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EFFECT OF WATER DEPTH
ON THE PERFORMANCE OF SOLAR STILL

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EFFECT OF WATER DEPTH ON THE PERFORMANCE OF SOLAR STILL

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Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
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Dedicated to my father, mother, siblings, and friends.

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ABSTRACT

Water is an important element for a human to be healthy and energetic as it will effect human daily life. Clean water in the world is decreasing at a fast rate due to the rapid growth of industrialization and increasing population. In the future, human has to depend on other water source that can be get easily in large quantity, which is sea water. One of the method to overcome water shortage problem is water purification by using solar still. Solar still is one of the method that can change sea water or brackish water to pure water. This research uses a modified solar still that has magnifying lens, copper as the heat transfer agent, aspirator pump, temperature indicator and basin that coated with black paint. Sea water and tap water is chosen as the sample. The sample was poured into the basin with an area of $0.25m^2$ with 3 different depth of water level, which are 3cm, 2cm and 1cm. The experiments were repeated twice for each depth of water level. The experiment was conducted for 18 days, starts from 8am to 6pm. The value of pH, salinity, total dissolved solid and conductivity is taken after each of the experiment end. The data obtained shows that the pure water produced increases as the depth of water level in the basin decreases. The data also shows that untreated tap water is not safe for consumption. However, the treated tap water and sea water is safe for consumption.

ABSTRAK

Air adalah elemen yang paling penting untuk manusia supaya tubuh badan kekal sihat dan bertenaga kerana ia akan mempengaruhi kehidupan harian manusia. Air bersih telah semakin berkurang secara mendadak di seluruh negara disebabkan pembangunan industri yang semakin berkembang dan populasi manusia yang semakin bertambah. Pada masa hadapan, manusia perlu bergantung pada sumber air lain yang boleh didapati untuk kuantiti yang banyak, iaitu air laut. Salah satu cara untuk mengatasi masalah kekurangan air tersebut ialah dengan cara penyucian air yang menggunakan mesin solar. Mesin solar ialah salah satu cara yang boleh menukarkan air laut atau air kotor kepada air murni. Kajian ini menggunakan mesin solar yang telah diubahsuai yang mengandungi kanta pembesar, kuprum sebagai ejen pemindahan haba, pum aspirator, penunjuk suhu dan basin yang dicat hitam. Air laut dan air paip telah dipilih sebagai sampel. Sampel tersebut telah dimasukkan di dalam bekas dengan keluasan 0.25m^2 dengan tiga paras kedalaman air yang berbeza iaitu 1cm, 2cm dan 3cm. Eksperimen tersebut diulang sebanyak dua kali untuk setiap paras kedalaman air tersebut. Eksperimen tersebut dilakukan selama 18 hari, bermula daripada pukul 8pagi sehingga 6petang. Nilai pH, tahap kemasinan, jumlah pepejal bubar dan kekonduksian diambil selepas setiap eksperimen berakhir. Data yang diperoleh menunjukkan kadar air murni yang terhasil bertambah apabila paras kedalaman air di dalam bekas berkurang. Data juga menunjukkan air paip yang belum dirawat adalah tidak selamat untuk digunakan. Namun begitu, air paip dan air laut yang telah dirawat adalah selamat untuk digunakan.

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LIST OF ABBREVIATIONS

(HTA)	Heat Transfer Agent
(MSF)	Multi Stage Flash
(MED)	Multi Effect Distillation
(MF)	Microfiltration
(NF)	Nano filtration
(RO)	Reverse Osmosis
(UF)	Ultrafiltration
(VC)	Vapor Compression
(NWCS)	National Water Quality Standards for Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Fresh water is the fundamental life source on earth because water are basic elements that influence the quality of civilized life. Nowadays, fresh water was getting polluted and decreasing continuously because of the industrial development, intensified agriculture, improvement of standard of life and increase of the world population (Haruna, et al., 2014). In future, human may depend on oceanic and brackish water resources for fulfilling our demand of water (Ali, et al., 2012).

In the last 40 years, the problem of freshwater shortage has been one of the main challenges in the world. According to Alkan, P.I., 2003, only about 3% of the world water is potable and this amount is not evenly distributed on earth and more than 80 countries, which between them have 40% of the world's population, are being suffered from this problem. Thus, over one billion people each year are exposed to unsafe drinking-water due to poor source water quality and lack of adequate water treatment (Haruna, et al., 2014). This results in 900 million cases of diarrhea each year (Radwan, 2009).

Other than that, the supply of drinking water is one of the major problems in developing countries as well as under developing countries. Clean or potable water is a basic human necessity and without water life will be impossible (Panchal, 2012). The beginning and extension of humanity is based on water. Although more than 75% of the earth covered with water, only 0.014% can be used directly for the human being and other organisms. On the other hand, sea water constitutes 97.5% of global water, also can be used after treated as distilled water (Kabeel, et al., 2014).

Scarcity of fresh water in large cities around the world have enhanced as the pollution in rivers and lakes have occurred. The main reason of the scarcity is the impact of industrial and sewage disposal. However, with an increasing population and rapid growth of industrialization, there is a great demand of fresh water, especially for drinking purposes (Omara, et al., 2011).

One of the method to solve water problem is water purification by using solar water distillation system. A single basin solar still is a simple solar device used for converting brackish or waste water into potable water. The interest in the solar still system (Figure 1) has been used due to its simple design, construction, and low operating and maintenance costs, mainly in remote areas far from an electricity supply grid (Zurigat, & Abu-Arabi, 2004). However, its low productivity stimulated the development of methods to increase its efficiency. The solar distillation systems are mainly classified into two categories; i.e. passive and active solar stills. Solar radiation is the only parameter which affects evaporation in passive solar still while in active solar still, the additional device such as fan, pump, sun tracking system or solar collectors are added (Kabeel, et al., 2014).

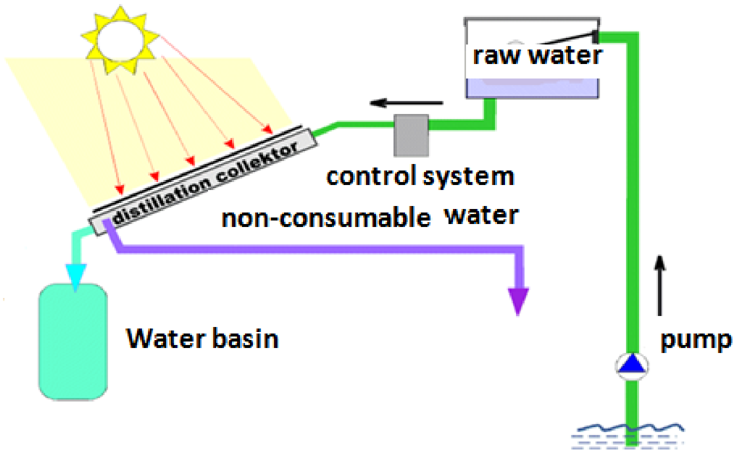

Figure 2-0: Solar Water Distillation System

The fundamental of solar water distillation are simple, yet effective, as distillation imitates the way nature purifies water as it utilize the energy of the sun as for heating the water to the point of evaporation. As the water evaporates, it vaporizes and condense on the glass surface for accumulation. This process removes impurities such as salts and heavy metals, and additionally destroys microbiological organisms (Al-Hayeka, & Badran, 2004). As a result, the water that been distilled is cleaner than the purest rainwater.

1.2 Motivation

The consumption of fresh water is increasing due to the increasing population and rapid industrial growth, which causing a serious depletion of fresh water. Hence, human being should start to depend on the brackish water for the source of water. One of the method to produce fresh water from brackish water is using solar distillation where the use of solar energy is utilized. However, one of the greatest challenge of a solar still is to increase its efficiency.

Numerous design and factor are considered to create a system that can produce the most efficient solar still which will be used to distillate brackish water to fresh water. Thus, the goal for this experiment is to efficiently produce clean drinkable water from solar energy conversion.

1.3 Problem Statement

The freshwater resources crisis and the need for water supplies are already critical in the whole world. Fresh water is the most important element for the human body to stay healthy and energetic. Water and energy are basic elements that affect the quality of human life (Haruna, et al., 2014). However, the production of clean water throughout the country have decreased. More than 900 million cases of diarrhea occurred every year worldwide (Rijab et al., 2001). Studies have shown that 0.5% of people exposed to unsafe water may die due to bacteria found in water that has been contaminated and 0.25% of people can die from dehydration caused by diarrhea.

In this study, seawater has been used as the main element for the success of the study. The sea water was used because it is readily available and it is a constant source of water. Sea water is usually found as a reliable solution in dry areas to meet the growing demand for water due to population growth, and economic and social development and also to reduce dependence on groundwater resources (R. Poblete, et al., 2016). In order to overcome the shortage of freshwater nowadays, a solar still that produce highest efficiency in converting brackish water to pure water must be proposed. Solar still also a process which is simple, yet effective because it uses solar energy for water heating to the point of evaporation.

The solar still also must be cost effective so the community in a rural area also can have their own solar still. In addition, the solar still also be able to remove any brackish groundwater contaminant. The solar still that has been designed to be used in this research consists of heat transfer agent (HTA), magnifying glasses and aspirator pump. From Literature, it was stated that the factors affecting the production rate of solar still are type of solar still, type of HTA, vacuum condition and symmetry or asymmetric solar still. In this study, the factors taken into consideration are level and concentration.

1.4 Objectives

The aim of this study is to investigate the production rate of clean water from the modified solar still.

1.5 Scopes of Study

To achieve the objective of this research, there are two scopes that have been identified:

1) The level of the feed. The dimension of the internal basin is 50mm x 60mm x 60mm. Hence, there will be 3 different feed level which are 45mm, 40mm and 35mm.
2) The concentration of the feed. There will be 2 different type of sample which are sea water and tap water.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This paper presents the numerous experimental studies on the effect of different design of solar still towards the heat transfer properties such as type of solar still, type of HTA and vacuum condition. Solar still have two different types which are passive type and active type. The experiment to study the effect of HTA is done by using cast iron and copper. The design of solar still in normal and vacuum condition has also been proposed.

2.2 Introduction

It is well known that water is a basic human need. However, the increasing of world population growth together with increasing of industrial and agricultural activities all over the world contributes to the depletion and pollution of fresh water resources. This causes a severe shortage of fresh water in the world nowadays. The rapid increasing need for energy and environmental concerns has focused more attention on renewable energy resources (Gnanadason, et al., 2011). To overcome this problem, there are various methods to produce fresh water from sea water, saline water or brackish water.

Desalination processes have received great attention as an alternative solution for fresh water production. Desalination is the process of removing salts and minerals from water, thus producing fresh water. Desalination is one of the methods which is suitable for potable water. The demand for authentic and autonomously operating desalination systems is increasing steadily. These system are meant for a fundamental need of drinking water and fresh water supply (Somanchi, et al., 2015). The use of sustainable energy offers a wide range of exceptional benefits and expected to have a flourishing future and an important role in the domain of brackish and sea water desalination in developing countries (Murugavel, et al., 2010).

2.3 Desalination Process

According to (Sharshir, et al., 2016), the saline or brackish water in desalination technologies is evaporated by the use of thermal energy and the resultant steam is collected and condensed as a final product. Thermal technologies include Vapor Compression (VC), Multi Stage Flash (MSF) and Multi Effect Distillation (MED) whereas membrane technologies includes Microfiltration (MF), Nanofiltration (NF), Ultrafiltration (UF) and Reverse Osmosis (RO). MSF, MED, and RO are commercially applied in huge capacities in cities and water is passed through a couple of special membranes, perpendicular to which there is an electric field. Water does not pass through the membranes while dissolving salts pass selectively.

Desalination plants generate pure water and brine (also known as retentate, concentrate, or reject), which is reported to be approximately 55% of the collected seawater (Meneses, et al., 2010). The unwanted by-product, brine, may have a concentrated salinity as high as two times the typical seawater salinity (Roberts, et al., 2010). The salinity of brine produced by desalination plants is reported to be approximately 60 parts per thousand (Ahmad, & Baddour, 2014). The temperature of the brine depends on the desalination technology. For example, the temperature of brine produced by evaporation technologies such as multistage flash (MSF) and multi-effect distillation (MED) could be very high (Al-Mutaz, & Al-Namlah, 2004).

2.4 Solar Energy

Solar energy is the best alternative heating energy source because it is inexhaustible, clean and available in almost all parts of the world. Moreover, the use of solar energy are more economical than the use of fossil fuels in remote areas having low population densities, low rainfall and abundant available solar energy. According to (Al-Hayeka, & Badran, 2004), it depends drastically on the intensity of solar radiation and the sunshine time interval during the day. According to Accary, et al., 2008, among renewable energy sources that used to supply thermal and electrical energy for desalination, solar energy has been the increased attention as its abundance in numerous locations that experiencing shortage of fresh water.

Solar energy is also a cost-effective method because it does not use any electrical source. However, there are limitations in the use of solar energy as it is dependent to the weather (R. Poblete, et al., 2016). Solar energy is one of the most promising applications for seawater desalination (M. Ahmed et al., 2010). Qiblawey, & Banat, 2008 provided an overview of solar thermal desalination technologies and concluded that solar energy aided desalination offers a promising solution for covering the fundamental needs of power and water in remote regions. The use of solar energy for brine management has been primarily based on the use of evaporation ponds historically.

2.5 Solar Still

The first "conventional" solar still plant was built in 1872 by a Swedish engineer Charles Wilson in the mining community of Las Salinas in what is now northern Chile. This still was a large basin-type still used for supplying fresh water with very high salinity (4-fold of seawater) of the nitrate mine effluents to supply with fresh water the workers of the mine and the nearby inhabitants (G Frick & J. Hirschmann, 1973).

A solar still was designed for the evaporation of desalination brine (R. Poblete, et al., 2016). Solar still have been used effectively, for centuries, to treat highly contaminated water and as a means of generating water in extremely arid and water-scarce regions. Solar distillation is one of the essential methods of harness the solar energy for the reservoir of consumable water to small population where the natural supply of fresh water is insufficient or of poor quality, and where sunshine is plentiful (Al-Hayeka, & Badran, 2004).

Availability of fresh water is fixed on the earth and its demand is increasing day by day due to increasing population and rapidly increasing of industry, hence there is an essential and earnest need to get fresh water from the saline/brackish water present on or inside the earth (Gnanadason, et al., 2011). This means of getting fresh water from saline/ brackish water can be done easily and economically by desalination (Al-Hayeka, & Badran, 2004).

The solar stills are simple and have no moving parts and it can be used anywhere with lesser number of issues. The operation of solar still is very simple and no specific ability is needed for its operation and maintenance. The use of solar energy is more practical than the use of fossil fuel in remote areas having low populace densities, low rain fall and plentiful available solar energy (Gnanadason, et al., 2011). Various parameters affect both efficiency and the productivity of the still. The efficiency can be elevated by altering model of the solar still, depths of water level, concentration of salt, different absorbing materials and evaporative methods (Natarajan, & Sathish, 2009).

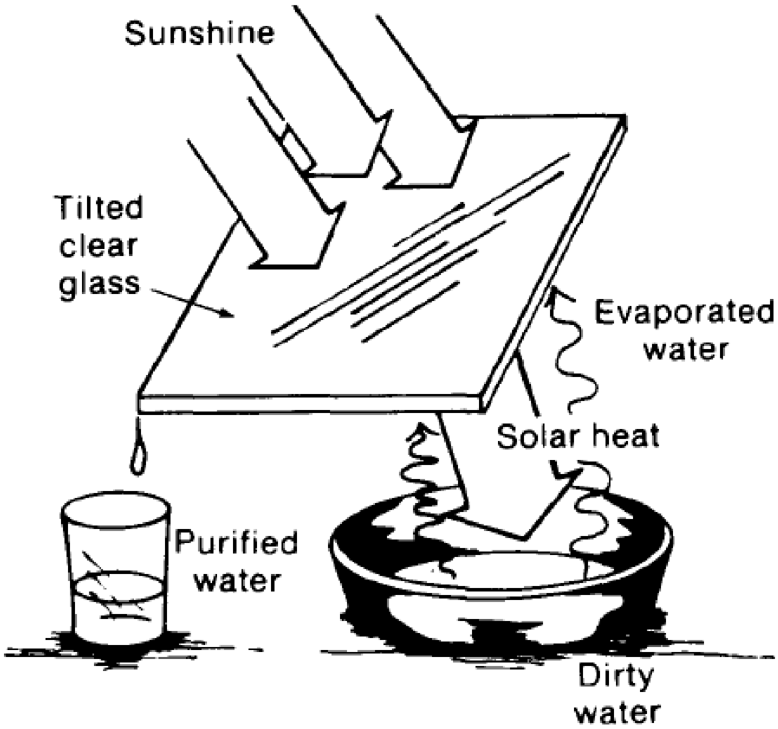

Figure 2-1: Basis Concept Of Solar Distillation (Taiwo, & Olalekan, 2010)

2.5.2 Type of Solar Still

There are various kind of design for solar still and are two different types of solar stills, which are active solar still and passive solar still. Active type solar still contains mechanical components such as pump, power blower and valve. The most commonly used is passive solar still.

2.5.3 Passive Solar Still

Passive type solar still does not have any mechanical components or any moving elements, so there is no power consumption and it reduce the cost. The passive solar still is a distiller that only need sunshine to operate as there are no moving parts to wear out (Al-Hayeka, & Badran, 2004). The distilled water from the present solar stills does not acquire the "flat" taste of commercially distilled water since the water is not boiled (which lowers pH).

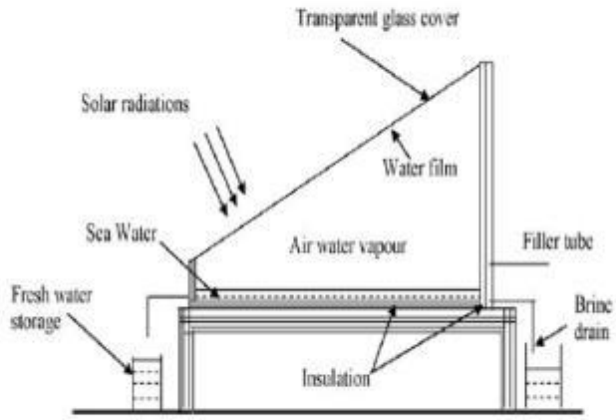

Figure 2-2: Schematic Diagram of a Passive Single-Basin Solar Still (Somanchi, et al., 2015)

These solar still use natural evaporation, which is the rainwater process. However it is recommended to add small amounts of minerals or salts to the distilled water, since the minerals found in water may be healthy. Lost minerals can also be replaced by trickling the distilled water through a bed of marble chips.

2.5.4 Design of Solar Still

There are many solar still designs that have been used to increase the productivity rate. For example, basin-type solar still (Figure 2-3). There are two types of basin-type solar still: single (Figure 2-4) and double-basin solar stills (Figure 2-5) (Al-Karaghouli, & Alnaser, 2004).

Certain aspects affect the selection of different Renewable Energy Sources for any given desalination technology. Since the main focus is the world's poorest countries that is believed to be in the tropics, the most feasible renewable source would be the solar energy. Nevertheless, the most important concerns should be the simplicity of the design, its reasonable, sustainability, maintainability and operational ability.

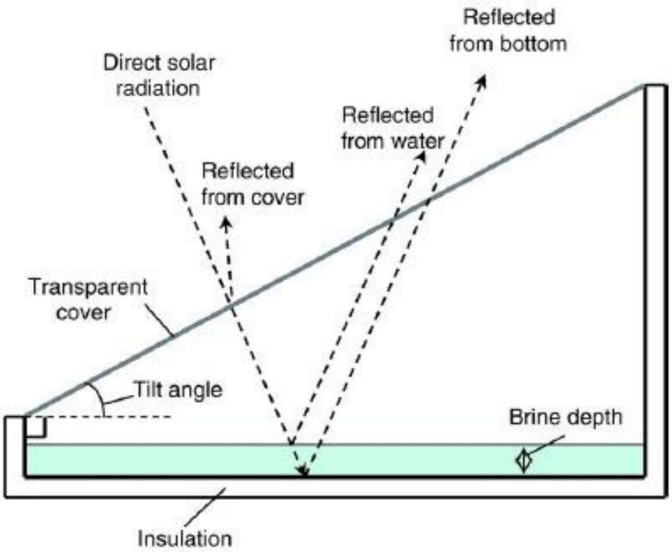

Figure 2-3: Schematic Diagram of a Basin-Type Solar Still
(Khalifa, & Hamood, 2009)

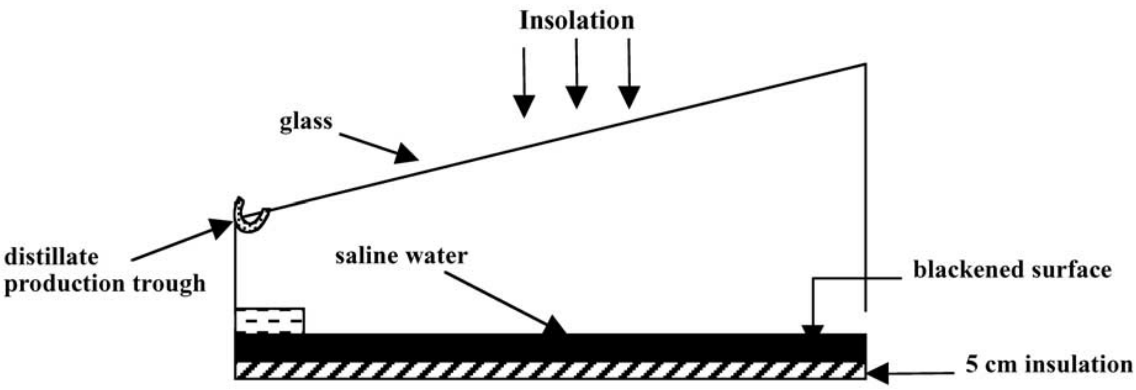

Figure 2-4: Cross Sectional Side View of the Single-Basin Solar-Still
(Al-Karaghouli, & Alnaser, 2004)

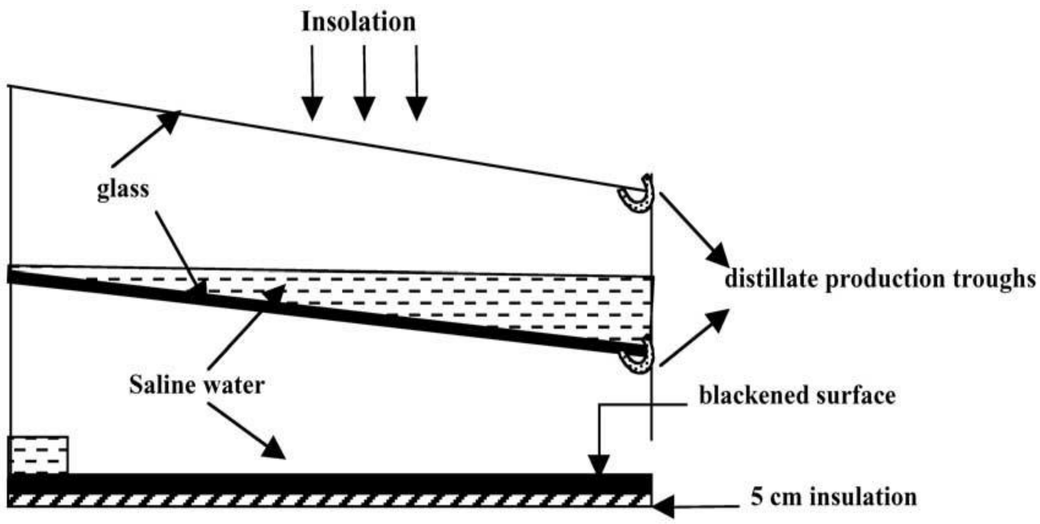

Figure 2-5: Cross-Section Side View of the Double-Basin Water Solar-Still (Al-Karaghouli, & Alnaser, 2004)

Each design have many advantage in their performances. For example, monthly average of daily distillate production of the double-basin still is higher than the average distillate production of the single-basin still (Al-Karaghouli, & Alnaser, 2004). This experiment uses double slope of solar still by using single basin. The main advantages of this type of solar still is that the latent heat of vapour, condensing over the lower surface of the lower glass cover is utilize in heating the upper layer of water, rather than being wasted to the atmosphere. However, the standard single basin-type solar still is the simplest and most sensible design for an installation and less complexity than the other types (Taiwo, & Olalekan, 2010).

2.6 Copper Sheet

In this experiment, copper is used for HTA in the basin. Copper has advantage that can absorb heat more efficiently than cast iron as the rate of heat transfer in the still made up of Copper is greater. The attempts to increase the distillation efficiency also made by painting black coating inside the still basin made up of Copper sheet (Gnanadason, et al., 2013).Solar still consists of a shallow triangular basin made up of copper sheet instead of cast iron as the HTA. As copper has higher thermal conductivity of 401 W/mK comparatively higher than cast iron, rate of heat transfer to the water in the still is more. The bottom of the basin is usually painted black to soak up sun’s heat which in turn heighten the evaporation rate.

The top of the basin is covered with a glass of 4mm thick tilted fixed at 32° so as to allow maximum transmission of solar radiation and helps the condensed vapor to trickle down into the trough, built in channel in the still basin. The edge of the glass is sealed with a tar tape so as to make the basin airtight. The entire assembly is placed on a stand structure made up of M.S angles (L-shaped structural steel). The outlet is connected to a storage container through a pipe (Gnanadason, et al., 2011).

It can be concluded that the efficiency is higher to for a solar still made up for copper and it can be increased further by black painting inside the still. This cost effective design is expected to provide the rural communities an efficient way to convert the brackish water into potable water.

Figure 2-6: Solar Still with Copper Coating (Gnanadason, et al., 2011)

In the basin type solar still, impure water is filled inside an air tight insulated basin covered with a transparent glass or plastic cover. When the still is exposed to the sun, the rays get transmitted from the cover to the absorber surface at the bottom, thus heating the water. The hot water then heats the air inside the still making it unsaturated. The water gets evaporated and saturates the surrounding air which is being circulated inside the still due to the temperature difference between the water surface and the cover lower surface. When the air touches the cover, water vapor present in the air gets condensed and collected using a drain (Somanchi, et al., 2015).

2.7 Vacuum Solar Still

It is a known that boiling takes place when the ambient temperature equals that of the vapour pressure of the liquid. This means that the rate of evaporation can increase by reducing the pressure of the still to ensure higher rates of evaporation even at low temperatures. One more additional feature in this still is that it would use the latent heat which is released during condensation to heat up the water at lower temperature.

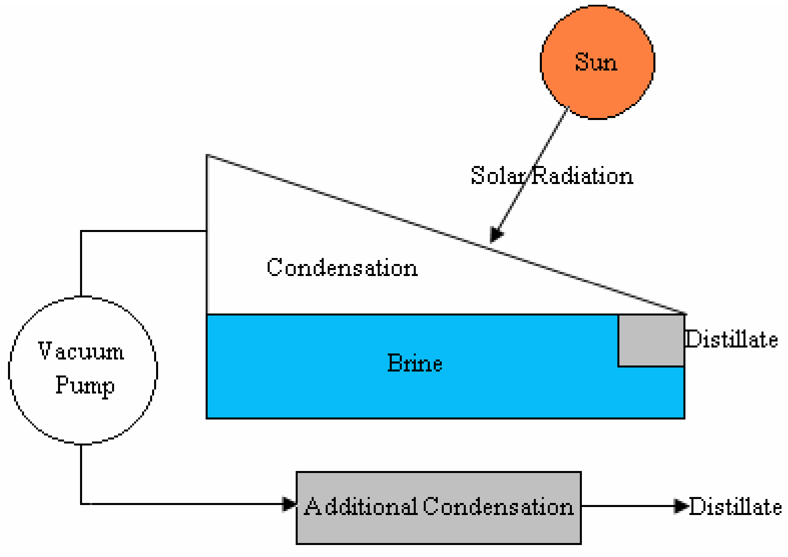

Figure 2-7: Vacuum Solar Still Setup (Gnanadason, et al., 2011)

The operating conditions was set about 60°C to ensure low heat transfer losses. At this temperature the vapour pressure of water is 20 kPa. So the pump need to be operated to reduce the pressure to this value and then leave it in the sun for distillation. This will ensure boiling of water inside the distiller when the temperature reaches 60°C, which is quite low and effortlessly achievable by using simple designs. In the design, a simple vacuum pump had incorporated to decrease pressure inside the distillation chamber which will be operated intermittently to maintain the vacuum constantly. At that time a separate condensation chamber is utilized to condense the vapour leaving through the vacuum pump. The value of the temperatures, solar radiation intensity and the yield of distilled water are recorded hourly to investigate the effect of each parameter on the still productivity without using vacuum.

The same measurement process is repeated for different parameters to find out the enhanced performance of the vacuum still and compare the performance of the still with and without vacuum. This shows an inflation in the rate of evaporation by decreasing the pressure of the still which will assure higher rates of evaporation even at low temperatures. Moreover this yet uses the latent heat which is released during condensation to heat up the water at lower temperature. Due to this vacuum inside the still, the evaporation rate increases more and the efficiency increases by 50% compared with the still operating at atmospheric conditions (Gnanadason, et al., 2011).

2.8 Factors affecting the productivity of solar still

There are numerous influences affecting the solar still productivity such as intensity of solar radiation, wind velocity, environmental temperature, glass – water temperature difference, water free surface area, deepness of water, inlet water temperature, area of absorber plate and glass cover angle. The intensity of solar radiation, wind velocity and environmental temperature cannot be controlled because those are metrological factors.

2.8.1 Environmental air temperature

The effects of environmental factors differ according to the opinions of different researchers. Voropoulos, et al., 2001, reported that enhancing productivity was achieved by reducing environmental air temperature. Badran, 2007 and El-Sebaii, 2004 improved the productivity by high-velocity wind but Nafey, et al., 2000, reported that higher productivity was obtained by a lower-velocity wind.

The cause of these differences may be reducing environmental air temperature or increasing velocity of wind leads to the higher temperature difference between the glass cover and the brine. In addition to that, the heat loss to the surrounds increased. As a result, decreasing environmental air temperature has a positive impact on the productivity, while increasing wind velocity has a negative impact. The results showed that a very small increase of 3% in solar stills performance was made possible by an environmental temperature of 5ºC (Nafey, et al., 2000) and was supported by Abu-Arabi, et al., 2002, who reported that an increase in the environmental air temperature by 10 ºC improved the output by 8.2%.

2.8.2 Angle, thickness and material for glass cover

Singh, & Tiwari, 2004 reported that the annual solar still yield reached a maximum value when the condensing glass cover inclination was equal to the latitude of the place. Based on their numerical analysis, better performance could be made from a glass slope angle of 15º. In a study by Akash, et al., 2000, it was found that a 35º glass inclination angle led to a maximum yield in the month of May. In Jordan, an experiments was conducted to investigate the effect of tilting cover on basin solar stills performance. It was found that tilting the covers alone could change the output by almost 63% (Khalifa, & Hamood, 2009).

The heat transfer through the glass cover improved when its thickness decreased and the thermal conductivity increased. Material selection for solar stills is very significant; the cover material may be made of either plastic or glass. Glass is the preferred because of its greater solar transmittance for different angles of incidence and its long-term use, whereas a plastic (such as polyethylene) can be used for short-term use.

2.8.3 Insulation solar still

The material and the thickness of the insulation are significant in a solar still. The report stated that the highest monthly-average daily output for a single-basin solar still, which is in June was 1105ml/day for a non-insulated still while for an insulated still, it was 1280ml/day (Al-Karaghouli, & Alnaser, 2004).

This shows that there is a noticeable increase in the rate of water production when an insulation material is added to the solar stills' sides. This is due to the effect of side insulation on keeping the heat inside the solar still for a longer period at night; therefore the side insulation has a greater advantage.

2.8.4 Glass– water temperature difference

Increasing the difference in temperature between the glass cover and the basin water leads to an increase in the natural circulation of the air mass inside the solar still. It increases both evaporative and convective heat transfer from basin water to glass cover.

The difference in temperature between the glass cover and water is considered as the driving force of the condensation process. Increasing the temperature difference between the glass cover and water can be achieved by using regenerative solar still, still with double glasses (Zurigat, & Abu-Arabi, 2004; Mink, et al., 1998; Abu-Arabi, et al., 2002)

2.9 Water Quality

Safe drinking water represent any significant risk to health over a lifetime of consumption. Those at greatest risk of waterborne disease are infants and young children, individuals who are weakened and the elderly, particularly when living under unsanitary conditions. Safe drinking water is essential for all common domestic purposes, including drinking, food preparation and personal hygiene (Gorchev, & Ozolins, 2011). In order to fulfil the safe drinking water needs of small communities located near questionable water sources, affordability, usage, maintenance, and operation parameters are important limitations to be considered. Obviously there is a critical need for and an interest in solar distillation technology as a low-cost solution to provide a safe source drinking water (Hanson, et al., 2004).

The water that is made in these stills is of a superior quality than filtered water because it is decontaminated using the distillation process, and because the water is slowly evaporated instead of rapidly boiled, the water tastes sweeter due to the natural process (Al-hassan & Algarni, 2013). Impurities such as salts, odor, heavy metals, bacteria, micro-organisms, sand, rust, fluoride and so on are completely removed in the distillation process. This process also destroys microbiological organisms (Al-Hayeka & Badran, 2004). Hanson, et al., 2004 found that a single-basin still design was successful in removing bacteria by more than 99.9% if cross contamination is avoided and non-volatile contaminants from drinking water.

CHAPTER 3

MATERIALS AND METHODS

3.1 Overview

The experiment procedure was divided into four parts (Figure 3-1). The first part of the experiment procedure was the experimental setup. This part involves the gathering of the experiment materials such as sample (sea water and tap water) and the material required to setup the solar still. The second part was the preparation of the sample. The sample were collected and the salinity, pH, total dissolved solid (TDS) and conductivity of the sample were recorded before the experiment. Next step was the data collection, which involves conducting the experiment. The data such as feed concentration and feed water level were recorded for analysis. Finally, all the data were analysed and a conclusion was acquired.

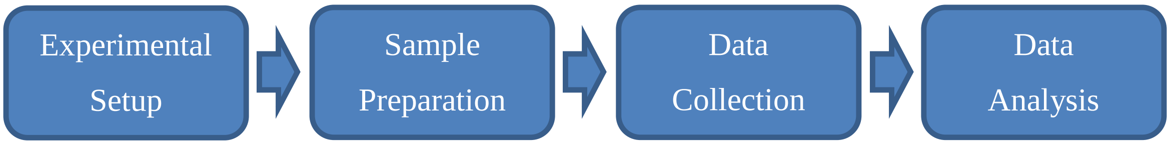

Figure 3-1: Experiment Procedure Flow

3.2 Materials

Copper metal sheet was selected mainly for this experiment as the heat transfer agent (HTA). The sample for this experiment was sea water and tap water. Other than that, the sample's salinity, TDS and conductivity were analyzed by using a Cond./TDS/Sal. Tester from Ionix Instruments (Figure 3-2) while the sample's pH was analyzed by using a compact pH meter from Horiba (Figure 3-3). A functional solar still that consist of aspirator pump, thermal detector, fan and valve were prepared and constructed.

Figure 3-2: Ionix Instrument portable tester

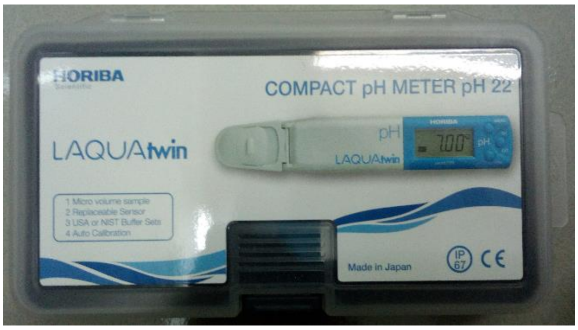

Figure 3-3: Horiba compact pH meter

3.3 Procedure

3.3.1 Characterization

3.3.1.1 pH

The pH of the untreated and treated water was measured using a pH meter. Firstly the pH meter was rinsed with distilled water for calibration purpose. A few droplet of the sample water were placed on the flat sensor of the pH meter and left to be stabilized before the reading was taken. The pH meter was rinsed with distilled water before each sample measurement. The pH of the sample water was measured before the first trial of the experiment and the product at the end each of the experiment.

3.3.1.2 Salinity

The salinity of the sample water was measured by using a salinity tester. The tester meter was calibrated by rinsed the sensor with distilled water. The sample was then poured into a small container and the tester sensor was placed inside the small container. The tester was left to be stabilized for 30 seconds and the reading was taken. The tester was rinsed with distilled water before measurement of each sample. The salinity of the sample water was measured before the first trial of the experiment and the product at the end each of the experiment.

3.3.1.3 Total Dissolved Solid (TDS)

The TDS of the sample water was measured by using a TDS tester. The tester meter was calibrated by rinsed the sensor with distilled water. The sample was then poured into a small container and the tester sensor was placed inside the small container. The tester was left to be stabilized for 30 seconds and the reading was taken. The tester was rinsed with distilled water before measurement of each sample. The TDS of the sample water was measured before the first trial of the experiment and the product at the end each of the experiment.

3.3.1.4 Conductivity

The conductivity of the sample water was measured by using a conductivity tester. The tester meter was calibrated by rinsed the sensor with distilled water. The sample was then poured into a small container and the tester sensor was placed inside the small container. The tester was left to be stabilized for 30 seconds and the reading was taken. The tester was rinsed with distilled water before measurement of each sample. The conductivity of the sample water was measured before the first trial of the experiment and the product at the end each of the experiment.

3.3.2 Experimental Procedure

For the main experiment, the solar still (Figure 3-4) was placed at a location where it can fully utilize solar energy for 10 hours. A copper sheet that acts as the heat transfer agent (HTA) was placed at the top of the inner basin with an area of $0.25m^2$ and the magnifying glasses were placed on top of it. The angles of the magnifying glass that had been installed on the inner basin were adjusted at approximately 45°, 90° and 135° respectively for each row of magnifying glass.

The sea water collected was poured into the inner basin at different level for each experiment. All the valve was closed to prevent sample or product to spill out. After that, the covered glass was sealed tightly to prevent any air to enter the solar still. After the experiment had finished, the salinity, pH, TDS and the reading level for the pure water (product), which indicates the amount of sea water that evaporates were measured and recorded. The second and third experiments were conducted at different depth of water level but with the same sea water.

Next, the experiment was conducted at the same depth of water level as experiment 1, 2 and 3 but with different type of water, which is tap water. There are 3 different feed level and 2 type of water in this experiment. All the data were recorded and analysed.

Figure 3-4: Solar Still

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The Solar still made up with Copper as HTA that was placed on the top of the internal basin was operated from 8.00 a.m to 6.00 p.m. The measurements of the water depth, temperatures, pH, conductivity, salinity, TDS and the production of pure water were taken at the end of each experiment. The purpose of the experiment were to study the effect of water depth on the solar still productivity in vacuum condition and the quality of the pure water produced. The output of the solar still varies directly with the temperature on the day the experiment been conducted, which dependent to the weather on those days.

In this still, the productivity increases as the water depth was at its minimum compared to the water depth at its maximum. The output is maximum during sunny day when the temperature is at its peak. The daily still output increase as the depth of water decreases from 3 to 2 and 1 cm respectively. By using heat absorbing material such as black painting on the basin and copper that acts as HTA, it improves the efficiency of the solar still (Gnanadason, et al., 2013). The average output is found to be 0.575 liters for water depth of 3cm, 0.625 liters for water depth of 2cm and 0.9 liters for water depth of 1cm for basin area of 0.25 m^2 based on data obtained from experiment of 18 days.

4.2.1 Productivity vs. Water Level

Figure 4-1 shows the productivity of solar still at different depth of water in the solar still basin. The productivity for sea water were recorded as 0.708 liters the highest followed by 0.625 liters and 0.5 liters the lowest representing 1cm, 3cm and 2cm respectively. On the other hand, the productivity for tap water were recorded as 1.08 liters the highest followed by 0.75 liters and 0.533 liters the lowest representing 1cm, 2cm and 3cm respectively. The sea water does not follows the trend line as tap water due to the inconsistency condition of weather during the experiment.

However, it reveals an increase in the productivity as the depth of water level decrease. The result was supported by the journal (Tarawneh, 2007) that stated the possibility of increasing the water productivity could be reached by lowering the water depths on the basin.

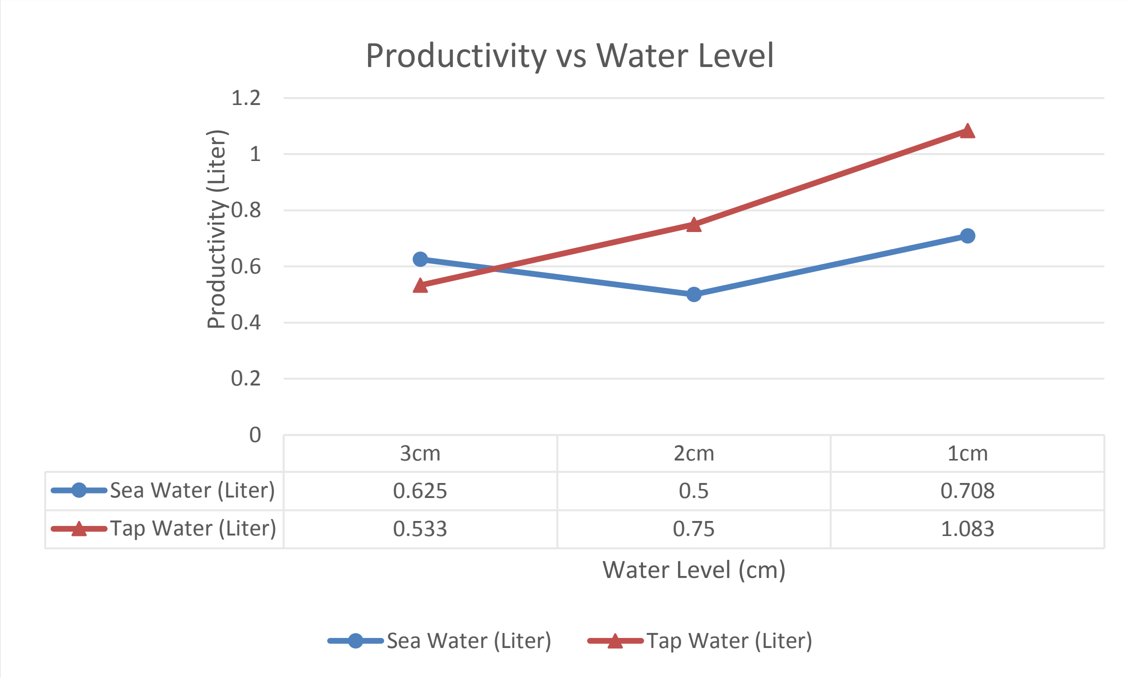

Figure 4-1: Productivity vs Water Level

4.2.2 pH vs Water Level

Figure 4-2 shows the pH for pure water produced at different water level. The average pH recorded for 3cm of sea water was 7.2, pH of 7.25 for 2cm and pH of 7.48 for 1cm of water depth. For the average pH of tap water, the pH is 7.2, 6.8 and 7.64 for water depth of 3cm, 2cm and 1cm respectively. The pH of treated water varies with the temperature on the day the experiments were conducted. Furthermore, the pH of tap water at 2cm was 6.8 possibly due to the impurities of water when collected before the experiment. The data shows that all the product was safe to drink as the value of the pH is within the safe range which is between 6.5-8.5 (NWCS, 2017).

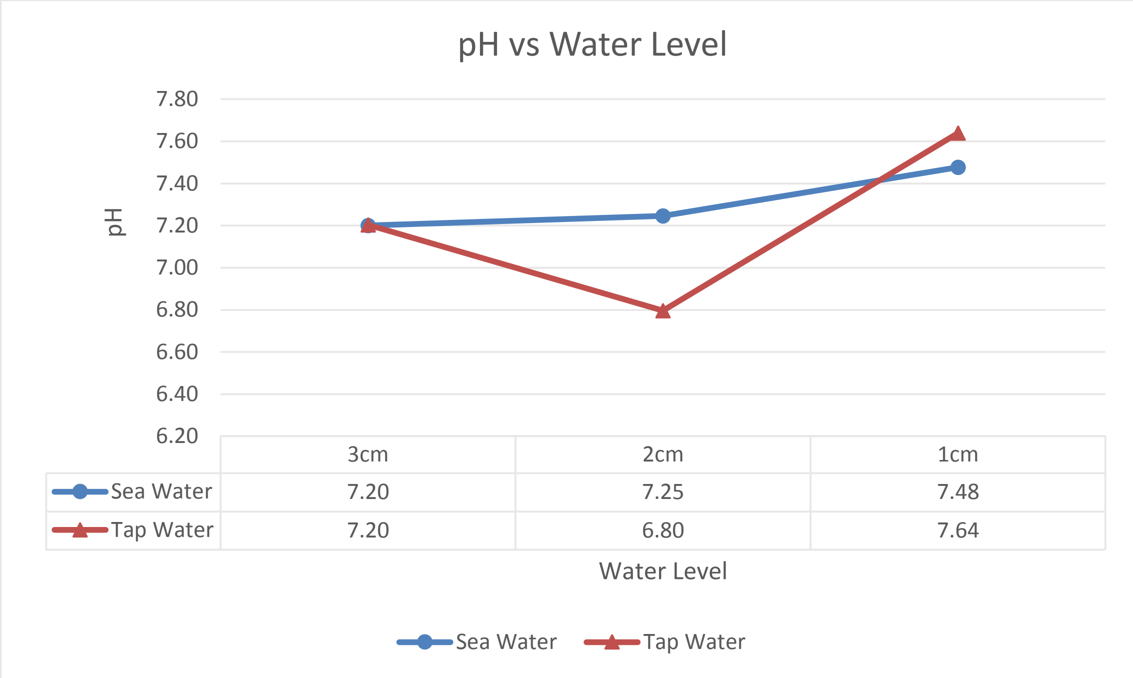

Figure 4-2: pH vs Water Level

4.2.3 Conductivity vs Water Level

Figure 4-3 shows the conductivity for pure water produced at different depth of water. The average value for conductivity of sea water at 3cm depth was 456.67µS, 438µS for 2cm and conductivity of 423.67µS for 1cm of water depth. On the contrary, the average conductivity for tap water recorded was 474µS for 3cm of water depth, 386.67µS for 2cm and conductivity of 741µS for 1cm of water depth. The conductivity of product varies with the temperature on the day the experiments were conducted. The data shows that all the product was safe to drink as the value of the conductivity is within the allowable standard which is below 1000 µS (NWCS, 2017).

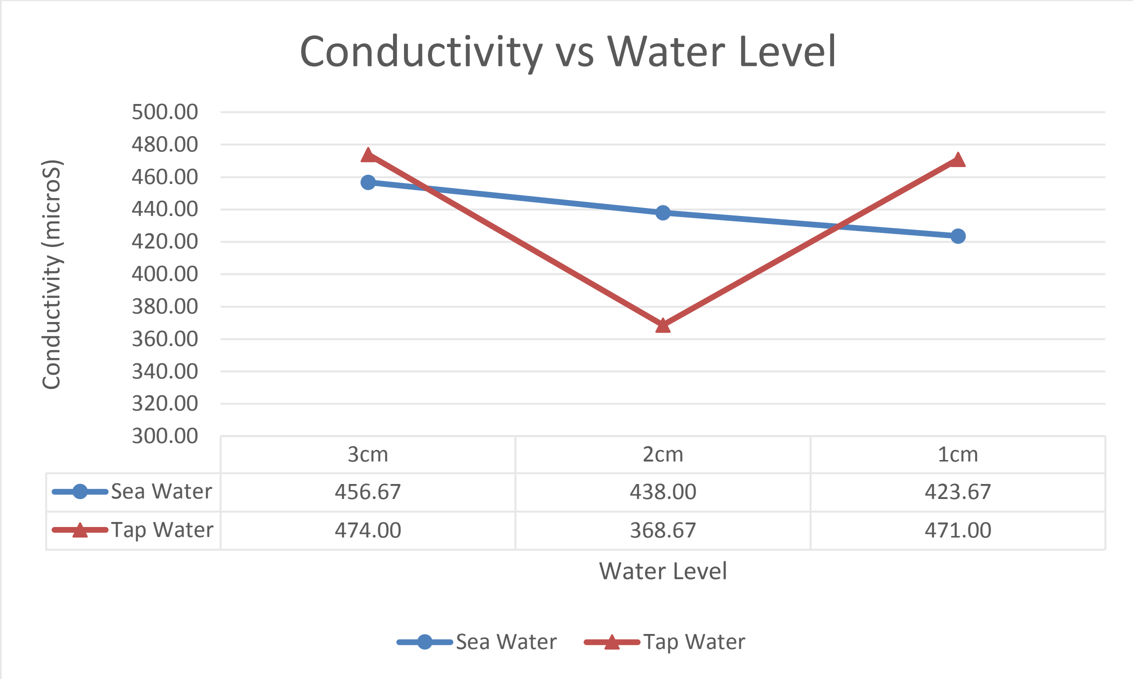

Figure 4-3: Conductivity vs Water Level

4.2.4 Salinity vs Water Level

Figure 4-4 was plotted for salinity of pure water produced at different depth of water. The highest average salinity recorded was 0.23ppt, followed by 0.22ppt and 0.21ppt cm the lowest representing for sea water depth of 3cm, 2cm and 1cm respectively. For 3cm of tap water depth, the salinity is 0.23ppt, salinity of 0.18ppt for 2cm and 0.24ppt for 1cm. The salinity of product varies with the temperature on the day the experiments were conducted. The data shows that all the product is safe to drink as the value of the salinity is within the acceptable criterion which is below 5.00ppt (NWCS, 2017).

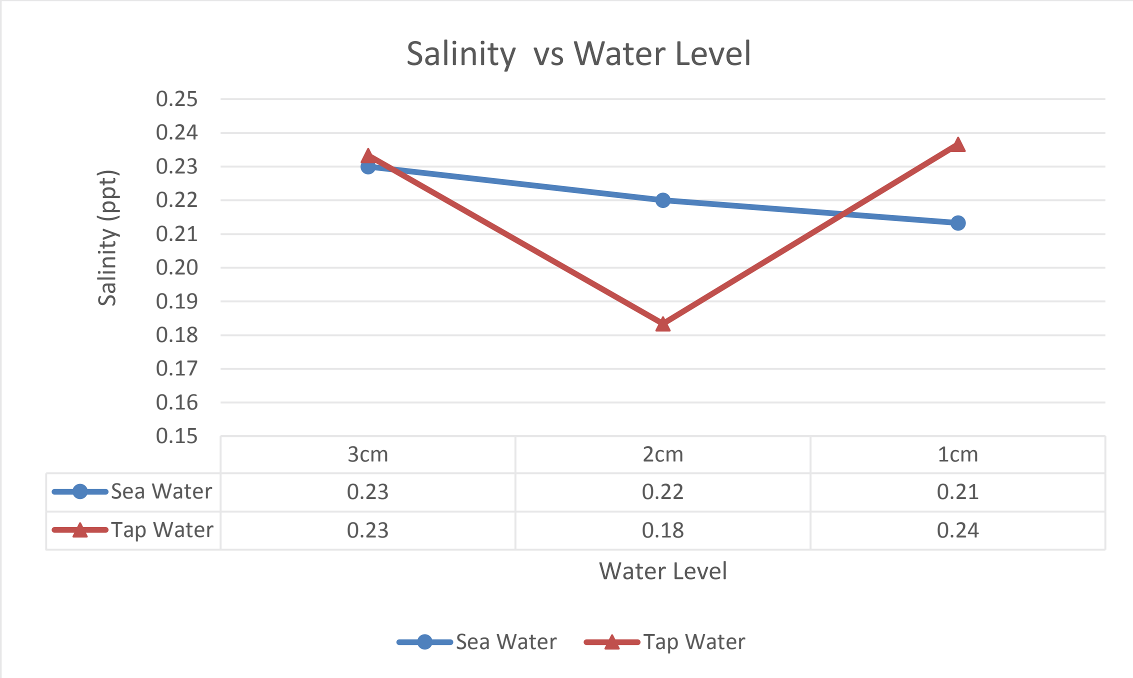

Figure 4-4: Salinity vs Water Level

4.2.5 Total Dissolved Solid vs Water Level

Figure 4-5 shows the TDS for pure water produced at different water level. For 3cm of sea water depth, the average TDS is 323.67ppm representing the highest value, TDS of 311ppm for 2cm and TDS of 301ppm for 1cm representing the lowest value. However, the highest value of TDS recorded was at 3cm of tap water depth, which was 337.33ppm, TDS of 261.33ppm for 2cm for the lowest value recorded and TDS of 334.67ppm for 1cm of water depth. The TDS of product varies with the temperature on the day the experiments were conducted. The data shows that all the product is safe to drink as the value of the TDS is within the decent norm which is below 500 ppm (NWCS, 2017).

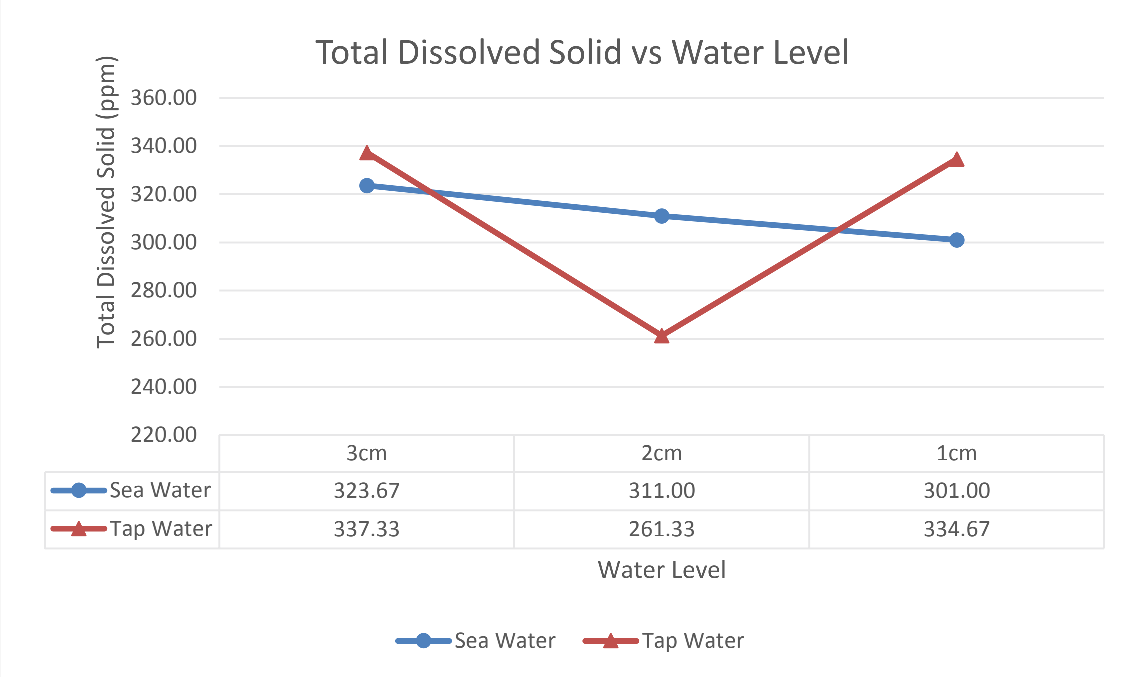

Figure 4-5: Total Dissolved Solid vs Water Level

4.3 Water Quality

As the performance of solar-stills were evaluated, the quality of the pure water produced were also evaluated. Four water quality parameters which are pH, conductivity, Salinity and TDS are crucial indicators of whether the water is safe to drink or not. Higher conductivity and salinity values indicate presence of dissolved salts. These parameters were tested before (untreated) and after (treated) the experiment were conducted.

The pH of both sea water and tap water before and after process was within the safe range from 6.5 – 8.5. Based on NWCS, the value of pH within the range of 6.5 – 8.5 is Class 1 Type, which indicate that there is no need for the water to undergo treatment and it is safe to consume. The conductivity of tap water before undergo process pass the maximum limit of Class 4 Type based on the NWCS, which indicated that it does not safe to consume and suitable for irrigation. The sea water before undergo treatment and for both sea water and tap water after the treatment are safe to consume as those fall to Class 1 Type after the treatment. The analysis of salinity and TDS shows similar trend as conductivity, where the tap water before process pass the maximum limit of Class 4 Type, which indicated that it does not safe to consume and suitable for irrigation (Al-hassan & Algarni, 2013). The presence of high levels of TDS, salinity and conductivity possibly due to excessive scaling in water pipes and household appliances.

The sea water before undergo treatment and for both sea water and tap water after the treatment are safe to consume as those three fall to Class 1 Type. The water after process from the solar still were found to be safe for consumption. The data obtained is shown in Table 4-1.

Table 4-1: Average Water Quality Analysis

Parameters	Sea Water		Tap Water		Standards
	Before	After	Before	After	NCWS
pH	6.95	7.31	7.29	7.21	6.5 – 8.5
Conductivity (μS)	833	439.44	17.6 mS	395.67	< 1000
Salinity (ppt)	0.42	0.22	8.85	0.22	< 5.00
TDS (ppm)	592	311.89	10 ppt	311.11	< 500

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Solar still is the best alternative method for desalination in rural area as it uses natural solar energy, clean and available in almost all parts of the world. The wide interest in the solar still system is due to its simple design, construction, and low operating and maintenance costs, mainly in remote areas far from an electricity supply grid. Desalination as a concept provides an ideal solution to safe water, but available desalination technologies are diverse and carry many limitations. The solar still performance evaluation has been based on productivity and water quality. The productivity efficiency improved as the Copper that acts as HTA has higher thermal conductivity and it conduct more heat to the water in the basin. The black paint coated on the basin also help to increases the temperature of the water in the basin. The findings in the experiments indicated the minimizing the water depth improved the rate of productivity. The water temperature also has a direct effect on the productivity of the solar still. The product of the solar still also safe to drink based on the parameter taken. Thus, it can be concluded that the use of solar still with Copper as HTA, coating of black paint on the basin and minimum water depth can increase the efficiency of a solar still.

5.2 Recommendation

Despite the depth of water level, the area of the basin of solar still should be revised as the surface area of water has its effect on the evaporation rate of water. As the surface area of water increases, the efficiency of production should also increases as the evaporation rate increases. Lastly, it is also important to add more precise measuring device such as level indicator that will result in higher precision and better evaluation.

REFERENCES

Abu-Arabi, M., Zurigat, Y., Al-Hinai, H., & Al-Hiddabi, S. (2002). Modeling and performance analysis of a solar desalination unit with double-glass cover cooling. *Desalination*, *143*(2), 173–182.

Accary, G., Morvan, D., & Me, S. (2008). The Human Line-1 Retrotranspsons Creates DNA Double Strand Breaks. *Fire Safety Journal*, *93*(5), 173–178.

Ahmad, N., & Baddour, R. E. (2014). A review of sources, effects, disposal methods, and regulations of brine into marine environments. *Ocean and Coastal Management*, *87*, 1–7.

Ahsan, A. et al. 2014. Assessment of distillate water quality parameters produced by solar still for potable usage. *Fresenius Environmental Bulletin*. **23**(3 A): 859–866.

Akash, B. A., Mohsen, M. S., & Nayfeh, W. (2000). Experimental study of the basin type solar still under local climate conditions, *41*, 883–890.

Al-hassan, G.A. & Algarni, S.A. 2013. Exploring of Water Distillation by Single Solar Still Basins. . **2013**(March): 57–61.

Al-Hayeka, I., & Badran, O. O. (2004). The effect of using different designs of solar stills on water distillation. *Desalination*, *169*(2), 121–127.

Ali, I., Joseph, B., Karthikeyan, R., & Yuvaraj, R. (2012). Performance Investigation of Solar Still Integrated to Solar Pond, *2*(March), 1–7.

Alkan, P.I. 2003. Theoretical and Experimental Investigations on Solar Distillation of İYTE Gülbahçe Campus Area Seawater MS Program : Energy Engineering. *Energy Engineering*. (April).

Al-Karaghouli, A. A., & Alnaser, W. E. (2004). Performances of single and double basin solar-stills. *Applied Energy*, *78*(3), 347–354.

Al-Mutaz, I. S., & Al-Namlah, A. M. (2004). Characteristics of dual purpose MSF desalination plants. *Desalination*, *166*(1–3), 287–294.

Anon. INTERIM NATIONAL WATER QUALITY STANDARDS FOR MALAYSIA. http://www.wepa-db.net/policies/law/malaysia/eq_surface.htm (23 May 2017).

Badran, O. O. (2007). Experimental study of the enhancement parameters on a single slope solar still productivity. *Desalination*, *209*(1–3 SPEC. ISS.), 136–143.

El-Sebaii, A. A. (2004). Effect of wind speed on active and passive solar stills. *Energy Conversion and Management*, *45*(7–8), 1187–1204.

G. Frick and J. Hirschmann, *Solar Energy*, *14*(1973), 405.

Gnanadason, M. K., Kumar, P. S., Sivaraman, G., & Daniel, J. E. S. (2011). Design and Performance Analysis of a Modified Vacuum Single Basin Solar Still. *Smart Grid and Renewable Energy*, *2*(4), 388–395.

Gnanadason, M. K., Kumar, P. S., Wilson, V. H., Kumaravel, A., & Jebadason, B. (2013). Comparison of Performance Analysis between Single Basin Solar Still made up of Copper and GI. *International Journal of Innovative Research in Science, Engineering and Technology (IJIREST)*, *2*(7), 3175–3183.

Gorchev, H.G. & Ozolins, G. 2011. WHO guidelines for drinking-water quality. *WHO chronicle*. **38**(3): 104–108.

Hanson, A. et al. 2004. Distillate water quality of a single-basin solar still: Laboratory and field studies. *Solar Energy*. **76**(5): 635–645.

Haruna, I. U., Yerima, M., Pukuma, A. D., & Sambo, I. I. (2014). Experimental Investigation Of The Performance Of Basin Type Single-Slope Solar Still, *3*(3).

Jubran, B. A. (2003). Effect of climatic, design and operational parameters on the yield of a simple solar still Al-Hinai, H. et al. Energy Conversion and Management, 2002, 43, (13), 1639–1650. *Fuel and Energy Abstracts*, *44*(2), 87.

Kabeel, A. E., Omara, Z. M., & Essa, F. A. (2014). Enhancement of modified solar still integrated with external condenser using nanofluids: An experimental approach. *Energy Conversion and Management*, *78*(November), 493–498.

Khalifa, A. J. N., & Hamood, A. M. (2009). On the verification of the effect of water depth on the performance of basin type solar stills. *Solar Energy*, *83*(8), 1312–1321.

Khalifa, A. J. N., & Hamood, A. M. (2009). Performance correlations for basin type solar stills. *Desalination*, *249*(1), 24–28.

M. Ahmed, W.H. Shayya, D.Hoey, A. Mahendran, R. Morris, J. Al-Handaly, Use of evaporation ponds for brine disposal in desalination plants, *Desalination*, *130*(2000), 155-168

Meneses, M., Pasqualino, J. C., Céspedes-Sánchez, R., & Castells, F. (2010). Alternatives for reducing the environmental impact of the main residue from a desalination plant. *Journal of Industrial Ecology*, *14*(3), 512–527.

Mink, G., Horvath, L., Evseev, E. G., & Kudish, A. I. (1998). Design Parameters, Performance Testing and Analysis of a Double-Glazed, Air-Blown Solar Still With Thermal Energy, *64*(1980), 265–277.

Murugavel, K. K., Sivakumar, S., Ahamed, J. R., Chockalingam, K. K. S. K., & Srithar, K. (2010). Single basin double slope solar still with minimum basin depth and energy storing materials. *Applied Energy*, *87*(2), 514–523.

Nafey, A. S., Abdelkader, M., Abdelmotalip, A., & Mabrouk, A. A. (2000). Parameters affecting solar still productivity. *Energy Conversion and Management*, *41*(16), 1797–1809.

Natarajan, E., & Sathish, R. (2009). Role of nanofluids in solar water heater. *The International Journal of Advanced Manufacturing Technology*, 3–7.

Omara, Z. M., Hamed, M. H., & Kabeel, A. E. (2011). Performance of finned and corrugated absorbers solar stills under Egyptian conditions. *Desalination*, *277*(1–3), 281–287.

Panchal, H. N. (2012). c r v i h o e f c r v i h o e, *5*(5).

Poblete, R., Salihoglu, G., & Kamil Salihoglu, N. (2016). Investigation of the factors influencing the efficiency of a solar still combined with a solar collector. *Desalination and Water Treatment*, *57*(60), 29082–29091.

Qiblawey, H. M., & Banat, F. (2008). Solar thermal desalination technologies. *Desalination*, *220*(1–3), 633–644.

Rijab, G. and Fujioka, R. 2001. Synergistic effect of solar radiation and solar heating to disinfect water sources. *Water Science Technology, 43*(12), 155-162.

Roberts, D. A., Johnston, E. L., & Knott, N. A. (2010). Impacts of desalination plant discharges on the marine environment: A critical review of published studies. *Water Research*, *44*(18), 5117–5128.

S.M. Radwan, A. A. H. and M. A. (2009). Single Slope Sollar Still for Sea Water Distillation.

Sharshir, S. W., Yang, N., Peng, G., & Kabeel, A. E. (2016). *Factors affecting solar stills productivity and improvement techniques: A detailed review*. *Applied Thermal Engineering* (Vol. 100). Elsevier Ltd.

Singh, H. N., & Tiwari, G. N. (2004). Monthly performance of passive and active solar stills for different Indian climatic conditions. *Desalination*, *168*(1–3), 145–150.

Somanchi, N. S., Sagi, S. L. S., Kumar, T. A., Kakarlamudi, S. P. D., & Parik, A. (2015). Modelling and Analysis of Single Slope Solar Still at Different Water Depth. *Aquatic Procedia*, *4*(Icwrcoe), 1477–1482.

Taiwo, A., & Olalekan, M. (2010). Improving the Performance of Solar Stills using Sun Tracking.

Tarawneh, M.S.K. 2007. Effect of Water Depth on the Performance Evaluation of Solar Still. *System*. **1**(1): 23–29.

Voropoulos, K., Mathioulakis, E., & Belessiotis, V. (2001). Experimental investigation of a solar still coupled with solar collectors. *Desalination*, *138*(1–3), 103–110.

Zurigat, Y. H., & Abu-Arabi, M. K. (2004). Modelling and performance analysis of a regenerative solar desalination unit. *Applied Thermal Engineering*, *24*(7), 1061–1072.