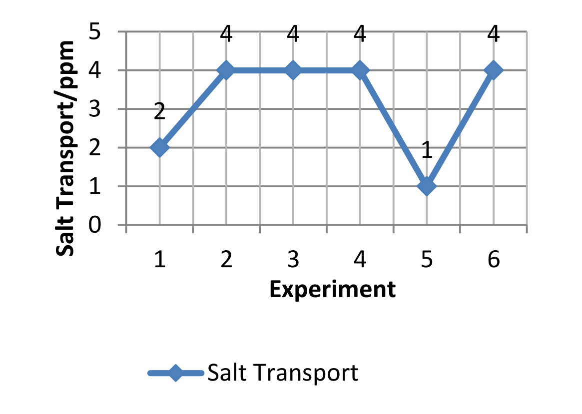

Figure 5 Salt Transports in 5 Cycles

Figure 6 showed the analysis of different battery (voltage) in one cycle. There are 3 batteries (3.6V) and 6 batteries (7.2V) have been used in the experiment 1 and 2 respectively. The salt transport of experiment 1 obtains 1ppm started at 8 minutes and then the total of salt transport is 2ppm obtained at 10 minutes which representing a cycle in desalination process. In other hand, the salt transport of experiment 2 obtains 2ppm started at 4 minutes, followed by increasing to 3ppm at 6 till 8 minutes, lastly total of salt transport is 4ppm obtained at 10 minutes. From there, the difference of battery served as external power source affects the salt transport in process desalination can be observed. The larger number the battery (voltage) used, the higher the salt transport can be obtained. Number of battery supply determined the salt transport in the process desalination. Based on the result, we found that experiment 2 with 6 batteries supply was achieve high capacity of salt transport if comparing with experiment 1 which just has 3 batteries as power supply. This is because 6 batteries supply will have larger voltage potential difference than 3 batteries supply; higher power supply will accelerate the process salt transport conducted on the graphite rod.

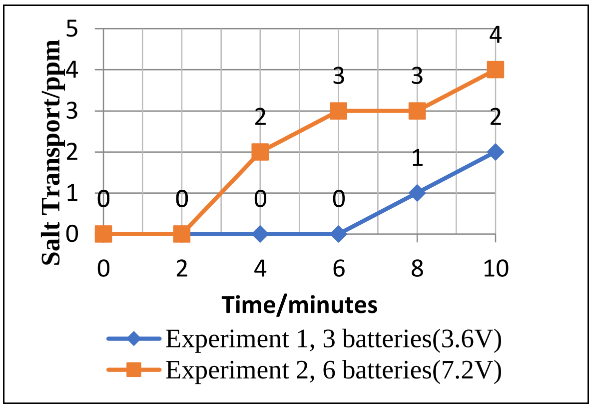

Figure 6 Analysis of Different Battery (voltage) in One Cycle

Figure 7 showed the analysis of different graphite pair in one cycle. There are 2 and 4 graphite pairs have been used for experiment 1 and 3 respectively. The salt transport of experiment 1 obtains 1ppm started at 8 minutes, followed by the total of salt transport is 2ppm obtained at 10 minutes. For experiment 3, salt transport obtains 2ppm begin at 6 minutes, then increasing to 3ppm at 8 minutes, finally the total of salt transport is 4ppm obtained at 10 minutes. From there, the difference of graphite pair used affects the salt transport in process desalination can be observed. The larger number the graphite pair used, the higher the salt transport can be transferred. Number of graphite pair was the factor that affected the salt transport generated in process desalination. The experiment 3 showed that has higher salt transport if comparing with experiment 1 which just has 2 graphite pair. The theory behind it is when the greater number of graphite pair used, the more surface area can be used for absorption then causing larger amount of salt transport is obtained.

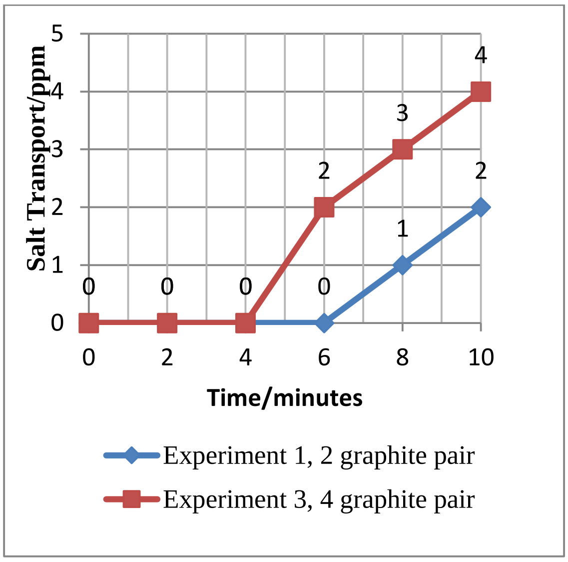

Figure 7 Analysis of Different Graphite Pair in One Cycle

Figure8 showed the analysis of different volume of saltwater in one cycle. There are 220ml and 500ml volumes of saltwater have been used for experiment 1 and 4 respectively. Experiment 1 obtains 1ppm started at 8 minutes and then the total of salt transport is 2ppm obtained at 10 minutes. For experiment 4, the salt transport starts with 2ppm at 4 minutes, after that it increase to 3ppm at 6 till 8 minutes, lastly the total of salt transport is 4ppm obtained at 10 minutes. From there, the difference of volume of saltwater affects the salt transport in process desalination can be observed. The lower the volume of saltwater used, the higher the salt transport can be obtained.

Volume of saltwater was the factor that affected the salt transport in process desalination. From the result, experiment 4 with 220ml volume of saltwater has higher salt transport than experiment 1 which has 500ml volume of saltwater. This is because low volume of saltwater has higher concentration of salt ion if comparing with large volume of saltwater when both are in the same concentration which TDS value. Therefore, saltwater with higher concentration of salt ion will allow more salt ion to be absorbed in process absorption, thus high salt transport can be achieved.

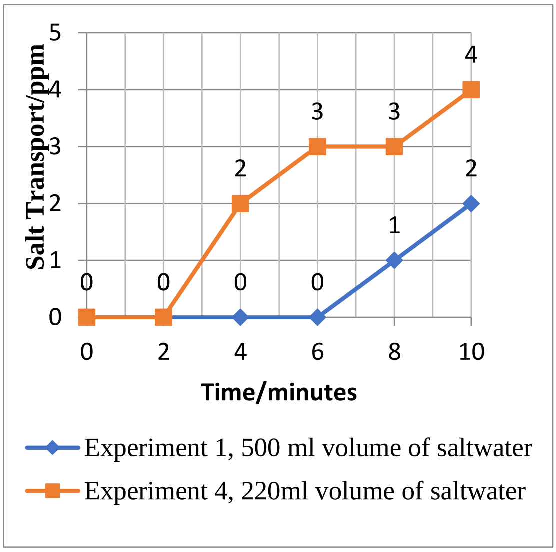

Figure 8 Analysis of Different Volume of saltwater in One Cycle

Figure 9 showed the analysis of different surface area in one cycle. There are 4.4cm and 8.8cm surface area of graphite rods have been used for experiment 1 and 5 respectively. The salt transport of experiment 1 obtains 2ppm started at 8 minutes, after that it increases to 2ppm which is the total of salt transport obtained at 10 minutes. For experiment 5, salt transport obtains 1ppm begin at 8 minutes and the total of salt transport is still 1ppm at 10 minutes. From there, the different surface area of graphite rod affects the salt transport in process desalination can be observed. The larger the surface area of graphite rod used, the higher the salt transport can be obtained.

The surface area of graphite rod was the factors that affected the salt transport. From the result, we knew that experiment 5 has lower salt transport if comparing with experiment 1 which has higher salt transport. This is because the larger surface area will allow more salt ion can be stored on the graphite rod, so high salt transport can be obtained.

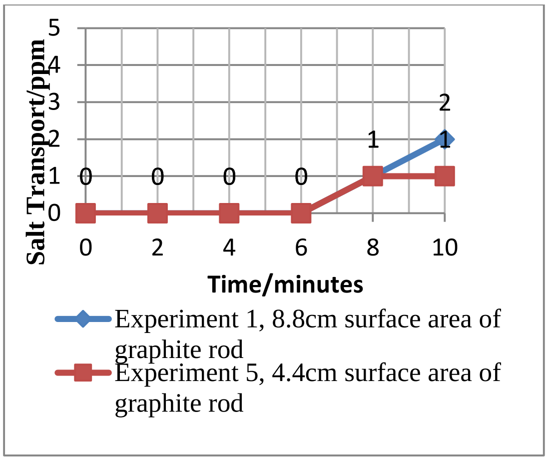

Figure 9 Analysis of Different Surface Area in One Cycle

Figure 10 showed the analysis of different dipping time in one cycle. There are 10 and 20 minutes dipping time have been used for experiment 1 and 6 respectively. The salt transport of experiment 1 obtains 1ppm started at 8 minutes and then the total of salt transport is 2ppm obtained at 10 minutes. Experiment 6 obtains 1ppm begin at 8 minutes, followed by 2ppm obtained at 10 till 14 minutes, after that it increases to 3ppm at 16 till 18 minutes, lastly the total of salt transport is 4ppm obtained at 20 minutes. From there, the difference of dipping time affects the salt transport in process desalination can be observed. The longer the dipping time used, the higher salt transport can be achieved. Dipping time determined the salt transport in the process desalination. From the result, experiment 6 with longer dipping time has salt transport higher than experiment 1 which has shorter dipping time. This is because longer dipping time allow more salt ion can be stored inside graphite rod, thus high salt transport can be obtained.

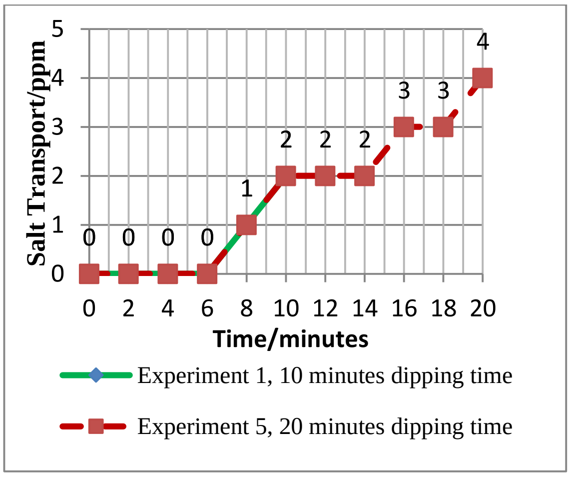

Figure 10 Analysis of Different Dipping Time in One Cycle

CONCLUSIONS

Desalination method plays an important role in desalination saltwater to produce fresh water for desalination plant. From desalination plant, an alternative source of water provided is suitable for human consumption and irrigation to solve the shortage of fresh water [6]. However, current desalination methods required high energy consumption, high maintenance cost, and components costly are expensive to be building up. The electrochemical water desalination method proposed is able to desalinate saltwater by using lower energy, cheaper component and sustainable.

Water treatment system using electrochemical water desalination has been demonstrated. Experiments with three different concentrations of saltwater were desalinated to drinkable water level in the different periods. The results obtained and recorded in table form were analyzed through a graph plotted. From the analysis, the factors that affected the result of experiment were discovered, these are high concentration of saltwater requires longer time to reach expected saltwater concentration level in order to complete the process desalination and the time required for process desalination depends on chosen value of expected saltwater concentration.

In addition, several set of experiment with different parameters have been implemented with same period of time in order to discover the factor that affect to the salt transport in the process desalination. The results were obtained and recorded in table form. Then, the analysis was made through the graph plotted based on data in table form. After that, the factors that affected salt transport in desalination were discovered. These are number of battery supply, number of graphite pair, dipping time, and volume of saltwater and surface area of graphite rod.

As a recommendation, the efficiency of water treatment system using electrochemical water desalination could be improved by adding membrane coating to both electrodes, which both have a high selectivity toward their respective counter ion then perfectly blocking for the co-ion. This will probably increase the desalination degree. In addition, large number of graphite pair in parallel used as electrode will probably accelerate the desalination process. Thus, it could be used to treat large volumes of saltwater. The project might be compatible with solar panel due to power supply required of project are just small values of voltage and direct current (DC).

For environmental protection, the project can be fixed with solar panel as a power supply. Hence, the project can be implemented at some areas like off-grid and remote location. Besides that, greater size of diameter electrode will has large surface area on electrode. The larger surface the electrode, the more salt ion could store in the electrode. Then, the capacity of desalination could probably be increasing. The ability absorption of electrode might be improved by providing specific design of pore size inside the electrode. When the smaller pore size is designed, more pore size can be formed on the electrode. With extra pore size on the electrode, more salt ion can be absorbed. Thus, it probably increases the capacity of desalination.

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