Solar Distillation using Energy Augmentation from the Roof

By

NorAsyidah Bt Mohd Ahmadan

Dissertation submittedinpartialfulfillmentof
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Department
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Approved by,

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(Dr. Nasiman B Sapari)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements,and that the original work contained herein have not been undertaken or done byunspecified sources or persons.

NOR ASYIDAH BT MOHD AHMADAN

ABSTRACT

Out of 100 % of water in the earth, less than 1% is the fresh water which can be used as drinking water. Limited source of fresh water is the major factor leading to water scarcity problem around the world. Seawater or brackish water is used as the alternative source of fresh water through desalination process but the current technology of desalination is expensive. Water desalination using solar still enables every house to produce its own drinking water by optimizing solar energy to distill seawater or brackish water without chemicals and electrical energy. Steel tubes system and basic basin solar still systems wereexamined in this study for augmentation of solar energy from the roof under local condition. The solar still was operated under two modes of operation; basic solar still alone and basic solar still connected to steel tubes system. Measurement of temperatures, solar intensities and distillate produce were taken in the month of November and December under monsoon season. The measurement was taken from 8am to 6pm. It was found that the production rate obtained is varied from 1.88 $kg/m^2/d$ to 2.26 $kg/m^2/d$. The production of solar still connected to steel tube system was expected to be higher. However, the connection was yet to be perfected.

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NOR ASYIDAH BT MOHD AHMADAN

Civil Engineering Department

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Water scarcity is the greatest crisis facing the humanity in this 21st century.The shortage of water is expected to be more critical in future due to worldwide rapid growth of industry and increase of human population. Research by Gadgil (1998)found that about 1.1 billion people in the world remain inaccessible to safe drinking water.

The research done by World Health Organization (WHO) found that 60 % of illness around the world is due to contaminated water and lack of sewer treatment. Unclean water causes illness such as diarrhea, cholera, dysentery, guinea worm infection, typhoid, intestinal worm infection and trachoma. This water related illness has killed nearly 2 million of people around the world and 90 % of the death is the children under the age of five(WHO, 2006). The death will keep increasing from time to time if the world can’t find an alternative to solve this problem.

According to the report of the United Nations Development Programme (1997), Malaysia’s rapid growth has caused environmental degradation.Developments of cities in Malaysia are responsible for the pollution of aquatic environment with sewage, municipal wastewater and industrial effluent (Halimahton and Elsadig, 2010). River water quality is currently degraded by sediments from land clearance and solid wastes.These situations will definitely cause water shortage in Malaysia in the future.

1.2 PROBLEM STATEMENT

Water is the essence of life and it is adversely affected by the pollution.Seawater comprises 97.5% of total global water resources whereas only 2.5% is the available fresh water in the form of deep wells and natural aqueducts(Kumar and Tiwari ,2008).Out of 100 % of water in the earth, less than 1% is the fresh water which can be used as drinking water. Limited source of fresh water is the major factor that leads to water scarcity.According to the World Watch Institute, in 2025 two third of world population will facing the shortage of drinking water due to water pollution and poor quality of fresh water.

To overcome this problem, seawater or brackish water is used as the source of fresh waterthrough desalination process but the current technology of desalination is expensive. Due to low income rate, some of the country could not afford to have the technology.Figure 1 and Table 1show the typical cost of thermal and reverse osmosis (RO) processes. Water desalination usingsolar still enables every house toproduce its own drinking water by optimizing solar energy to distillate seawater or brackish water without chemicals and electrical energy.

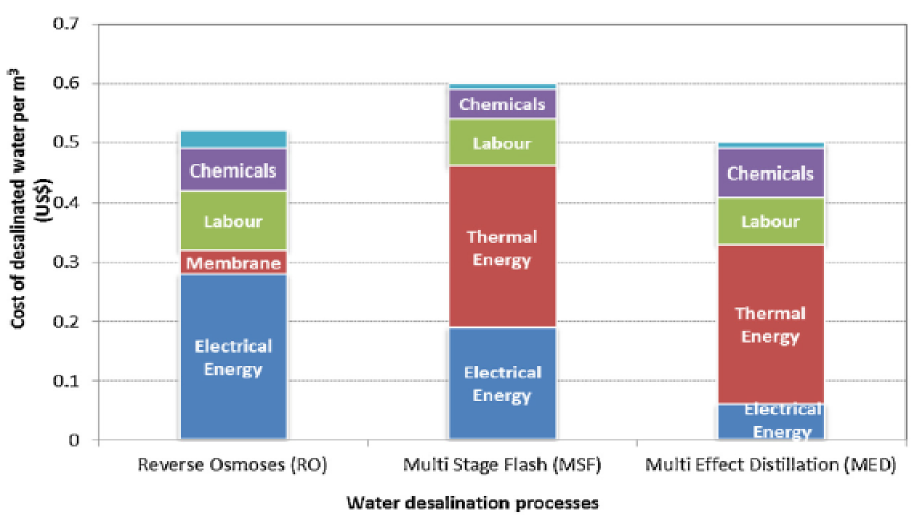


Figure 1: Typical cost of thermal and RO desalination process (Lattemann et al, 2010)

Type of feed water	Capacity of desalination plant (m^3/day)	Desalination cost per m^3 (US$)
Brackish water	Less than 20	5.63–12.9
	20–1200	0.78–1.33
	40,000–46,000	0.26–0.54
Seawater	Less than 100	1.5–18.75
	250–1000	1.25–3.93
	15,000–60,000	0.48–1.62
	100,000–320,000	0.45–0.66

Table 1: Cost of desalinated water in membrane RO plants (Shatat et.al, 2013)

1.3 OBJECTIVES

The objectives of this study are as follows:

a) To produce fresh water by cheaper method using solar still.
b) To determine the rate of drinking water production of the solar still under Malaysian climate.
c) To determine the efficiency of the solar distillation system.
d) To optimize the production of freshwater using energy collected from the roof.

1.4 SCOPE OF STUDY

In order to achieve the objectives mentioned in Section 1.3, the scopes of study are as follows:

1. Literature survey
    - A comprehensive desk study on the factors affecting the production of distilled water using solar still.
    - Search of the latest research done on the solar still patent and desalination technologies.
2. Enhancement of the solar still design
    - Additional system is introduced to the existing single slope basic solar still to increase the production rate.
3. Identify the suitable design and selection of materials
    - Focussing on the solar energy augmentation from the roof using steel tubes system.
    - Determine the dimension of solar still.
    - Selection of material for each component in solar still.
4. Fabrication of the solar still.
    - The solar still will be fabricated according to the finalized design.
5. Set-up to conduct the experiment
    - Finding the suitable location to conduct the experiment.
    - Check the solar still components to avoid errors during the experiment.
6. Analysis and interpretation of the experimental results
    - The experimental data are to be processed by presenting it in a graphical method.
    - Efficiency of the solar still will be analyzed and calculated.
7. Publication/ Report writing
    - Writing the final report of the research.

1.5 RELEVANCY OF THE PROJECT

This project is relevant to human, health and the environment. Desalination is believed to be an effective way to satisfy the increasing demand of fresh water. According toVelmurugan and Srithar (2011), forpeople living in remote areas or islands, solar still presents some specific advantages such as:

- Environmental friendly
- Clean and free energy
- Easy construction using locally available materials

1.6 FEASIBILITY OF PROJECT WITHIN SCOPE AND TIME FRAME

For this project, the first semester focuses on literature review for solar still, formulation of methodology and identifying the ideal design and system of solar still. The second semester was mainly on fabrication of solar still, experiments, collecting data and analyzing the result.

CHAPTER 2
LITERATURE REVIEW

2.1 DESALINATION

Oceans and seas are the largest reserves of water as shown in figure 2.However, due to its high salt concentration; they are not suitable for human use. According to Saidur et al (2011), 97 % of available water in the earth is seawater. The increment of fresh water demand causing more and more interest is paid to the desalination of seawater and brackish water into drinking water.The research done by Rodriguez and Camacho (2001) verify that thermal desalination is one of the most promising methods of renewable energies in seawater desalination. According to Velmurugan and Srithar (2011), desalination is one of the earliest forms of water treatment and it is still popular treatment solution.

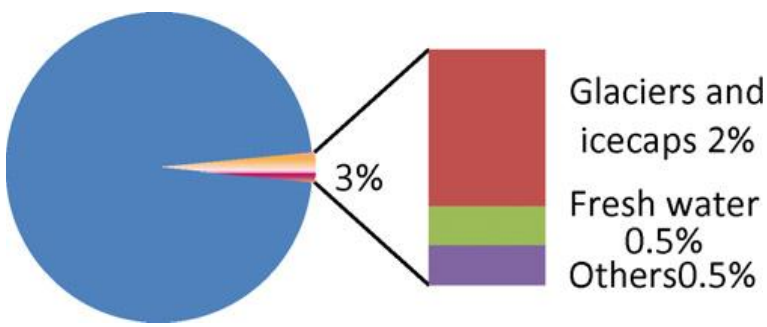


Figure 2: Earth's water distribution (Saidur et.al, 2011)

In the paper produces by Qiblawey and Banat (2008), they had explained about desalination process in nature which produces rain. Figure 3 explained the principle of desalination. The process initiated when thermal energy from sun will be absorbed by the sea and cause water to evaporate. Once this vapor cools down to its dew point, condensation occurs and producing freshwater that comes down as rain. In this project, the same principle is used in designing man-made distillation systems using alternative sources of heating and cooling.

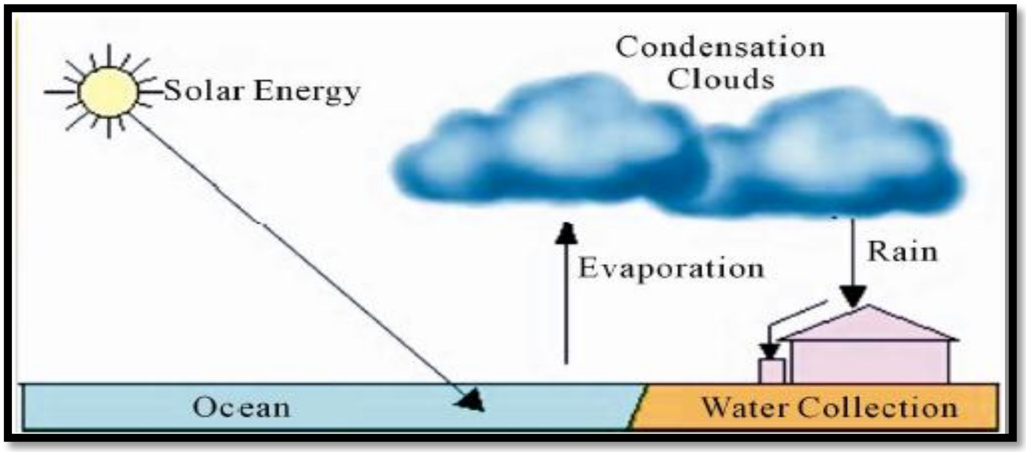


Figure 3: Principle of desalination (Gnanadason et. al, 2011)

Desalination has been widely used worldwide. Currently, 125 countries around the world are taking advantage of desalination methods to access fresh water from brackish and seawater (Saidur et.al, 2011). Figure 3below shows five leading countries by desalination capacity.

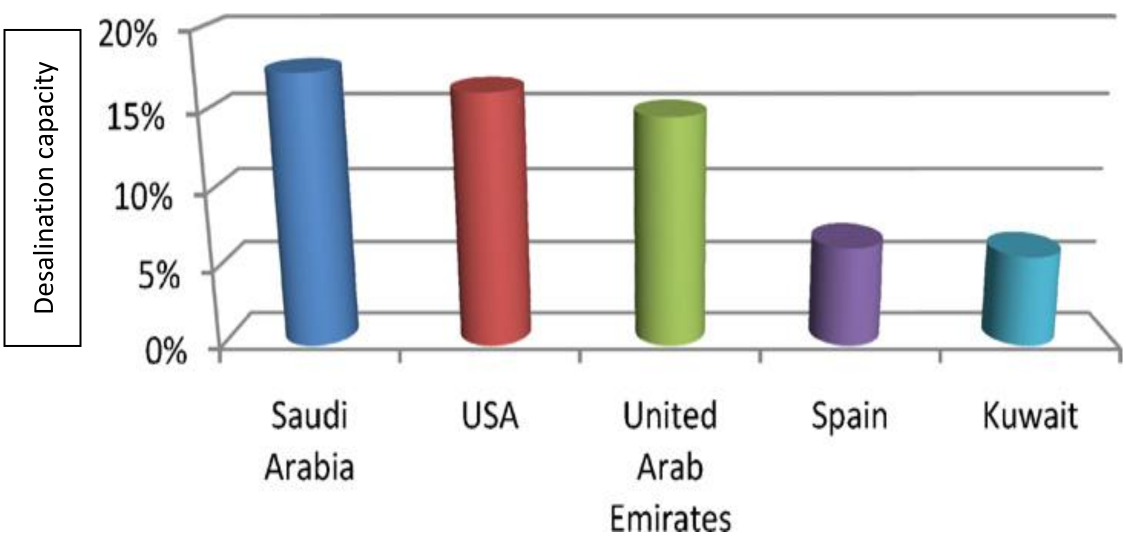


Figure 4: Five leading countries by desalination capacity (Saidur et. al, 2011)

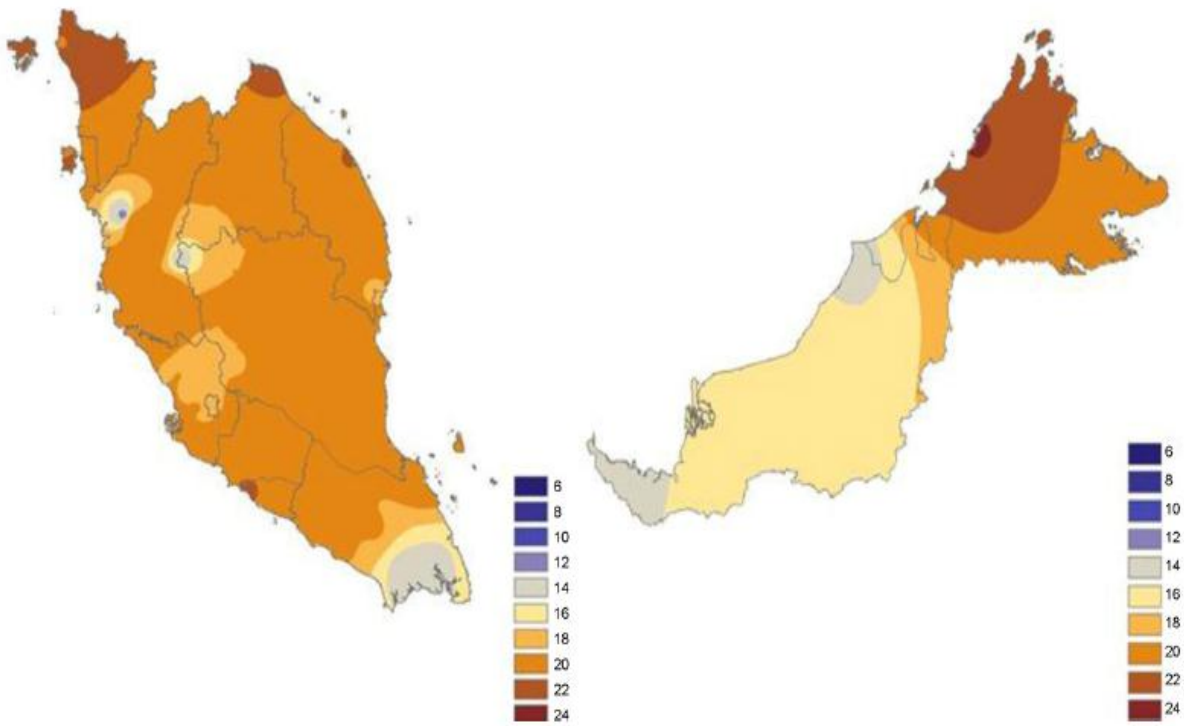


Figure 5: Average solar radiation in Malaysia in MJ/m2/d

According to Wan Nik et al (2011), Malaysia is a country which has abundant of solar energy. Muzathik et al (2010) had measure that the annual average daily solar irradiations for Malaysia have a magnitude of 4.21–5.56 kW h m^{-2}, and the sunshine duration is more than 2200 h per year. In other research by Jamaludin (2009)the monthly solar radiation in Malaysia is approximately around 400–600 MJ/m2. It goes higher during the Northeast monsoonperiod and lowers during the Southwest monsoon. Mekhilef et al (2012) found that the average daily solar radiation in Malaysia is around 14-24 MJ/m^2/d.

2.2 DEVELOPMENTS OF SOLAR STILL

Currently, solar stills are widely used in the solar desalination process. It can provide a solution for those areas where the quality of water is not good but having a plenty of solar energyespecially in Middle East and North Africa. Solar desalination can be either direct or indirect. Direct solar desalination as the use of solar energy to produce distillate directly in the solar collector whereas indirect solar desalination combines external energy source with the conventional techniques(Qiblawey and Banat, 2008). Figure 6 below shows the water desalination technologies.

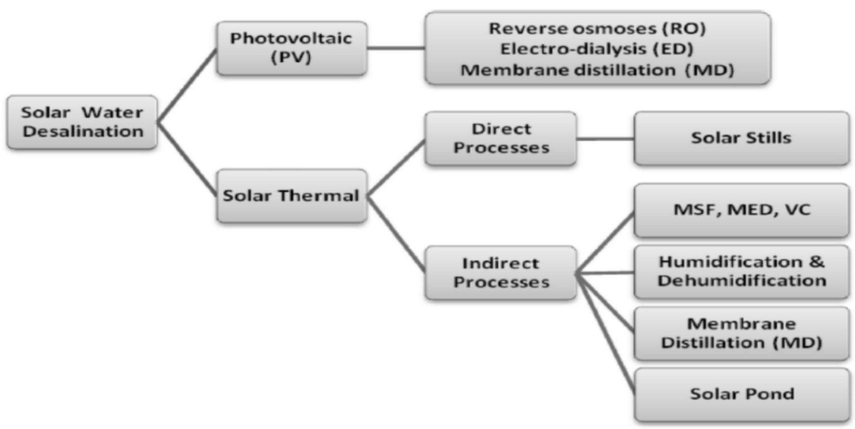


Figure 6 : Water desalination technologies (M.Shatat et.al, 2013)

The installation of direct solar desalination like solar still is cheap and having a low maintenance cost compared to other desalination method.Velmurugan and Srithar (2011) reviewed the advantages and disadvantages of solar stills in their paper. Two major advantages of solar still are free energy and environmentally friendly. However, the disadvantage is lower output of distilled water compared to other desalination process but still can be used for low capacity and self-reliance water supplying systems since its only used solar energy to produce drinking water .

Kaushal and Varun (2010) had reviewied on the classification of solar still. The conventional solar still is a single slope solar still. It consists of black painted basin contains brackish or seawater. The system is enclosed in a completely airtight surface formed by a transparent cover. The water in the basin is heated up by sun energy and theevaporated water flow through channel below the crease of bending to the distilled water collector. Figure 7 below shows the diagram of simple solar still.

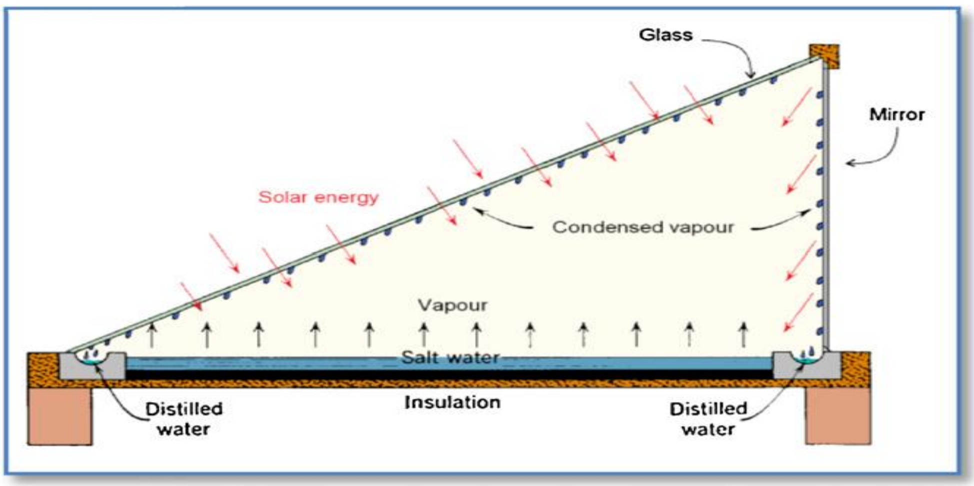


Figure 7: Simple solar still (Al-Hayeka & Badran, 2004)

The other types of solar still that was developed in the past are passive active solar still, multi-effect diffusion type solar still, tilted wick solar still, water film cooling over glass cover of a still including evaporation effects, solar still made up of tube for sea water desalting and roof type solar still. Each type of solar still had its own advantages and disadvantages as summarized in Table 2.

Apart from that, Rajaseenivasan and Murugavel (2013) had investigated the productivity of double basin double slope solar still. In this experiment, single basin and double basin slope stills are fabricated with the same area and tested under the same climatic condition. The result was compared with the single basin still. It was found that the productivity increases significantly by 85% compared to single basin production.

Types of solar stills	Geometry	Properties	Results	Advantages	Disadvantages
Simple solar still	Area = 500 mm × 500 mm, insulation = 1.5 mm, glass thickness = 5 mm	Intensity of insulation. Productivity steady state efficiency	Results obtained with the no insulation condition are more realistic since the presences of wind increase the energy losses from system.	Easy to install. Easy to operate. Less capital cost. Simple construction.	Efficiency is low. Productivity of water is low. Used in small area.
A roof type solar still	Base = 500 mm × 500 mm, bags = 500 mm^2, tube = 15 mm, fibrous sheet = 1.3 mm, side angle = 14.6°, inclination angle = 9.7°	Photocell temperature. Productivity solar intensity	Water to power ratio for such a hybrid system may be a key factor to determine the optimum condition. Main aim is to increase production.	Portable. Used in caravans recourse survey and military front. In laboratory.	Low performance. Used for small purposes.
Water film cooling over a glass cover of a still	Area = 500 mm × 500 mm, insulation = 1.5 mm, glass thickness = 5 mm	Steady state efficiency. Ambient temperature. Wind speed. Humid ratio.	For a conventional still, efficiency increases at low V_a and then decreases. A high value of h_{cf} results E. loss	More efficient than simple still. Productivity of water is higher.	Very sensitive. Glass temperature is main problem.
Passive active solar still	Area = 500 mm × 500 mm, insulation = 1.5 mm, glass thickness = 5 mm, pump. l_{re} = 1 m	Annual yield. Water depth. Inclination of flat plate collector	The performance of passive solar still in terms of hourly yield for different water depth.	Passive stills are more economical to provide potable water.	High capital cost. Depth increases efficiency decreases.
Multi-effect diffusion type solar still	Height of the still = 1 m. Length of the flat plate reflector = 1 m. Width of the still and flat plate reflector = 1 m. Diffusion gap between partition = 5 mm. Number of partitions = 10. Emissivity of glass cover = 0.9. Air gap between the glass cover and first partition = 10 mm. Reflectivity of the flat plate reflector = 0.95. Emissivity of the front surface of the first partition = 0.3	Solar radiation. Solar absorption. Time. Daily amount of distillate. Partitions. Overall productivity. Thickness of diffusion gaps between partitions. Feed rate of saline water. Reflectivity of flat plate reflector. Angle of flat plate reflector	The overall daily productivity is 1/5 of scale. The daily amount of distillate is largest on second partition and decreases from second to last partition. The overall daily productivity is larger on the winter solstice 39.7 kg/m^2 day than on spring equinox 34.2 kg/m^2 day since the sun rays are more inclined on the winter solstice than on the spring equinox, and this causes solar absorption.	Suitable for small purposes. More efficient when gap is very small. Mainly used in military fronts. Easy to operate. User friendly.	Diffusion gap between the partitions is the main problem. Air gap between the glass cover should be optimal.
Tilted wick solar still	Width of the still = 1 m. Length of the still = 1 m. Height of reflector = 0.5 m. Angle of the still = 30°. Azimuth angle of still = 0°. Diffusion gap between wick and glass cover = 10 mm. Absorptivity of wick = 0.9. Absorptivity of glass cover = 0.08. Reflectivity of reflector = 0.85	(1) Distillate production rate. (2) Solar radiation absorbed on wick. (3) Daily amount of distillate. (4) Angle of still. (5) Time	Distillate production rate as well as the solar radiation absorbed on the wick is greater for the still with reflector more than the still without a reflector during the time from 8 a.m. to 4 p.m. because the evaporating wick could not receive radiation from the reflector during the period.	Daily productivity of the still with reflector increases by 9% as compared to simple solar still. Productivity of water is more and used for economical purposes.	With out reflector productivity decreases. Wick is the main problem. Continuous feed of water is required for wick. Contamination due to wick always occur.
Solar still made up of tubes for sea water desalting	Table area = 1 m^2. Width = 0.5 m. Length = 2.0 m. Horizontal transparent tubes = 0.10–0.25 m, i.e. inner diameter. Horizontal tube = 0.01 m, i.e. inner diameter. Thin transparent plastic foil = 0.01 m	Daily energy efficiency of the still. The latent heat of vaporization. Temperature	Enhanced fresh water productivity is obtained with respect to conventional solar still in which sea water evaporation and water vapour condensation occur in one confined space.	Used for costal area. Easy to manufacture. Efficiency is higher than simple still. Fibrous material used. Due to tube contamination is much less.	Capital cost is high. Very sensitive apparatus. Due to fibrous material cost increases.

Table 2: Comparison of different types of solar still (Kaushal & Varun, 2010)

2.3 VARIOUS MODIFICATION OF SOLAR STILL

Due to low performance of solar still, various modification has been made to improve its productivity. The modification of solar still design is made according to the factors that are affecting the productivity which are solar intensity, wind velocity, ambient temperature, and absorber plate area, temperature of inlet water, glass angle and depth of water. According to Safwat Nafey et al. (2000) solar intensity, wind velocity, ambient temperature cannot be controlled as they are metrological parameters whereas the other parameters can be varied. Velmurugan and Srithar (2011) have carried out an extensive review on modifications and performance improvement in the solar still.

The productivity of solar still increases with the free surface area of the water. Bassam et al. (2003) used sponges to increase the free surface area of the water in the basin. The experiment was carried out with various sizes of sponge cubes, sponge to basin water volume ratio and water depth. The optimal combination was sponge cubes with 6cm sides, 20% sponge to basin volume ratio and 7 cm basin water depth. It was found that the increase in distillate production of the still range from 18% to 273% compared to identical still without sponge cubes under the same condition. Figure 8 shows the schematic diagram of solar still with sponges.

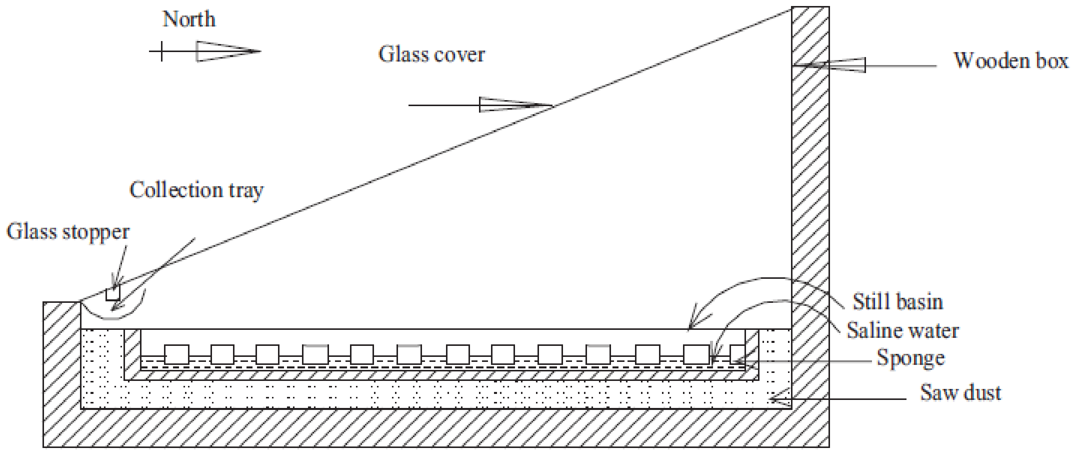


Figure 8: Simple solar still with sponge cubes (Velmurugan & Srithar, 2011)

Other than that, the yield of solar still also depends on the water-glass temperature difference. The temperature difference between water and glass act as driving force of distillation process. To improve the temperature difference, regenerative solar still, solar still with double glasses and triple –basin solar still was used. The experiment done by Yousef et al. (2004) shows that regenerative solar still can increase 20% of the solar still productivity compared to the conventional still.

According to Abdullah (2013), depth of water in solar still inversely affects the productivity of the solar still but maintaining minimum depth in solar still is a big challenge. For maintaining minimum depth,wicks, plastic water purifier and stepped solar still was used. Kabeelat et al. (2012) found that maximum productivity of 30.4% higher than conventional still is achieved at a tray depth 5mm. Figure 9 shows the stepped solar still.

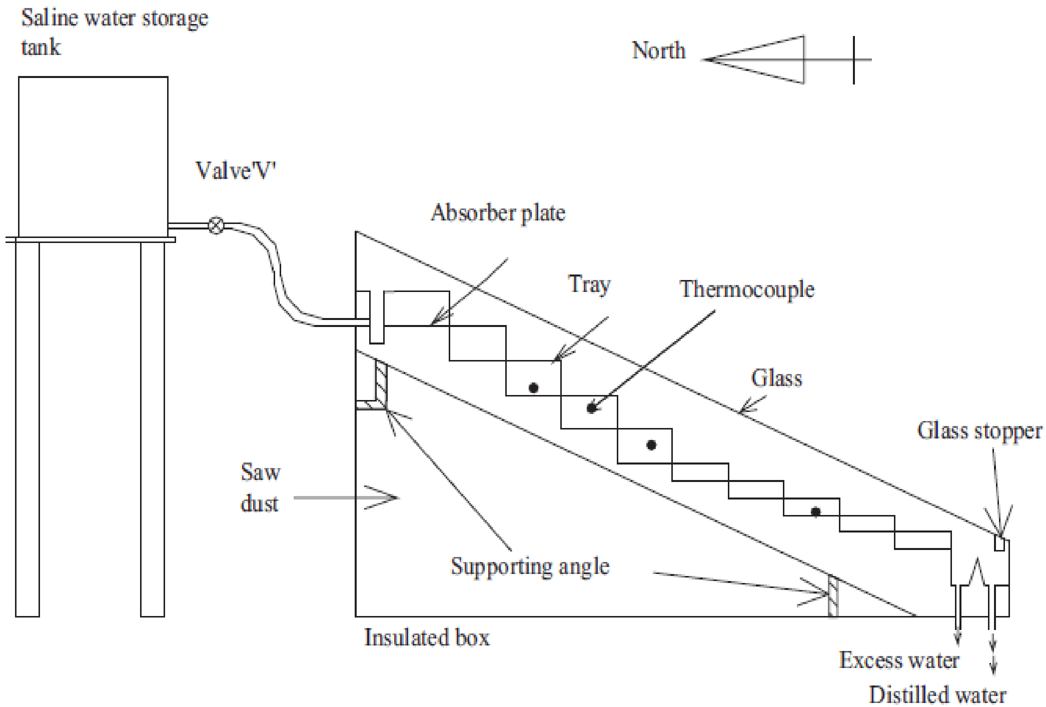


Figure 9: Stepped solar still (Velmurugan and Srithar, 2011)

Singh et al. (2013) studied the thermal analysis of a solar still integrated with evacuated tube collector in natural mode. The system consists of a solar still and water in the tube evacuated tube collector. The single slope solar still is mounted on iron stand. The still consists of an air tight basin with the basin liner painted black to increase the absorption. Transparent glass with thickness of 0.004m and inclination at an angle 45̊ from horizontal was used. Evacuated tubes of 1.4 m long and absorber diameter of 0.004 m are mounted over a diffuse reflector with center line spacing 0.07 m. The tubes are filled with water and blackened at its outside surface. The hot water will rises up to the solar still due to low density whereas the cold water takes its place due to gravity and high density. Circulation flow rate inside the collector loop is influence by the instantaneous solar energy input, fluid collector and the collector configuration. The result shows that the best combination was found by integration of 10 evacuated tubes integrated with water depth of 0.03 m which produce daily yield of 3.8 kg/m^2.

On other research by Singh and Tiwari (2004) found that the annual yield of solar still was optimize when the inclination of condensing glass cover is equal to latitude of the place. The other modification is presented in Table 3 below.

Categorization		Authors	Daily solar radiation ($MJ/m^2/d$)	Ambient temperature (°C)	Wind speed (m/s)	Location (latitude)	Daily yield ($kg/m^2/d$)	Efficiency (%)
Basic type: basin solar still		Tayeb [10]	14.6	–	–	El-Minia, Egypt (28.1°N)	∼1.3	∼22
		Tiwari and Tiwari [11]	∼21.2	–	–	New Delhi, India (28.4°N)	∼1.7	∼19
		Velmurugan et al. [12]	16.2	–	0.8	Madurai, India (9.5°N)	∼1.6	∼39
Installing reflectors	A basin type solar still with internal and external reflectors	Tanaka [13,14]	14.6	9–22	–	Kurume, Japan (33.2°N)	∼4.0	–
	A tilted wick solar still with a flat plate bottom reflector		∼23.3	25 (average)	1	Kurume, Japan (33.2°N)	6.8	–
	A basin solar still combined with a curved reflector	Dev et al. [15]	∼26.0	30–48	1.5–9	Muscat, India (23.4°N)	6.3	–
Coupled with solar collectors	A solar still augmented with a flat-plate collector	Badran et al. [16]	∼23.3	18–25	–	Amman, Jordan (31.6°N)	∼2.3	22
	A double-effect active solar still coupled with a compound parabolic concentration collector	Prasad and Tiwari [17]	22.6	17–30	–	New Delhi, India (28.4°N)	∼14.4	–
	A solar still coupled with a solar collector field	Voropoulos et al. [18]	18.5	∼15 (day average) ∼11 (night average)	–	Athens, Greece (37.6°N)	∼47.7*	–
Enhancing condensation	A passive solar still with a separate condenser	Madhlop and Johnstone [19]	∼27.0	20–28	2	Glasgow, UK (55.5°N)	∼6.0	52
	A solar still coupled to an outside condenser	E1-Bahi and Inan [20]	∼22.2	15–35	–	Ankara, Turkey (39.6°N)	∼7.0	∼75
	Using copper as condenser material	Dimria et al. [21]	∼12.4	10–26	4	New Delhi, India (28.4°N)	3.6	∼26
	Double condensing chamber solar stills	Aggarwal and Tiwari [22]	∼10.3	7–18	–	New Delhi, India (28.4°N)	∼1.0	–
Increasing free surface area	A fin type solar still	Velmurugan et al. [12]	∼16.2	–	0.8	Madurai, India (9.5°N)	∼2.5	60
	A floating perforated black plate	Nafey et al. [23]	–	–	–	Suez, Egypt (30°N)	3.2	–
	A floating cum tilted-wick type solar still	Janarthanan et al. [24]	∼22.3	26–36	–	Coimbatore India (11°N)	∼1.5	–
	A weir-type inclined solar still	Sadineni et al. [25]	∼26.0	25–34	1.5–4	Las Vegas, USA (36.1°N)	5.5	–
	A weir-type cascade solar still	Tabrizi et al. [26]	∼26.4	25–33	0–9	Zahedan, Iran (29.5°N)	5.1	∼46
	A solar still with energy storage medium – jute cloth	Sakthive et al. [27]	∼20.2	11–22	–	Fukuoka, Japan (33.2°N)	∼4.0	∼52
Recovering vapor latent heat	A vertical multiple-effect diffusion solar still	Tanaka [28]	∼15.0	30–35	–	Coimbatore, India (11°N)	13.3	∼156
Coupled with heat storage	An integrated basin solar still with a sandy heat reservoir	Tabrizi and Sharak [29]	∼23.4	–	0–4	Zahedan, Iran (29.5°N)	∼3.0	–
	A solar still using phase change material as storage medium	El-Sebaii et al. [30,31]	∼24.8	30–35	–	Jeddah, Saudi Arabia (22.8°N)	∼9.0	∼85
	A single-basin solar still integrated with a shallow solar pond		∼27.1	18–30	2	Tanta, Egypt (30.5°N)	∼6.6	∼57
	A single basin double slope solar still with energy storing materials	Murugavel et al. [32]	∼21.6	20–27	0.2–1.2	Tamil Nadu, India (11.2°N)	∼2.1	–

Note: this value * is the daily productivity of the solar still coupled with a solar collector field when the cumulative solar radiation is 18.5 $MJ/m^2/d$. The solar field consists of 24 flat-plate solar collectors, but the total area is not reported.

Table 3: Categorization and modification of solar still (Xiao et.al, 2013)

2.4 FACTORS AFFECTING EFFICIENCY OF SOLAR STILL

H. Aghaei Zoori et al. (2013) has determined that various parameters affect the production rate of solar still. The parameters are inlet brine flow rates, water thickness over the absorber plate, solar radiation intensity, ambient temperature and brine temperature. To maintain high water temperature, a high incoming radiation must be absorbed by brine water in the basin as heat. Hence, low absorption glazing and a good radiation absorbing surface are required. Heat loss from the floor and walls must kept low by adding insulation. Shallow depth should be maintained to optimize the heat absorption.

Besides that, the production rate also will be affected by the temperature difference between feed water and condensing surface. Large temperature difference will produce more water droplets. This condition can be achieved if the condensing surface absorbs little or none of the incoming radiation. Some problems with solar stills which would reduce their efficiency are:

1. Poor fitting and joints, which increase colder air flow from outside into the still.
2. Cracking, breakage or scratches on glass, which reduce solar transmission or let in air.
3. Growth of algae and deposition of dust, bird droppings, etc. To avoid the stills need to be cleaned regularly every few days.
4. The saline water in the still is too deep, or dries out.

According to H.N Panchal et al.(2009) certain instrument are used for evaluation of solar still efficiency. Pyrometer is used to measure the global radiation of sun and anemometer for measuring wind speed. Bottles are used to measure the condensate water. The efficiency of solar still is measured in terms of distilled water output and by comparing the results with previous research result.

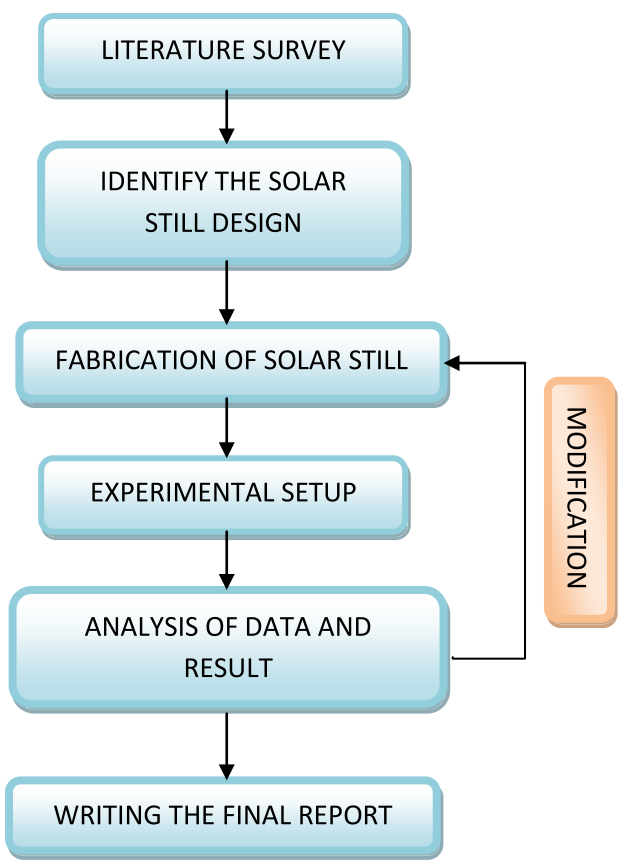
CHAPTER 3

METHODOLOGY

3.1 BASIC CONCEPT OF SOLAR STILL

Desalination is one of the earliest forms of water treatment. As early as in fourth century, Aristotle described a method to evaporate impure water and then condense it for potable use. In solar still, evaporation and condensation take place in one container.Solar radiation absorbed by black basin and heated up the water in the basin, and evaporates in the saturated condition inside the still.The water rises until they contact with the inner surface of the glass or plastic cover and condensed into pure water.The water run down along the cover bottom surface due to gravity and is collected using glass stopper.

3.2 PROJECT ACTIVITIES



3.3 EXPERIMENTAL SETUP

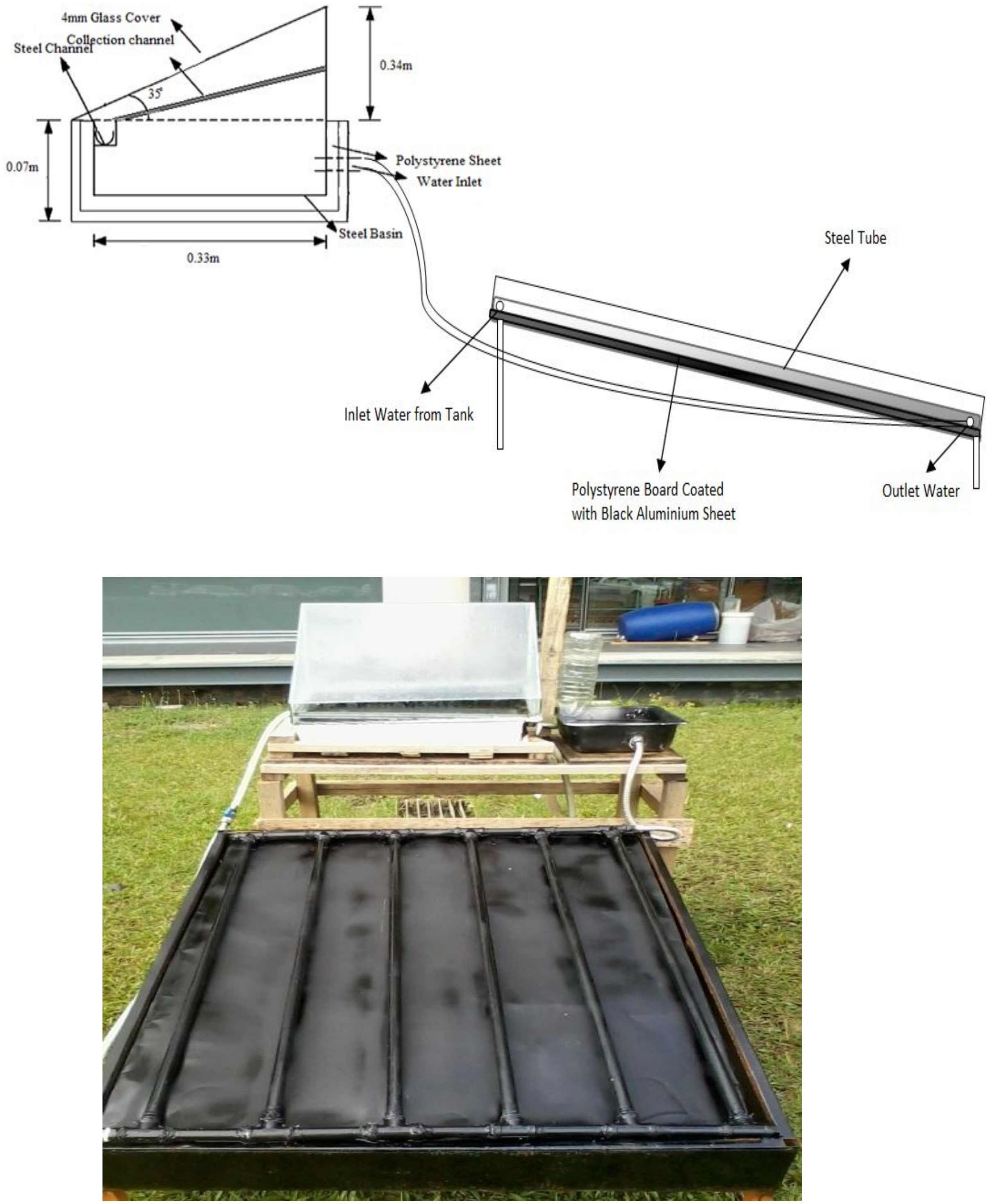


Figure 10: Solar still connected to steel tube collector

Figure 11: Single slope solar still system

Figure 12: Steel tube system (solar collector)

Basin area of the solar still is 0.1749 m^2(0.33m x 0.53m). The still was made from stainless steel with the whole basin surfaces are coated with black paint to increase absorptivity. The bottom and side wall of the basin were well insulated by polystyrene board. To collect distillate output, a trough was fixed at the end of the low side of basin. Plastic pipes were connected to the troughs to drain the fresh water to external measuring cylinder.The basin was covered with a commercial clear glass sheet inclined at approximately 35̊. The whole experiment was kept in open area. The experimental setup was provided with facilities to measure the temperatures at different points of the still (water and glass cover temperature).

The higher the temperature of water in the solar still, the higher the rate of distilled water production. The solar still was connected to steel tubes system. Figure 12 shows the steel tubes system for water input.The tube size is 0.5 inch with the length of 106cm.The tube and the bottom surfaces was painted black to increase the absorptivity. When the temperature of water in the tube increase due to sun radiation, hot water in the steel tube will rises up due to its low density whereas the cold water takes place due to gravity. The temperature of water in the tube and the solar still basin will be increase and causes the water to evaporate.Water droplets will be formed at the surface of glass cover. Then, the evaporated water flow to the water channel located around the base solar still and goes into the bottles.

The experiment was conducted from 8.00 am to 6.00 pm during the period of November and December 2013. The solar still was operated in two modes; soalr still alone and solar still connected to steel tubes system. Solar radiation, production of fresh water, water and glass temperature are monitored and measured every 2 hours.The detailed analysis is shown in Table 4. According to Abdullah (2013), the daily efficiency, η_d of the solar still is obtained by the summation of the hourly condensate production, m_{ew}, is multiplied by latent heat, h_{fg} , hence divided by daily average solar radiation $I(t)$ over the whole area A of the solar still.

Detailed analysis	
Is	Hourly solar radiation
Tw	Temperature of water in basin of solar still
Tic	Temperature of inner glass of solar still
W_{hexp}	Hourly water production of solar still
Toc	Temperature of outer glass of solar still
Ta	Ambient temperature
W_{dexp}	Daily water production of solar still

Table 4: Detailed analysis of solar still

Figure 15: Solarimeter

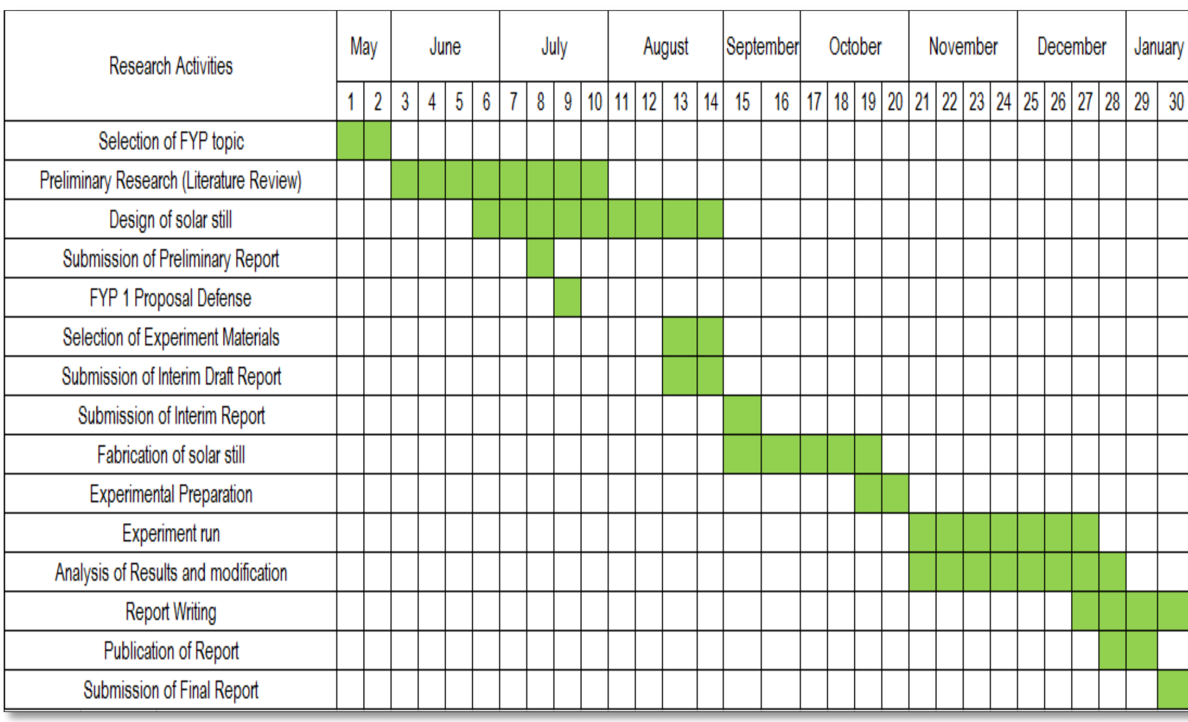
Figure 13: Data collection

Figure 14: Production measurement

3.4 EQUIPMENT AND MATERIALS

- Steel basin
- 4mm thick clear glass
- Aluminium sheet
- 6 Stainless steel tubes and connectors
- Measuring cylinder
- Flexible pipe
- Solarimeter
- Thermometer
- Polystyrene as insulators
- Aluminium plate
- Black paint spray

3.5 GANTT CHART



CHAPTER 4

RESULT AND DISCUSSION

Result of the monitoring of various parameter including temperatures versus time, daily quantity of the distillate, solar radiation and efficiency of solar still are presented in Table 4. The day of 25th November 2013 was sunny, windy with a clear sky and a maximal ambient temperature is 26℃. Figure 17 shows the graph of various temperature and solar intensity versus local time. The water temperature reaches highest reading between 12.00 to 2.00 p.m. The maximum water temperature was around 60˚C. From the graph, it is found that the distillate production increases when the difference between water and glass temperature, ΔT increases.The highest value of ΔT recorded is 9˚.

Time	Is (W/m2)	w dexp (ml)	cummulative production (ml)	Temperature (˚C)			
				Tic	Toc	Ta	Tw
8:00 AM	196	0	0.00	29	30	22	28
10:00 AM	227	2.86	2.86	34	28	24	34
12:00 AM	670	714.69	717.55	49	29	26	55
2:00 PM	568	697.54	1415.09	52	27	25	60
4:00 PM	483	583.19	1998.99	37	25	24	43
6:00 PM	226	263.01	2262	29	32	23	33
	395						

Table 2: Result tabulated on 25th November 2013

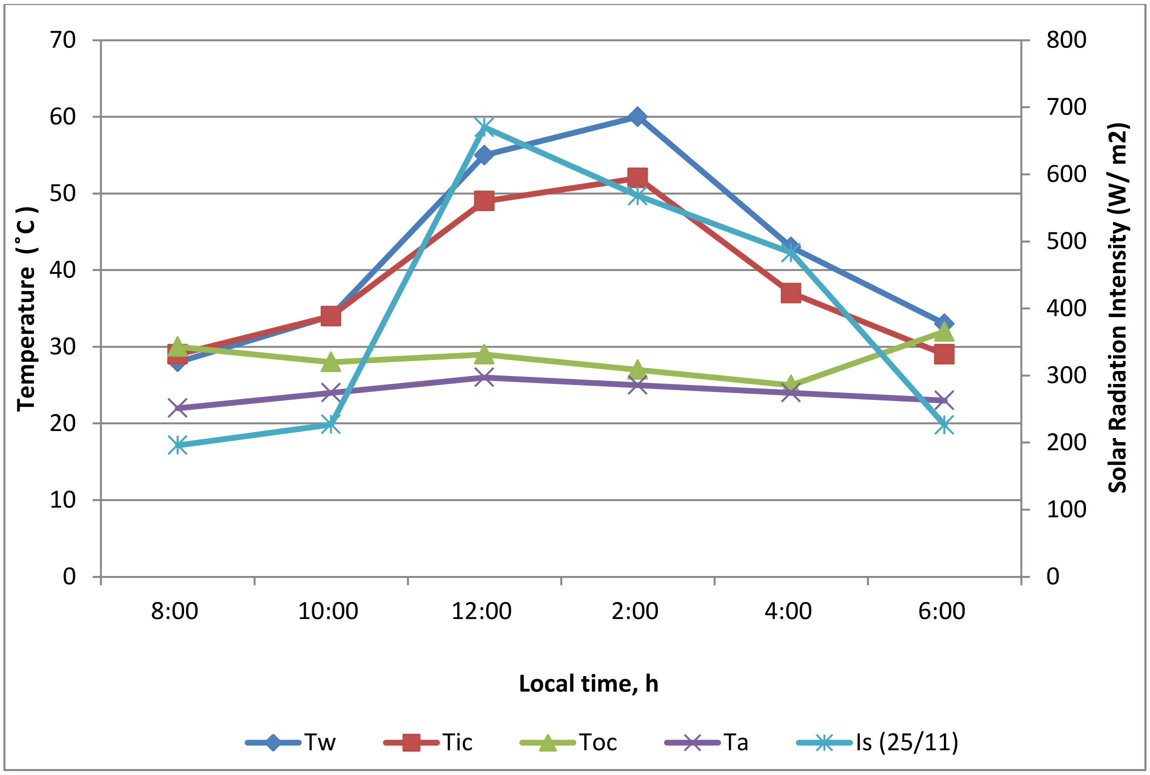


Figure 16: Variation of temperature and solar radiation on the 25th November 2013

Figure 18shows the production of solar still on 25th November 2013.The graph shows that the production of freshwater increases as the solar intensity increases. Distilled water production increase gradually until it reaches maximum value at 12.00 pm. The maximum hourly production is 714 ml/m^2/h with solar radiation intensity 670 W/m^2. Average solar radiation intensity of the day is 395 W/m^2 approximately 14.19 MJ/m^2. Cumulative production is 2.26 kg/m^2/d. According to World Health Organization (WHO), a person needs 2-3 Liter per day for survival. It shows the application of solar still can support the daily drinking water need for a person.

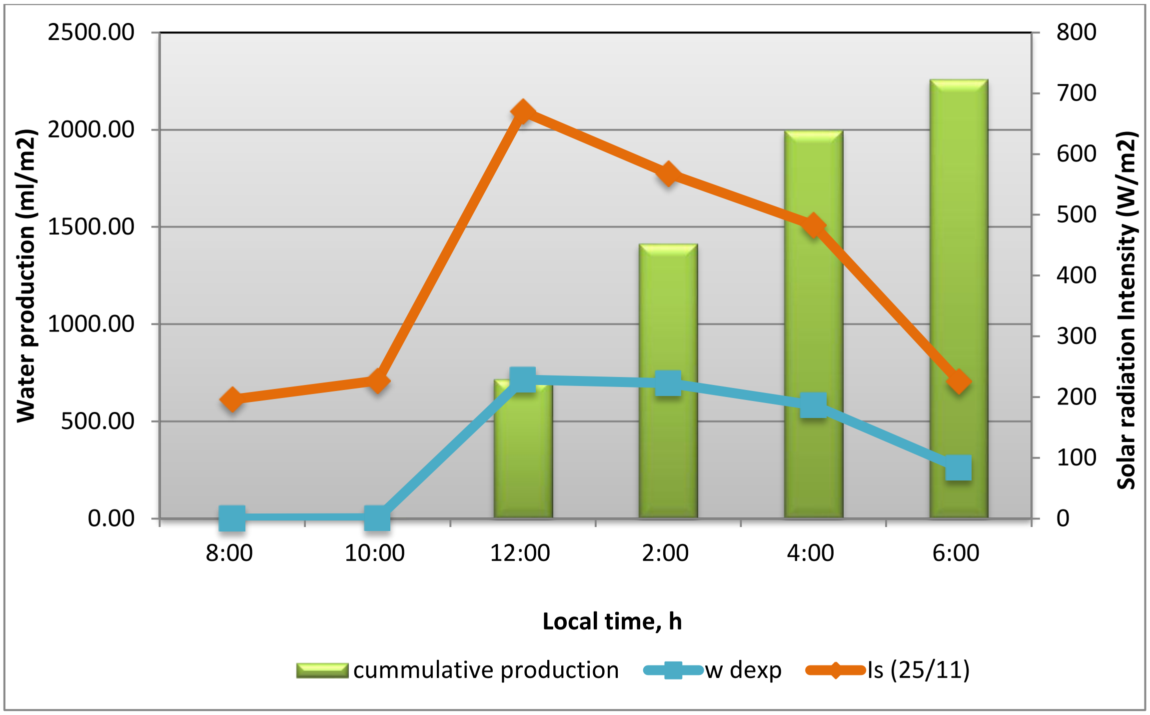


Figure 17: Cumulative and daily production of solar still on 25th November 2013

Malaysia is a tropical climate country which has a monsoon season and sunny season.The data in this study was collected during the month of November and December 2013. The temperature and solar radiation is varies significantlysince November and December are under monsoon season. The range of productivity and solar radiation intensity is shown in Figure 19 and Figure 20. The average daily solar radiation varies from 395 W/m^2 to 217 W/m^2 whereas the daily productivity ranges from 1.88 kg/m^2/d to 2.26 kg/m^2/d. The figures shows during peak hours the solar radiation is varied from 445 W/m^2 and 670 W/m^2 with productivity varied from 97.2 ml to 714 ml per hour.

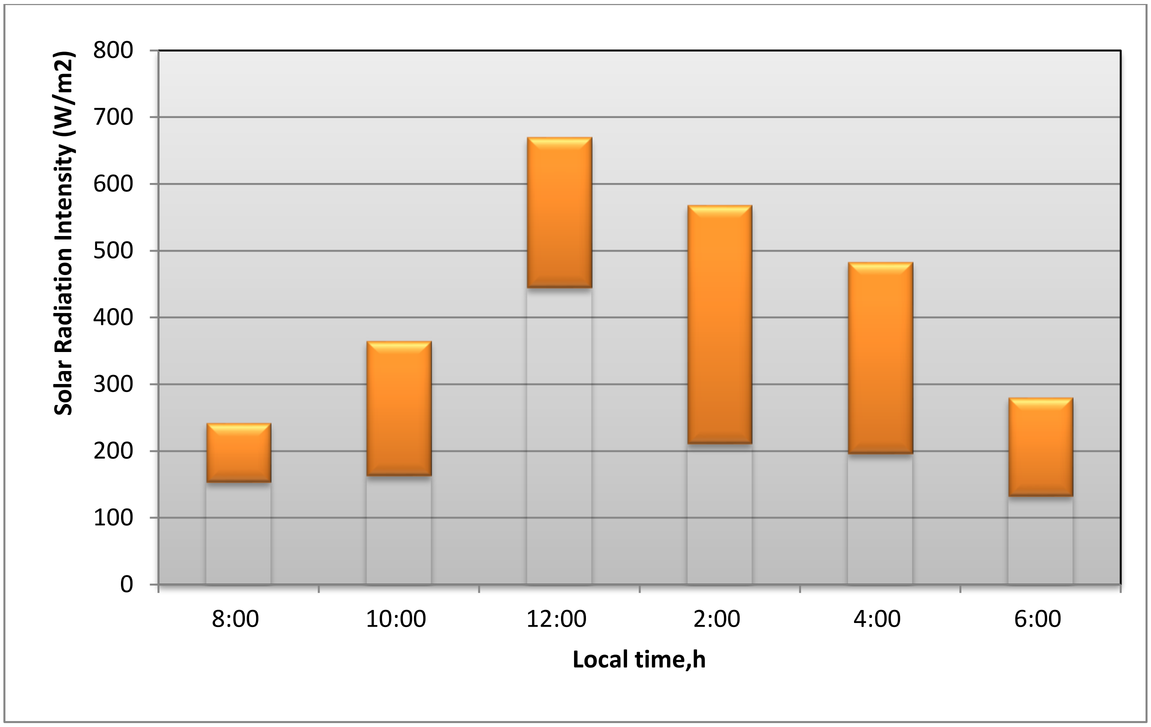


Figure 18: Maximum and minimum solar radiation during sunny days

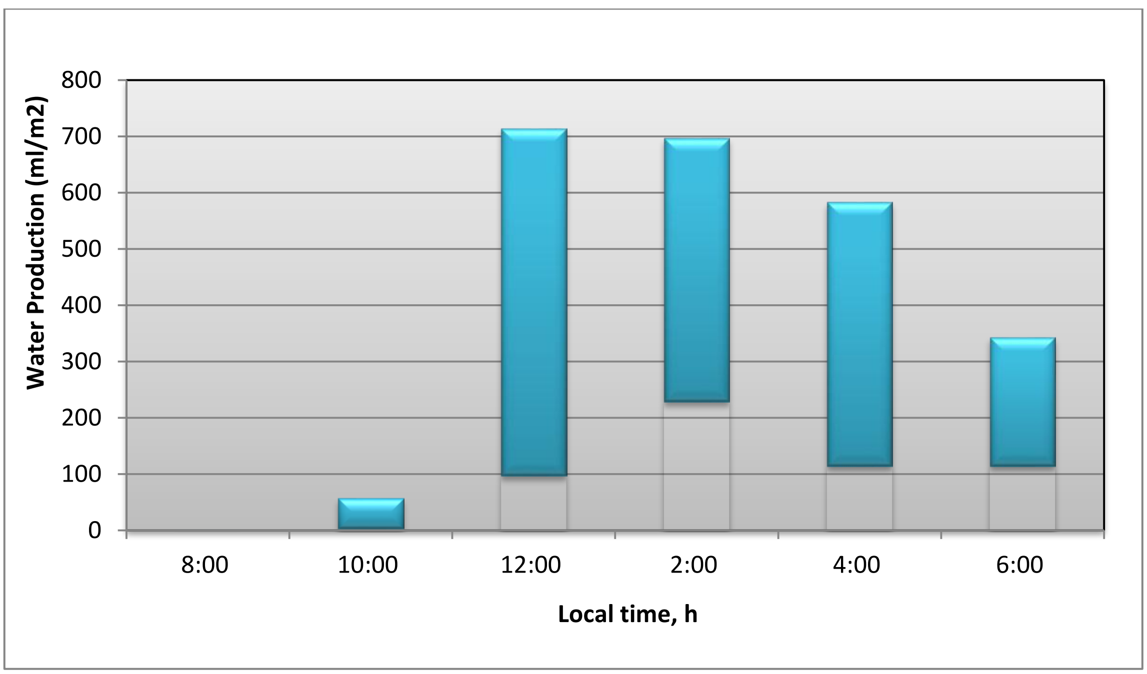


Figure 19: Maximum and minimum water production during sunny days

The efficiency, $\boldsymbol{\eta_d}$ of solar still is obtained by summation of the condensate production, $\mathbf{m_{ew}}$ multiplied by the latent heat H_{fg}, hence the result is divided by the daily average solar radiation ***I(t)*** over the whole solar collection area(Z.M. Omara et.al,2013).The average efficiency of basic solar still is between 19% to 39 % (Xiao et.al, 2013).The efficiency obtained in this study is37.7%.This indicates that the solar still in this study can be categorized as an efficient solar still. The calculation is as follow:

$$\boldsymbol{\eta_d = \frac{\sum, m_{ew} \times h_{fg}}{\sum A \times I(t)}}$$

Where, m_{ew} = Mass of water production

H_{fg} = Latent heat of vaporization

I(t) = Daily solar radiation

A = Whole area of solar collector

Calculation of solar still efficiency:

$$\boldsymbol{\eta_d = \frac{2.262\ kg/m^2 \times 2372000\ J/kg}{395 W/m^2 \times 3600 s \times 10}}$$

$\boldsymbol{\eta_d}$ **= 0.3773 = 37.73 %**

The purpose of connecting solar still with steel tubes system is to increase the productivity by increasing the inlet water temperature. Figure 21 shows the hourly and daily water production of solar still with and without steel tube collector. The productivity of both conditions was compared and both have similar average solar radiation intensity.The result shows that the productivity of solar still without steel tubes system is higher compared to the productivity after connecting solar still with steel tubes system. The efficiency of solar still reduces from 37.73% to 18.04%. This indicates the steel tube collector is not working well because theoretically the efficiency of solar still is supposedly increase when attach to steel tube collector.

Time	Is (W/m2)	w dexp (ml)	cummulative production (ml)	Temperature (˚C)			
				Tic	Toc	Ta	Tw
8:00 AM	245	28.6	28.6	25	28	20	27
10:00 AM	385	174.4	203.0	37	35	24	40
12:00 AM	556	257.3	460.3	55	40	27	52
2:00 PM	529	344.2	804.5	57	37	24	55
4:00 PM	284	640.4	1444.9	35	27	22	34
6:00 PM	87	228.7	1673.6	27	20	21	25
	347.6						

Table 3: Result tabulated on 24th November 2013

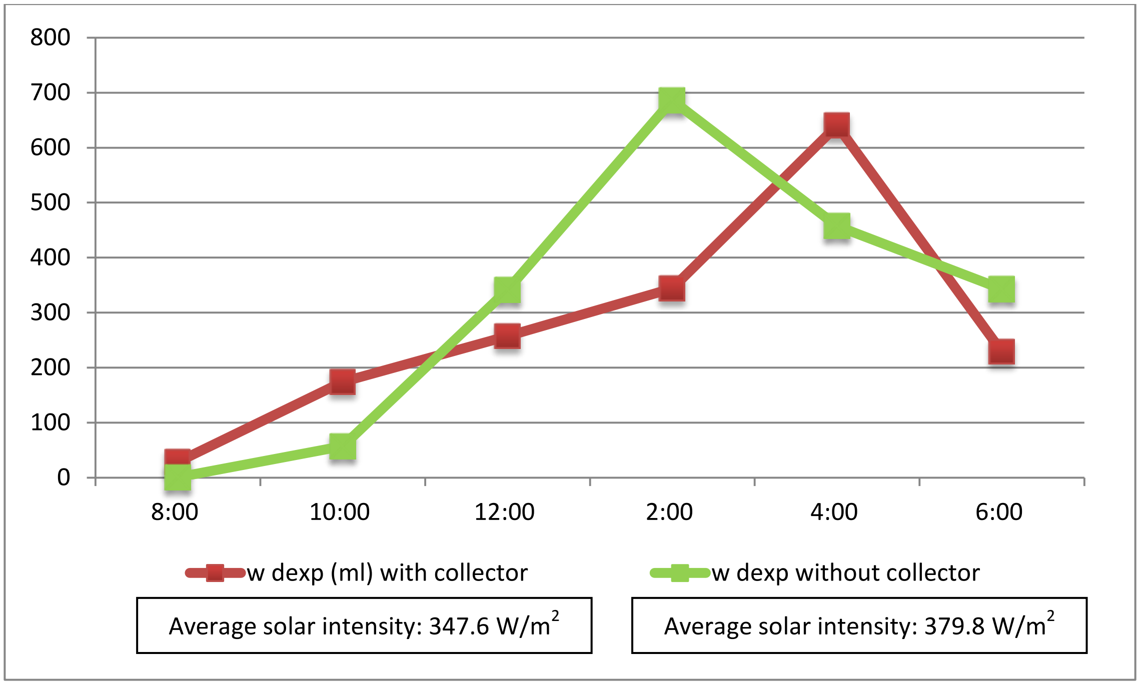


Figure 21: Productivity of solar still with and without steel tube collector

Calculation of solar still efficiency:

$$\eta_d = \frac{1.673\ kg/m^2\ \times 2372000\ J/kg}{347.6W/m^2 \times\ 3600s\ \times 10 \times (0.1757\ m^2)}$$

η_d =0.1804 = 18.04 %

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Desalination using solar still is a good alternative for producing drinking water. With a proper combination and modification of the existing solar still, the efficiency and yield will increase. The daily production rate of solar still varies from 1.88kg/m^2/d to 2.26kg/m^2/d under monsoon season. The productivity is expected to increase during dry season due to high solar intensity.In the future, every house can produce its own drinking water by installing the solar still system in the roof. The solar still can support the drinking water need for the whole family by increasing the basin area and operation hours. Solar still system in this study is capable of producing water 2.26 Kg/m^2/d during sunny days using solar energy only and thus it is low in maintenance. The efficiency of basic solar still alone is 37.73%. The production of using tube collector above the roof requires improvement on hydraulic and connectivity of the tube particularly the connection between tubes and solar still so as to achieve higher water temperature inside the solar still. This part of the experiment is very challenging to be perfected.

5.2 RECOMMENDATION

The main concern in this study is the design of solar still system. During the experimental studies, a few errors in design and data collectionwere identified. The errors and modification was tabulated below:

Error	Modification
Water leakage and pressure drop due to poor fittings between steel tubes.	The thread of steel tubes at both ends should be in one direction to ensure the connection between tubes is tight and free from leakage. The connection should be welded and sealed.
High water depth in the basin due to high water inlet point.	The water inlet point of solar still basin should be at the bottom to ensure water depth in the basin is always shallow. The shallow the depth of water, the higher rate of distilled water production.
Circulation of water in the steel tubes does not occur.	Water in the tubes should circulate before going to the basin. The circulation will ensure the water is heated before evaporation occurs. The basin should have an outlet point to allow circulation of water. Optimum inclination of steel tubes system and pressure needed should be calculated before designing the steel tube system.
Low accuracy oftemperature measurement	Thermocouple should be used in measuring the temperature since it is more sensitive and accurate compared to thermometer.
The effect of wind velocity is neglected	The wind velocity should be monitored because wind velocity will affects the rate of productivity.

Since the distilled water produced in this study is used for drinking, one of the issues that people are concerns about are the minerals content in the water. Distilled water is the water that has undergone a process that strips away any or all impurities. However, the process also takes away the minerals as well.To overcome this problem, mineralization process has to be considered as one of the process in water desalination. A volcanic rock called magnetic ceramic has been used in reverse osmosis (RO) to provide antioxidant benefits and trace minerals to distilled water .The same method canbe applied into the solar still system.

REFERENCES

Al-Hayeka, I., & Badran O.O. (2004).The effect of using different designs of solar stills on water distillation. Desalination 169 (2), 121-7.

Abdullah, A.S. (2013). Improving the performance of stepped solar still. Desalination 319, 60-65.

Asadi, Z., Suja, F., Ruslan, M.H., & Abd Jalil, N.(2013). The application of a solar still in domestic and industrial wastewater treatment. Solar energy, 93, 63-71.

Arunkumar, T., Jayaprakash, R., Ahsan, A.,Denkenberger, D., & Okundamiya, M.S.(2013). Effect of water and air flow on concentric tubular solar water desalting system. Applied energy, 103 , 109-115.

Borhan,H. ,& Ahmed,E.M. (2012). Green Environment: Assessment of Income and Water Pollution in Malaysia. Procedia – Social and Behavioral Sciences, 42,166-174.

Bassam, A.K., Hijileh, A., & Rababa'h, H.M. (2008). Experimental study of solar still with sponge cubes in basin. Energy conversion and management ,44, 1411-8.

Gadgil, A. (1998), Drinking water in development countries, *Annu. Rev. Energy Environment*, *23,253-286.*

Jamaludin, A.F.B. (2009), Energy mix and alternative energy for sustainable development in Malaysia, University Putra Malaysia.

Kumar,S. and Tiwari,A. (2008). An experimental study of hybrid photovoltaic (PV/T) – active solar still. Int. J. Energy Res, 32, 847-858.

Karagiannis.I.C., & Saldatos,P.G. (2008). Water desalination cost literature: review and assessment. Desalination, 223, 448-456.

Khawaji, A.D., Kutubkhanah, I.K., & Wie, J.M. (2008).Advances in seawater desalination technologies. Desalination, 221, 47-69.

Kaushal,A. and Varun. (2010). Solar stills:A review. Renewable and sustainable energy reviews, 14, 446-453.

Kabeel, A.E. ,& El-Agouz, S.A.(2011).Review of researches and developments on solar stills, Desalination ,276, 1-12.

Li,C.,Goswami, Y., & Stefanakos, E. (2013), Solar assisted sea water desalination : A review. Renewable and sustainable energy reviews, 19, 136-163.

Muzathik, A.M., Wan Nik, W.B., Samo, K.B., Ibrahim, M.Z., 2010.Reference solar radiation year and some climatology aspects of East Coast of West Malaysia. American Journal of Engineering andApplied Sciences 3, 293–299.

Murugavel, K.K.,Anburaj, P., Hanson, R.S, & Elango, T.(2013). Progresses in inclined type solar stills. Renewable and sustainable energy reviews, 20, 364-377.

Mekhilef , S., Safari, A., Mustaffa,W.E.S., Saidur, R.,Omar, R., & Younis,M.A.A.(2012). Solar energy in Malaysia: Current state and prospects. Renewable and sustainable energy reviews, 16, 386-396.

Panchal,H.N,. Bhavsinh,Z. &,Dodia, K.(2013). Present status of solar still: A critical review.International Journal of Research Review in Engineering Science and Technology (ISSN 2278-6648).

Qiblawey,H.M., & Banat,F. (2008). Solar thermal desalination technologies. Desalination, 220,633-644.

Rodriguez, L.G.and Camacho,C.G. (2001). Perspective of solar assisted seawater distillation, *Desalination 136, 213-218.*

Singh, R. (2008). Worldwide water crisis.Journal of membrane science, 313, 353-354.

Rajaseenivasan,T., & Murugavel, K.K. (2013), Theoretical and experimental investigation on double basin double slope solar still. Desalination ,319 ,25-32.

Rahbar, N., & Esfahani, J.A. (2013), Productivity estimation of a single slope solar still: theoretical and numerical analysis. Energy, 49 ,289-297.

Reddy , K.S, Ravi Kumar, K, S.O'Donovan , T.,& Mallick, T.K. (2012).Performance analysis of an evacuated multi-stage solar water desalination system. Desalination ,288, 80-92.

Rajaseenavesan , T, Elango, T,& Murugavel, K.K, (2013).Comparative study of double basin and single basin solar stills. Desalination, 309, 27-31.

Saidur, R., Elcevvadi, E.T, Mekhilef, S., Safari, A., & Mohammed, H.A.(2011). An overview of different distillation methods for small scale application. Renewable and sustainable energy reviews ,15, 4756- 4764.

Safwat, N.A., Abdelkader, M., Abdelmotalip, A.,& Mabrouk, A.A. (2000), Solar still productivity . Energy conversion and management ,42, 1797- 809.

Sampathkumar, K.,& Senthikumar,P. (2012).Utilization of solar waterheater in a single basin solar still-An experimental study.*Desalination, 297, 8-19.*

Singh, R.V., Kumar,S. Hasan, M.M. Khan, M.E.,& Tiwari,G.N.(2013). Performance of a solar integrated with evacuated tube collector in natural mode.*Desalination, 318*,*25-33.*

Sharma, N., & Diaz. G. (2011), Performance of a novel evacuated-tube solar collector based on mini channels.*Sol.Energy, 85, 881-890.*

Velmurugan,V. ,& Srithar, K.(2011). Performance analysis of solar stills based on various factors affecting the productivity- A review. Renewable and sustainable energy reviews 15,1294-1304.

Wan Nik, W.B, Ibrahim, M.Z, Samo,K.B., & Muzathik, A.M. (2012), Monthly mean hourly global solar radiation estimation. Solar Energy ,86 , 379-387.

World Health Organization. (2006). Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade. Retrieved from http://www.who.int/water_sanitation_health/monitoring/jmpfinal.pdf

Xiao, G., Wang, X., Ni, M., Wang, F., Zhu, W., Luo, Z.,& Cen, K.(2013). A review on solar still for brine desalination.*Applied Energy, 103, 642-652.*

Yousef H Zurigat, Mousa K Abu Arabi. Modelling and performance analysis of a regenerative solar desalination unit. Applied Thermal Engineering 2004;24:1061–72.

Zoori, H.A,.Tabrizi, F.F., Sarhaddi, F. & Heshmatnezhad. Comparison between energy and exergy efficiencies in a weir type cascade solar still. Desalination 2013: 325: 113-121.