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THANEISSHA A/P MARIMUTHU

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Engineering Technology in Electrical

Faculty of Engineering Technology
UNIVERSITI MALAYSIA PAHANG

JANUARY 2017

STATEMENT OF AWARD FOR DEGREE

1. Bachelor of Engineering Technology

Thesis submitted in fulfilmentof the requirements for the award of the degree of Bachelor of Engineering Technology in Energy and Environment.

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ABSTRACT

Water which is crucial to living things on earth is the constituent of the environment. Our earth is rich with ocean which is also known as seawater. Yet, water crisis has become a serious problem that humanity facing nowadays especially in developing countries. Worldwide population expansion and industrial development have led to an enormous demand for fresh water supply. Therefore, we developed a solar desalination plant which can be the solution for this problem. Solar desalination refers to any process that eliminates some amount of salt and other minerals from saline water using sunlight. The objectives of this study are to design a low cost point focus parabolic solar still (PPSS) made up of non-fragile materials and to minimize the heat loss in this prototype by using heat exchanger. Our PPSS also entails of solar tracking system to capture the maximum amount of sunlight. The freshwater productivity was measured along the evaluation of the impacts of environment and operational parameters which includes solar irradiation, salinity and conductivity in December at Gambang, Pahang. The maximum productivity obtained is 170ml of fresh water where the average solar intensity for that day was 735.69W/m^2. Our productivity is considered lower than the existing PPSS due to certain limitations such as weather condition, the size of the parabolic dish and absorber. From the results, it is found that the productivity of fresh water increases as the solar irradiation increases because the rate of evaporation depends on solar intensity and the weather. Finally, the sample has been analyzed before and after the desalination process to compare the salinity and conductivity. Through this process, PPSS is proven to be an effective method in reducing the salinity and conductivity in seawater. The freshwater obtained can be used for domestic purposes.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

°C	Degree Celsius
J	Joule
K	Kelvin
kg	Kilogram
kPA	KiloPascal
kWh	Kilowatt-Hour
L	Liter
L/h	Liter per hour
m	Meter
ml	Milliliter
mL/d	Milliliter per day
mm	Millimeter
m^2	Meter Square
m^3	Meter Cubic
m^3/d	Meter Cubic per day
Min	Minute
ppm	Parts per minute
W	Watt

LIST OF ABBREVIATION

PPSS	Point-focus parabolic solar still
AlBr	Aluminum Brass
CO_2	Carbon Dioxide
ED	Electrodialysis
LDR	Light Dependent Resistor
MD	Membrane Distillation
MSD	Multi-Effect Distillation
MSF	Multi-Stage Flash
O & M	Operating and Maintenance
OSW	Office of Saline Water
PV–RO	Photovoltaic Driven Reverse Osmosis
RO	Reverse Osmosis
TBT	Top Brine Temperature
VC	Vapor Compression

CHAPTER 1

INTRODUCTION TO SOLAR DESALINATION

1.1 BACKGROUND OF STUDY

Living things on Earth depends on the continuous flow of water through hydrologic cycle which exists in the form of water vapor, liquid water, and ice. In fact, the Earth is often compared to a majestic blue marble because of the presence of water on the Earth's surface. This is because 71% of the Earth's surface is surrounded by water and the other 29% consists of continents and islands. Precisely, 96.5% of the Earth's water consist salty water which can be found in ocean meanwhile the remaining 3.5% is freshwater from lakes and frozen water locked up in glaciers and the polar ice caps (Williams M., 2014). It is estimated that the total volume of water on Earth is approximately 1.4 billion km^3 whereas the volume of freshwater resources is around 35 million km^3 which is equivalent to 2.5% of the total volume (Gleick P.H., 1993). Figure 1.1 shows the distribution of water on the Earth's surface.

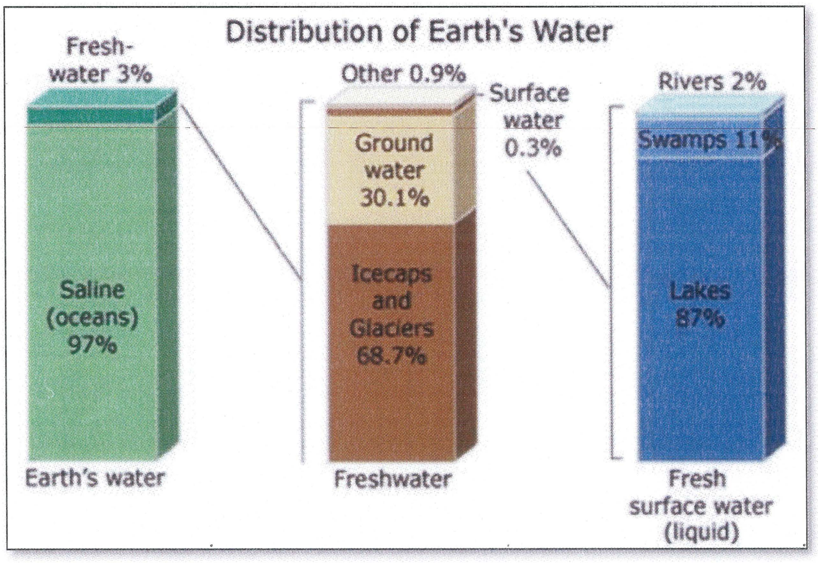


Figure 1.1: Distribution of water in Earth's surface (U.S. Geological Survey, n.d)

Water is a basic need for life where it can be used for many purposes. Therefore, provision of water has become a serious issue nowadays. It is undeniable that about 1.1 billion people in this world are facing water scarcity issue. Especially the developing countries find it difficult to get sufficient water for agriculture and economic developments. The high rate of population growth and climate change phenomena results in higher demand of freshwater supply. On top of that, factors such as industrialization and urbanization also affect the freshwater demand. Anthropogenic activities also contribute significantly to freshwater demand. This is due to pollution created by human which comes from many sources including run-off, pesticides and fertilizers that wash away from farms, sewage system, and industrial waste.

In order to overcome this problem, desalination method is introduced whereby saline water from ocean is converted to freshwater to provide enough potable water. Advancement in technologies has come up with many techniques of desalination. Precisely, solar energy technologies are among other renewable energy sources that are emerging as a potential sustainable energy source for desalination. Solar energy has been given priority because it is renewable energy which is naturally replenished and will not get depleted due to continuous use. Solar energy is commonly and widely implemented because it is free and environmental friendly. There are many use of solar energy. For instance, solar energy can be used to produce electricity, water heating system and solar cooling including solar desalination.

Solar desalination is similar to desalination where the saline water is converted to freshwater using solar or sunlight in this case. Solar desalination may be a promising technology in future because it mainly consumes two sources (saline water and sunlight) which can be found vastly in Earth. Countries that received sunlight either for long hours or throughout year including Malaysia are encouraged to build solar desalination plant because the maximum amount of sunlight can be harvested. In fact, solar irradiance is an important factor that needs to be considered before installing solar desalination to measure the capacity of collecting sunlight. Solar irradiation simply means the radiation from the sun whereas solar insolation is a measure of incident solar irradiation energy received on a given surface area over a certain period of time. Figure 1.2 shows the world solar insolation map. Based on the Figure 1.2 it is found that most of the countries in the world that have higher capacities to use solar applications.

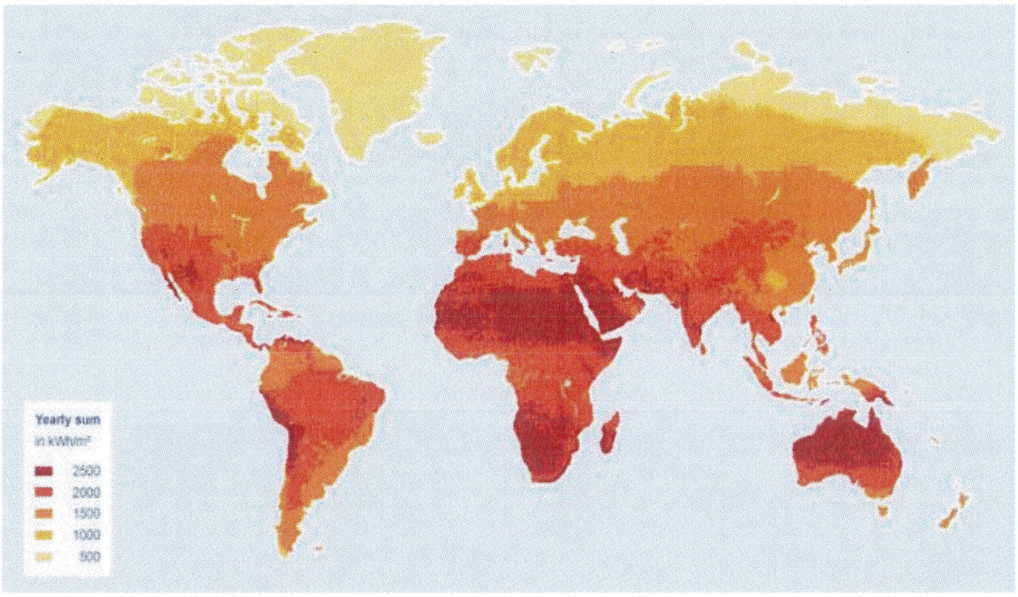


Figure 1.2: Solar insolation in world map (Maehlum M.A., 2014)

Over the years, researches have proposed techniques of solar desalination and methods to improve the efficiency at the same time cost-effective. There are many types solar desalination plants located all around the world which are used either for small or large scale depending on the purpose. The two main of solar desalination process developed are thermal distillation process and membrane process. The process of thermal solar desalination is very simple. In fact, this process also occurs naturally where the solar radiation falls on the surface of the sea is absorbed as heat and vaporizes the water. The vapour from seawater rises above the surface and the direction is moved by winds. Then, this vapour cools down to its dew point where condensation takes place and subsequently fresh water precipitates as rain. The thermal distillation systems available nowadays are small-scale replicate of this natural process. There are many types of solar stills which follow the principle of thermal distillation such as basin type solar still, spherical solar still, single-slope solar still, double-slope solar still and etc. In addition, use of concentrated solar thermal-desalination plants provides an exciting opportunity to build in future for large scale and more efficient desalination plants.

Thus, the design of energy-efficient and cost effective solar desalination system is very important in order to produce maximum output. Besides that, important aspects like the durability of the material and purity of water should be taken into account. This is because seawater has high salinity content which is not easy to remove. Along the way, there are some disadvantages of solar desalination process. Sunlight is intermittent and therefore yield produced will be affected during raining season. In addition, static solar collector does not have the capacity to harvest maximum sunlight. So, there is a need to be inclined towards the sun's orientation to get maximum solar energy or by installing solar tracker. Moreover, the installation cost and maintenance cost of solar desalination is high. Therefore, in this thesis, a prototype known as point focus parabolic solar still was designed to improve the efficiency and fulfill the need of people which is to ensure continuous water supply. Furthermore, this project intended to supply fresh water which undergoes solar desalination as well as concerning other factors such as the minimization of heat loss, durability and cost.

1.2 PROBLEM STATEMENT

The supplement of fresh water is becoming an essential matter in many countries nowadays especially in arid areas, it is difficult to obtain potable water. It is undeniable that water is a basic need of our life. The importance of providing potable water can hardly be overstressed. Water is abundantly available on Earth covering three quarter of the Earth's surface, where the source is mostly form oceans. Thus, desalination is the suitable process to make use the ocean water by converting it to potable water. However, the main drawback of ocean is their high salinity content.

Desalination simply means to remove salt from seawater or saline water. Desalination is crucial in real life as we consume fresh water daily for domestic purpose, drinking, irrigation and etc. Basically, there are many types of desalination process. Since the process to separate the salt from water is not easy, solar desalination method is introduced to resolve the problem. On the other hand, energy is as important as water for the growth of good standards of life because it is required for all the human activities. In this case, solar desalination is introduced as it is free and renewable energy.

Unlike other desalination techniques which operate using machines to purify water, solar desalination uses direct sunlight to carry out the process to separate the salt from water through vaporization and condensation processes using solar stills. The disinfection stage can be eliminate in this process because the radiation from sun will kill all the microorganisms in the saline water and leave behind the impurities as the water evaporates. On top of that, solar desalination is considered environmental friendly because it does not produce any pollution. However, the productivity of solar desalination depends on the weather which is intermittent. There are also cases where the heat losses to the surrounding reduce the efficiency of solar still.

Solar desalination processes have been used for many decades. Throughout the applications of solar desalination, few drawbacks are observed including flaws in the design and the materials are usually fragile. Besides that, it has high capital cost and low efficiency. After screening all the problems, we have come up with a simple design which is point focus parabolic solar still that able to work efficiently and made up of non-fragile material. In our prototype, we made modifications where we incorporate heat exchanger to re-use the heat and at the same time increase the productivity. Lastly, sun tracking system will be installed in our prototype to harvest the maximum sunlight.

1.3 OBJECTIVES

The objectives of the project are:

i) To investigate the productivity of point-focus parabolic solar still with low cost parabolic dish made up of non-fragile materials.
ii) To design low cost solar tracker that is compatible for users.
iii) To minimize the heat loss in point-focus parabolic solar still by installing heat exchanger.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND OF SOLAR DESALINATION

Water and energy are two inseparable and vital commodities for human, plant and animal sustainability on earth. Besides, water also serves few sectors such as agriculture, sanitation, and industrial processes. With total global water reserves of about 1.4 billion km^3, around 97.5% of it is in the oceans and the remaining 2.5% is fresh water present in the atmosphere, ice mountains, freshwater lakes, rivers and groundwater, as shown in Figure 2.1 (World resource, 2012). The breakdown structure shows that water is used prominently for irrigation at 70% followed by industry at 22% and domestic use at 8%. Now, the world's water consumption rate is doubling every 20 years with the population growth.

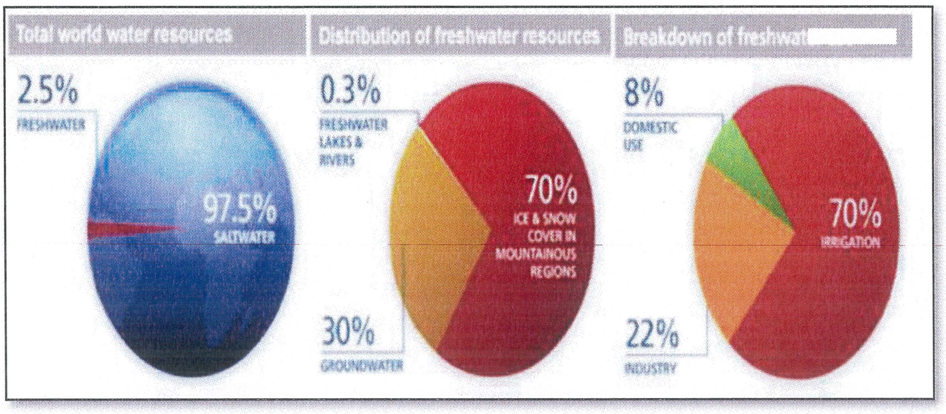


Figure 2.1: Distribution of world water resources (World resource, 2012).

Since those days, humans survive with water from rivers, lakes, and recently aquifers where ground water can be extracted as potable water. These sources of water aggregate to less than 1% of total amount of the water on Earth, yet it is sufficient to fulfill the human's demand for centuries as well as the vast array of flora and fauna (Mateo, 2011). However, Ning (2015) acclaims that the fast population growth and industrialization especially in developing countries have raise the demands for both freshwater and energy. The lack of drinking water has been a big challenge which continues to present and continues in the future. The drinking water scarcity is directly related to 80% of the world's illnesses and to 50% of total immature death. Worldwide, the distribution of drinking water is not proportional to the needs for each area. (Chaouchi, Zrelli and Gabsi, 2007).

In these circumstances, made to find an alternative source of energy rather than those of fossil fuels and compliance to environmental requirements, seems essential to seek solutions. In this context, renewable energy has a certain interest especially solar energy (Chaouachi, 2011). During World War II, the insufficient of potable water make people realize the importance of desalination technology. Subsequently, the U.S. Department of the Interior, through the Office of Saline Water (OSW) provided funding during the 1950s and 60s for initial development of desalination technology as well as for construction of demonstration plants (Krishna, 1989). On top of that, it is found that earliest documented work is that of an Arab alchemist in the 15th century where he used polished Damascus mirrors for solar distillation (Malik et al., 1985).

Desalination process simply requires solar energy which is environmental friendly, renewable, clean and abundantly available in the earth's crust. The sun, radiates the energy uniformly in all directions in the form of electromagnetic waves. Approximately, 3.8 × 1024 J per year solar radiation is absorbed by the earth and the atmosphere. The energy radiated by the sun on a bright sunny day varies from 4 to 7 kWh/m^2 in different regions (Arjunan et al., 2009). Since solar energy is cheap, it can be used either for seawater desalination by producing the thermal energy required to handle the phase change processes or by generating the electricity required to drive the membrane processes (Arunkumar, 2012). Gorjian et al. (2014) defines "desalination" as any process that removes some amount of salt and other minerals from saline water or brackish water and is the well-known treatment solution throughout the world today. In other words, desalination is a process which uses natural evaporation and condensation processes by which many impurities ranging from salts to microorganisms can be effectively eliminated from sea water to produced drinking water.

2.2 CLASSIFICATIONS OF SOLAR DESALINATION

Basically, solar desalination can be divided into two which are direct and indirect solar desalination. Direct solar desalination convert solar energy to produce distillate or potable water directly meanwhile indirect solar desalination combines conventional desalination techniques, such as multistage flash desalination (MSF), vapor compression (VC), reverse osmosis (RO), membrane distillation (MD) and electrodialysis, with solar collectors for heat generation. Indirect solar desalination can be grouped into two which are membrane methods and distillation methods. Reverse Osmosis (RO) and Electrodialysis (ED) are classified under membrane methods whereas the Multi-Stage Flash (MSF), Multi-Effect Distillation (MED) and Vapor Compression (VC) are the two conventional distillation methods being used in solar driven desalination technologies. Figure 2.2 shows the classification of solar desalination technologies.

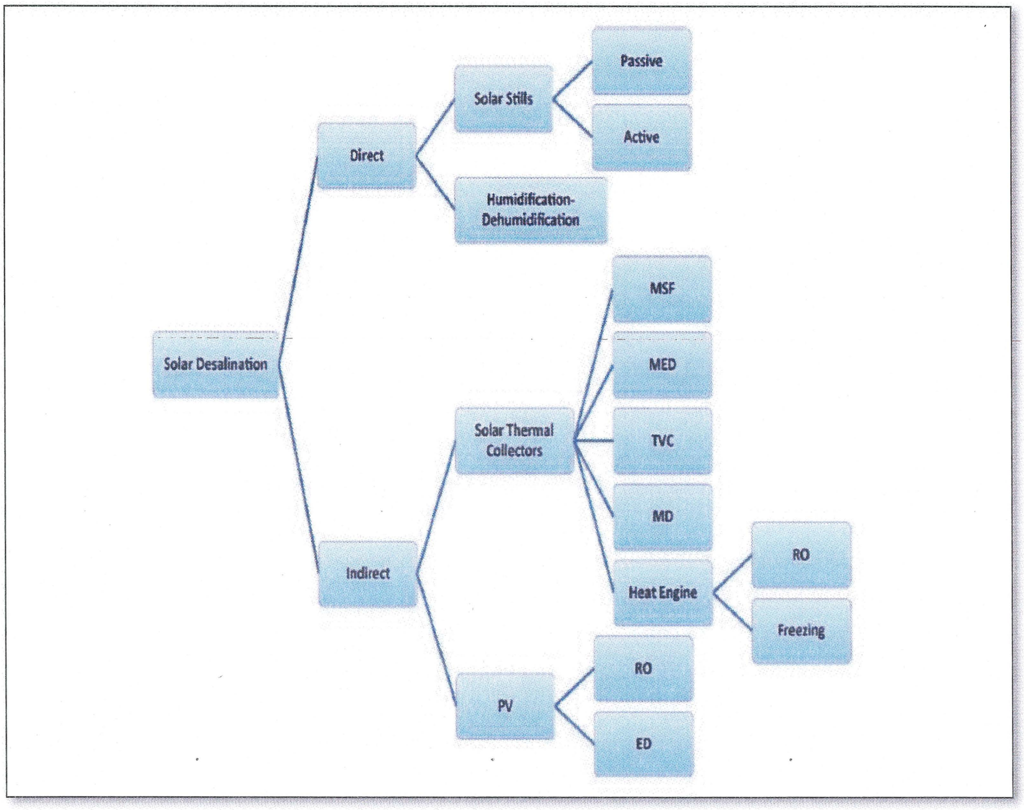


Figure 2.2: Classifications of solar desalination technologies (Ali et al., 2011)

Solar stills are the device is used to make potable water from the saline water with the aid of solar energy which is considered as direct solar desalination. A solar still is a primitive yet effective device for desalination of non-potable water. Solar still can be broadly classified into two categories, active solar still and passive solar still which depend on the way of harnessing the solar energy as shown in Figure 2.3. Active solar stills use thermal collectors, photovoltaic panels, and concentrator along with distillation unit whereas passive solar stills directly use solar radiation in the distillation process to produce potable water (Manchanda and Kumar, 2015).

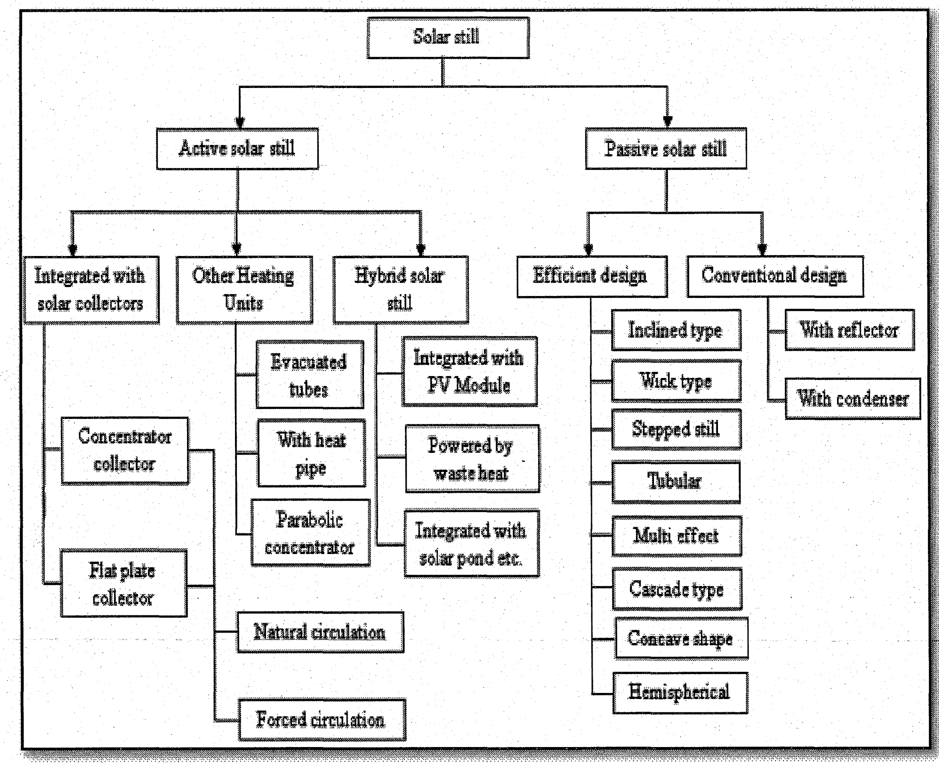


Figure 2.3: Classifications of solar still (Manchanda and Kumar, 2015)

2.2.1 Direct Solar Desalination

2.2.1.1Passive Solar Still

Passive solar stills will be very simple in construction and operation. The sizes are smaller and cost lesser. Passive solar stills only utilize exorbitant available solar energy to remove the impurity in contaminated water, thus it is safe, clean, eco-friendly, and energy saving. The examples of passive solar stills are:

(i) Basin Type Solar Still

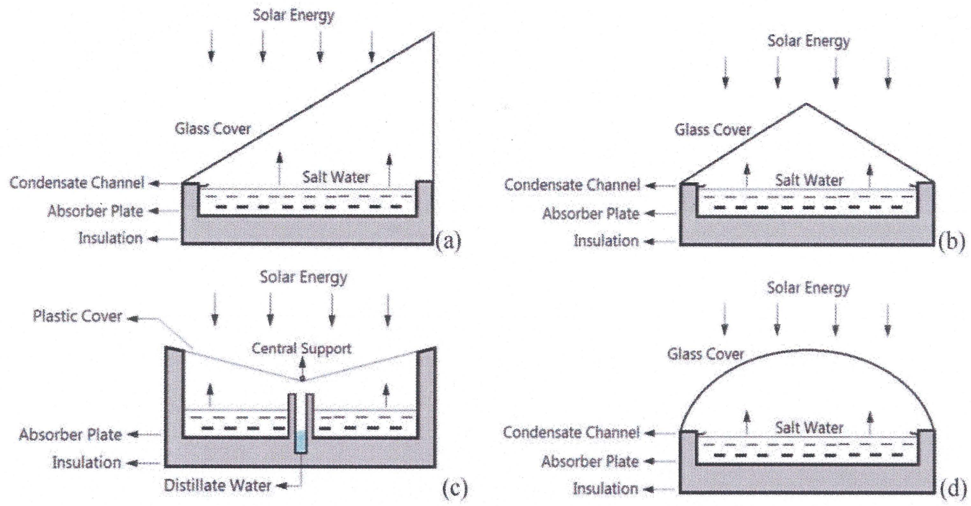


Figure 2.4: (a) single-slope basin still, (b) double-slope basin still, (c) V-type solar still, (d) Hemispherical type solar still (AnfasMukram and Suneesh, 2013)

As shown in Figure 2.4, basin type solar stills have been modified into several types according to their cover designs such as single slope, double slope, V-type and hemispherical. This basin type solar still is the most widely used nowadays due to its simplicity and low cost. Zaki et al. (1993) acclaims that the average distillate production rate of a standard single-basin still is between 2 L/m^2 depending on the insulation quality. However, the productivity varies according to the design. For instance, the double slope basin will yield better than single slope basin. The concept of this process is very simple where the still traps solar energy within the enclosure. This heats up the water causing evaporation and condensation on the inner face of the sloping transparent cover. This distilled water is generally potable and the quality of the distillate is very high because all the salts, inorganic and organic components and microbes are left behind in the bath. However, few modifications have been done in order to increase the productivity and efficiency of basin type by integrating with solar connecting panel or heater which refers as active solar still. After few improvements have been made, today's state-of-the-art single-effect solar stills have an efficiency of about 30–40% (Mink et al., 1998).

(ii) Wick Still

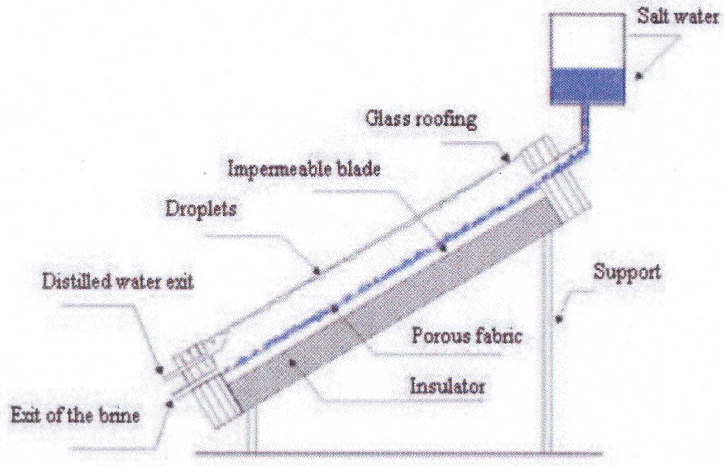


Figure 2.5: Solar distiller with wick (Chaouachi, 2011)

In an inclined still as shown in Figure 2.5, water flows from the top to the bottom of the absorber surface. In order to maintain uniform thickness of water, a wick is used to draw water by capillary effect. The saline water passes through the drilled holes and drops onto the black absorber plate to be evaporated by absorbing heat from the plate which is heated by solar irradiation. Vapor rises up and condensates as fresh water which finally accumulates on the inner surface of the glass cover and flows downwards to the condensate outlet port by gravitational forces. They found that water droplet falling onto the absorber plate does not distribute perfectly on the absorber plate surface. Hence, by using a wick on the absorber plate, it helps to distribute water more evenly over the absorber plate using capillary effect which improves evaporation rate. Sodha et al. (1981) has designed a simple multiple wick solar still made of a frame of aluminum, a glass cover and a water reservoir made of galvanized iron.

Another way of improving the performance is to cool glass cover to ease condensation. Shaded plate is a simple yet effective solution. Deniz (2013) acclaims that this arrangement provides a chimney effect in this gap and enhance convective heat transfer to the atmosphere which cools down this part of the glass and increases the condensate production rate. Tanaka et al. (2013) have proven the superiority of the tilted wick type solar still and confirmed an increase in productivity by 20–50%.

(iii) Weir Type Cascade Solar Still

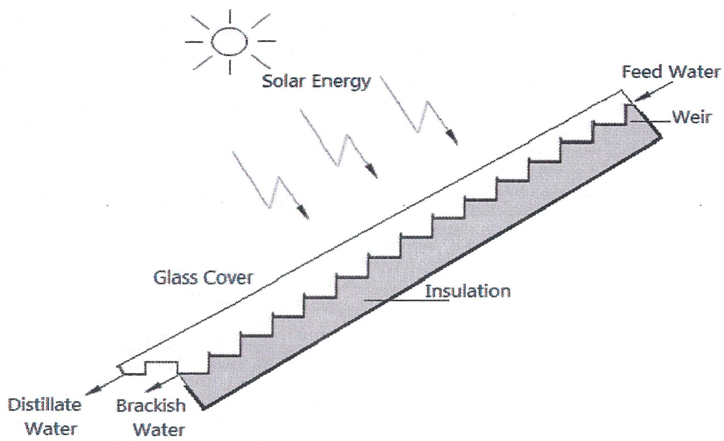


Figure 2.6: Weir type cascade solar still (Sivakumar et al., 2013)

Figure 2.6 shows the weir type cascade solar still which is almost similar to the wick type where the solar still is inclined. The advantages of weir-type cascade solar stills is it do not suffer from dry spot or channelization problems since the brine is forced to flow each step one by one without leaving any dry surface on the absorber plate which increases the efficiency. Further research and modifications have been done to these weir-type cascade stills by include wick on each cascaded steps and phase change material (typically paraffin wax) beneath the absorber surface to store energy when it is abundant and give it back to the salt water when it is needed in cloudy days or evening times (Zoori et al., 2013). From Table 2.1, it shows that the productivity of the weir-type still is approximately 20% higher than conventional basin-type solar still. Besides, the average productivity of the still is approximately 5.5 L/m^2 in a day.

Table 2.1: Distillate productivity from the conventional basin and weir-type (single-pane) stills, September 2006 (Sadineni et al., 2006)

Day	Distillate productivity (l/m^2/day)	
	Conventional basin-type still	Weir-type still (single-pane)
8 September	4.6	5.5
9 September	5.1	6.3
10 September	4.3	5.2
11 September	4.8	5.6
12 September	4.9	5.8
13 September	4.2	5.0
14 September	3.4	4.1

(iv) Spherical Solar Still

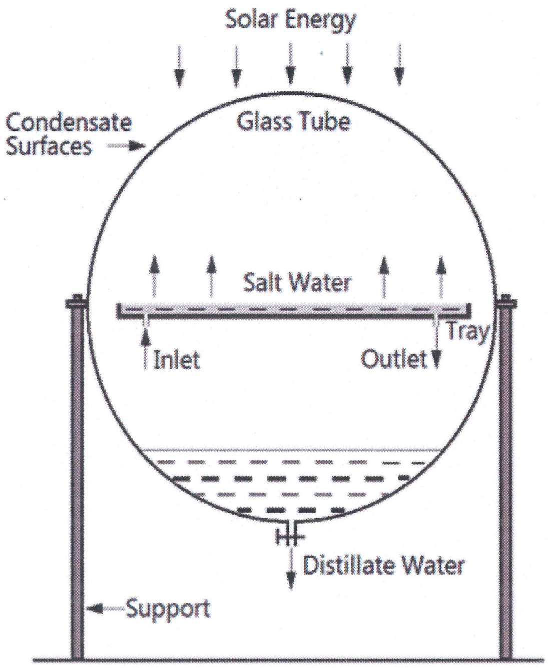


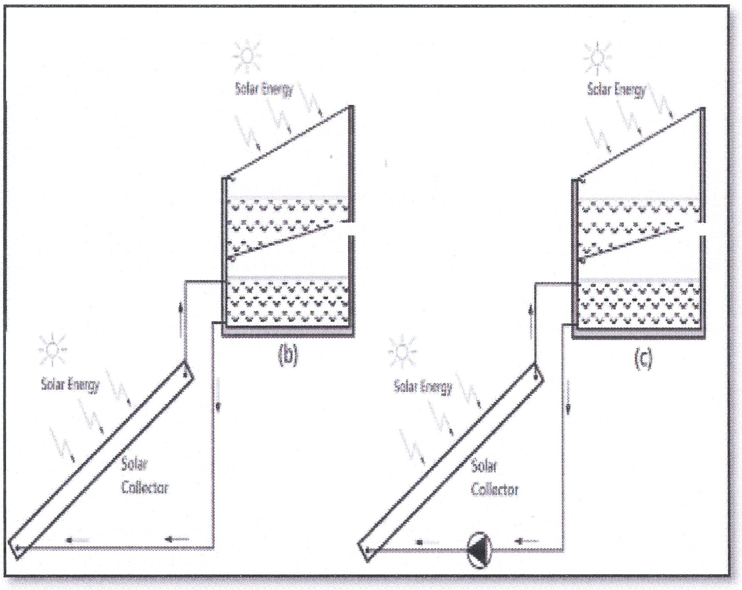
Figure 2.7: Spherical Solar Still (Ning, 2015)

Figure 2.7 represents the simple spherical solar stills which are about 30% more efficient than an equivalent conventional solar still. They have even more condensation area per evaporation surface compared to cylindrical solar stills but it is not scalable as easy as cylindrical ones (Arjunan et al., 2009). As an improvement for the productivity, the circular absorber basin can be coated with black paint for maximum absorption of incident solar radiation (Arunkumar et al., 2012). Moreover, a wiper can be installed to wipe out the water frequently to the distillation container and thus increases the yield. However, this spherical solar still have not been used widely as other solar stills due to the difficulty in fabrication process.

2.2.1.2 Active Solar Still

Researches have been conducted in attempt to improve the efficiency and productivity of solar stills and finally come up with few methods. They are decreasing the depth of water in the basin, mixing black dye with the salt water, using better insulation to minimize the heat losses, improving the vapor tightness, proper orientation of the still as to receive more solar irradiation and more. All these are considered as passive methods, however, there are a number of active methods of improving thermal efficiency such as integrating a still with a solar heater of concentrator. Active solar stills receive additional thermal energy from an outer source to the water in the basin which improves the rate of evaporation. The examples of active solar stills are:

(i) Double basin still coupled to a collector



(a) (b)

Figure 2.8: (a) Double basin still coupled to a collector in the natural circulation mode and (b) Double basin coupled to a collector in the forced circulation mode (Sampathkumar et al., 2010)

Figure 2.8 shows the active solar still, where the double basin is incorporated with the solar collector to enhance the productivity. In active solar still, the water circulation through the heater or the concentrator could either be through natural circulation (thermosyphon) or through forced circulation using a pump. However, the collector should be used in closed cycle to avoid precipitation of salt and other contaminants in the tubes and demolish the performance of the collector.

(ii) Parabolic trough solar collector

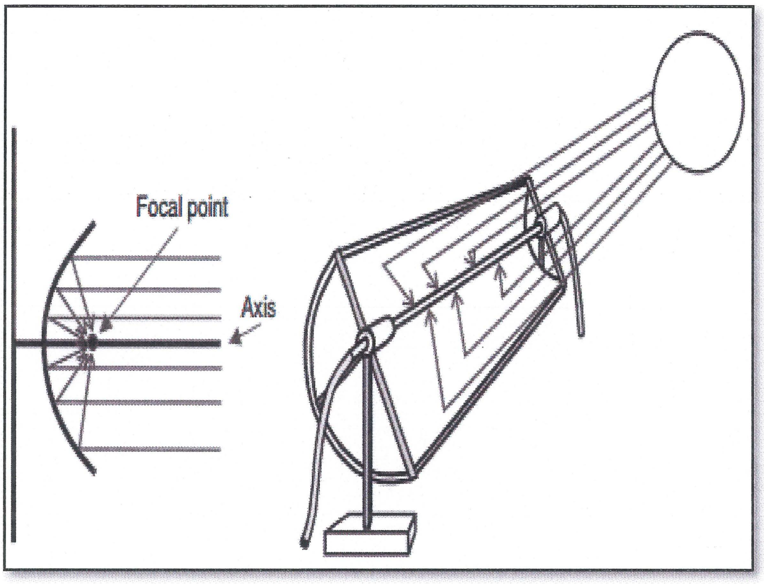


Figure 2.9: Parabolic trough solar collector on the right side and the concentrated focal point on the left side (Federal Technology Alert, 2007).

Figure 2.9 shows the parabolic trough solar collector on the right side and the concentrated focal point on the left side. The parabola is an intriguing geometric shape with important practical uses including concentrating sunlight. The curve of a parabola is set as such that light travelling parallel to the axis of a parabolic mirror will reflect to a single focal point from any place along the curve. Since the sun is far away, all light coming directly from it is essentially parallel, so if the parabola is facing the sun, the sunlight is concentrated at the focal point. A parabolic trough extends the parabolic shape to three dimensions along a single direction, creating a focal line along which the absorber tube is run (Federal Technology Alert, 2007). Some design goals of a parabolic trough solar collector achieve high performance, reliability and durability (Xiao, 2007). The drawback of this solar still is the cost is high and often used for large scale purpose. Improvements have been suggested in reflective and absorbent coatings and development of triple-effect absorption cooling which will incrementally improve economics, but there are no known technological developments that could dramatically lower the cost of parabolic-trough.

(iii) Point-focus parabolic solar still

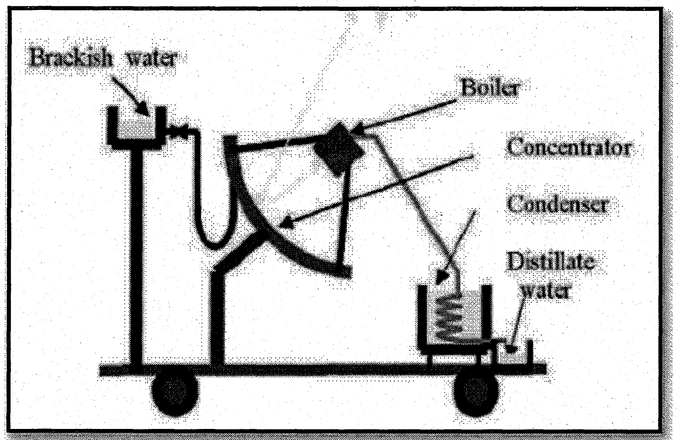


Figure 2.10: Point-focus parabolic solar still (Chaouchi et al., 2007)

The point-focus parabolic solar still (PPSS) is the active solar still type as shown in Figure 2.10. This system consists of a parabolic dish concentrator, a single or two axis sun tracker based on programmable logic controllers (PLCs) and condenser. The concentrating solar energy on the focal line of a parabolic trough has line that usually a pipe that contains a thermal fluid which heats it up to high temperature. Then, to improve the efficiency, heat exchanger can be added where the fluid is pumped to a heat exchanger which heats water. It eventually vaporizes and immediately condensed which is later withdrawn as desalinated water. The productivity of such units is high (Mousa et. al., 2010). Improvements have been made through high temperature and low heat loss area of the still basin or the absorber which is located on the focal point of parabolic concentrator greatly increases the efficiency of the still (Ning, 2015).

There are few advantages of PPSS which is parabolic typically have concentration ratios of 10 to 100, leading to operating temperatures of 100–400°C. This type of still is capable of producing from 0.5 to 0.6 gallons per day per square foot of reflector area. This type of output far surpasses other types of stills on a per square foot basis. Despite this still's outstanding performance, it has many drawbacks; including the high cost of building and maintaining it, the need for strong, direct sunlight, and its fragile nature.

Table 2.2: Experimental obtained data for PPSS (Chaouchi et al., 2007)

Time (h)	Incident radiation (W/m^2)	Distillate output (L)	Ambient temp. (°C)
09:00	352	0.255	28.0
10:00	409	0.612	28.5
11:00	441	0.785	28.6
12:00	455	0.725	29.6
13:00	453	0.776	30.0
14:00	465	0.853	30.8
15:00	420	0.749	29.8
16:00	405	0.737	29.4
17:00	217	0.378	29.0
18:00	150	0.242	28.5

Table 2.2 shows the data for incident radiation and distillation output collected for 9 hours which is from 9am to 6pm. At the flow rate of 40L/h, the highest yield of 0.853L is produced at 2pm and the lowest yield is 0.242L at 6pm. Besides, the pattern can be seen where the productivity increases from morning to afternoon, reaches peak at 2pm and decreases rapidly from afternoon to evening. The total yield produced is 6.112L per day for PPSS. Furthermore, there are several parameters which should be impose in designing which affect the performance of a point-focus parabolic solar still such as ability of absorbing material, geographical position, water depth and others.

2.2.1.3 Comparison of productivity for different types of solar stills

Table 2.3 shows the comparison of productivity for different types of solar stills which are basin type solar still, wick still, weir type cascade solar still, spherical solar still, double basin still coupled to a collector and point-focus parabolic solar still.

Table 2.3: Comparison of productivity for solar stills

Type of Solar Still	**Methodology/ Modifications/ Analysis**	**Capacity ($L/m^2/day$)**	**References**
Basin Type Solar Still	Simple basin that need for regular flushing of accumulated salts	2.00	Zaki et al., 1993
Wick Still	Effect of corrugated work by wick surface on the performance of the still	4.20	Kassem, 2016 [28]
Weir type cascade solar still	Absorber Plate, condensing cover, and insulation	3.85	Sadineni et al., 2006
Spherical Solar Still	circular absorber basin coated with black paint	2.30	Arunkumar et al., 2012
Double basin still coupled to a collector	Double basin solar still integrated with flat plate solar collecter	5.18	Tiris, 1998 [29]
Point-focus parabolic solar still	Concentrator (mirror + parabolic dish) and heat exchanger	3.56	Arunkumar et al., 2013

2.2.2 Indirect Solar Desalination

Indirect solar desalination are generally use for large scale of applications. Solar energy is collected in these system by using non-concentrating or concentrating solar thermal collectors or photo-voltaic panels. The energy harvested is then used to drive thermal desalination processes such as Multi-Stage Flash (MSF), Multi-Effect Distillation (MED), Thermal Vapor Compression (TVC) or in membrane desalination methods such as Reverse Osmosis (RO) and Electrodialysis (ED). Figure 2.11 shows indirect solar desalination technologies with possible solar energy conversion device. Based on the classifications, indirect solar desalination can be grouped into thermal, mechanical or electric driven technologies. MSF, MED, TVC and MD are thermal desalination technologies where solar thermal collectors are necessary as their energy source meanwhile RO and freezing are mechanical driven technologies. On the other hand, ED is the only solar desalination technology that consume electricity.

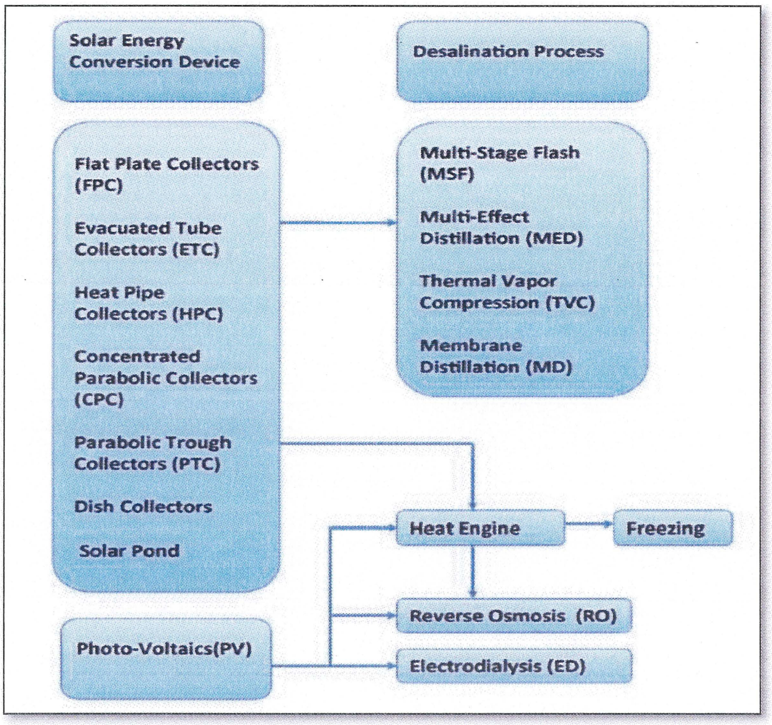


Figure 2.11: Indirect solar desalination technologies with possible solar energy conversion device (M.T. Ali et al., 2011)

2.2.2.1Multi-Stage Flash (MSF)

MSF is an old technology which has been implemented since 1960s (Karlsruhe, 2008). Nowadays, MSF as a well-known technology has been used on large applications (more than 50 000 m3/day), with coupling of heat generation from a power plant or MSF process can also be used with solar power (Compain P., 2012). MSF is considered as thermal distillation process that encompasses of two main steps which are evaporation and condensation of water. These two steps are coupled to each other in several stages so that the latent heat of evaporation is recovered for reuse by preheating inlet water. The incoming feed water is heated to its highest temperature in the brine heater by condensing saturated steam from the cold end of a steam cycle power plant or from another heat source. Then the preheat seawater flows directly into the first evaporation stage which has lower pressure. The sudden introduction of hot water into the chamber causes it to boil immediately because it has lower pressure (Review of CSP and Desalination Technology, 2007). Sometimes, this condition may cause it to almost explode or flash into steam. However, only a small percentage of the water is converted to vapour. The vapour produced by flashing is condensed on tubes of heat exchangers that pass through the upper part of each stage. Meanwhile, the tubes are cooled by the incoming saline water going to the brine heater, thus pre-heating that water and reuse part of the thermal energy used for evaporation in the first stage.

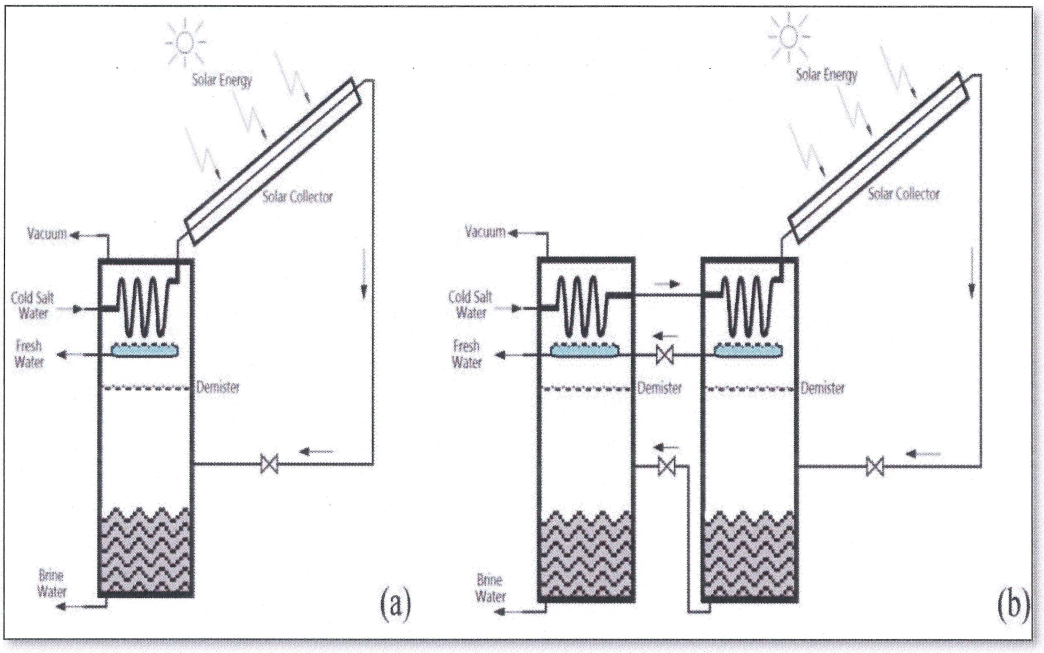


Figure 2.12: Process of (a) one stage flash distillation, (b) two stage flash distillation (Deniz E., 2015)

Figure 2.12 represents the process of one stage flash distillation and two stage flash distillation. There are pros and cons of this application. The advantage is the energy use for MSF distillation of seawater is 13.5-25.5 kWh per m^3 which is far better and more efficient than implementations of RO and MED (Reif J.H. and Alhalabi W., 2005). Besides that, MSF is widely accepted due to its reliability and easy process control with simple layout (Al-Sahili, et al., 2007). However, the disadvantages are it has high capital cost and high maintenance requirements. Many improvements were suggested over the years including technical advances and cost reductions which relate mainly to improved corrosion resistance by the use of expensive alloys, increase in size and enhancement in control technology and scale inhibitors (El-Nashar A.M., n.d). In order to maximize water and energy recovery, each stage of an MSF unit is recommended to operate at a successively lower pressure.

Location	Year	Energy source	Feed water type	Energy source details	Capacity (m^3/d)	SEC (kWh/m^3)	Specific plant details
La Paz, Mexico [50]	1980	PTC-FPC	Seawater	194 m^2 FPC, 160 m^2 PTC with two-axis tracking	10	<144	10 stage
Las Barranas, Mexico [51]	1980	PTC-HPC	Seawater	550.8 m^2 PTC, 1540 m^2 HPC, 16 m^3 hot oil storage, 114 m^3 hot water storage	20		
Gran Canary, Spain [52]	1981	Low Concentration Solar Collectors	Seawater		10		
Safat, Kuwait [42]	1983	PTC	Seawater	220 m^2 PTC, 7 m^3 hot water storage	10	81–106	12 stages, GOR 6.5–8, RR 6%, 10 times output of solar still of same collection area
El Paso, USA [43]	1987	Solar Pond	Seawater	3000 m^2 with 3.75 m depth	2.35–7.2		Multi-effect Multi-Stage Spin Flash (MEMS), Brine Concentrate Recovery System (BCRS) for testing Zero Discharge Concept, PR 1.7–3.3
Gaza, Palestine [53]	1999	FPC-PV	Brackish Water	5.1 m^2 FPC, PV with battery storage	0.2		4 stage MSF, thermo-siphoning from FPC, experimental, batch process, PV for vacuum pump and controls
Berken, Germany [54]		Solar Collectors	Seawater		10		
Lempedusa Island, Italy [23]		Solar collectors			0.3		
Bari, Italy [54]		Solar Collectors	Seawater		5		
Island Of Cape Verde [44]	1999	Solar Pond			5		Atlantis (Auto flash), 30–95 °C TBT
Suez, Egypt [45]	2005	FPC		2.39 m^2 FPC	0.009		PR 0.7–0.9, 40–60 °C TBT, RR 0.6%

Figure 2.13: Summary of Solar-MSF desalination plants (Ali M.T. et al., 2011)

The world's largest desalination plants are based on this technology. Figure 2.13 shows the list of solar MSF desalination plants at different location along with a summary of their performance parameters. MSF plants can be integrated to any heat sources including solar concentrating (PTC, LFC, TSC, SDC) collectors, solar pond and flat plate, evacuated and heat piped collectors and any type of waste heat at moderate temperatures. Based on the table, it is found that parabolic trough collector and flat plate collector have been use widely to harvest the sunlight which is incorporated with MSF system. The output produced is high where the maximum is 20m^3/d. In fact, half of the countries listed above able to yield 10m^3/d.

2.2.2.2Multi-Effect Distillation (MED)

Multi Effect Distillation (MED) was developed in early 1950s. Initially, it lost favor and was replaced with MSF because it has some problems with scaling on the heat transfer tubes (Al-Shammiri M. and Safar M., 1999). However, over the time MED has gained attention due to the better thermal performance compared to MSF (Review of CSP and Desalination Technology, n.d). MED is a process is based on using latent heat of condensation of the vapor from the first cell to supply heat to a second cell. The evaporation takes place in cells where equilibrium temperature (T_e) liquid or vapor is between 40°C and 68°C. Initially, the steam produced in the first cell is injected into the second effect to make sure the evaporation and condensation takes place at a lower temperature. This step is then repeated in all following cells respectively. In the case of utilizing solar source as heat source, the hot water from the solar collector is let to pass through the bottom tray either directly or through a heat exchanger. MED units with horizontal sprayed tubes are generally made with materials like, aluminum brass (AlBr) for tubes and stainless steel 316L for the casing (Compain P., 2011).

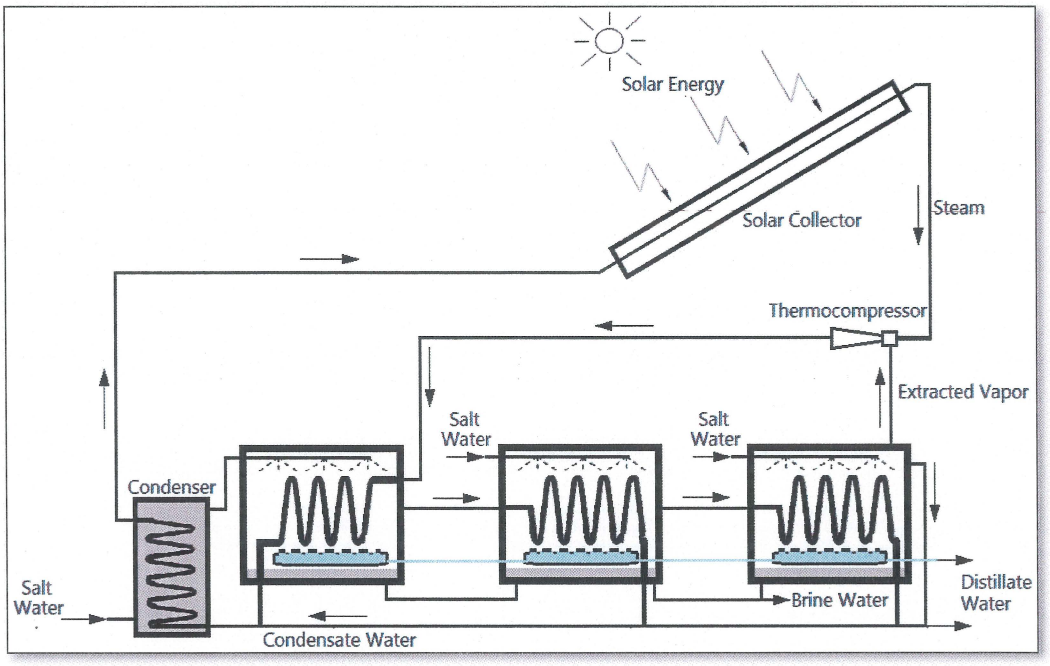


Figure 2.14: Typical arrangement of a multiple effect solar distillation with thermo-compression (Deniz E., 2015)

Solar-assisted MED process consists both thermal energy (thermal vapour compression) and mechanical energy (mechanic vapour compression) to produce potable water. Figure 2.14 shows the typical arrangement of a multiple effect solar distillation with thermo-compression. In very large desalination systems, MED may be competitive to reverse-osmosis desalination, and may be appropriate for large-scale deployments of solar-powered desalination systems (Reif J.H. and Alhalabi W., 2005). Multi-Effect Distillation (MED) is more energy efficient than other evaporation techniques, including the Multi-Stage Flash system (Awerbuch, 1997). In addition, it is also considered to be more sophisticated (Semiat R., n.d). In order to improve the performance, each stage is run at a successively lower pressure. This is to allow the plant to be configured for a high temperature (> 90 °C) or low temperature (< 90 °C) operation. Furthermore, the top boiling temperature in low temperature plant can be as low as 55 °C which helps reduce corrosion and scaling, and allows the use of low-grade waste heat (Miller J.E., 2003).

Moreover, the MED process usually operates on a once through system having no large mass of brine recirculation round the plant. This reduces the pumping requirements and has a good effect on the scaling tendencies in the plant (El-Nashar A.M., n.d). Most of large scale solar thermal plants used MED due to its low top brine temperature (TBT) requirements along with low specific energy consumption requirements as compared to MSF. Figure 2.15 presents the list of solar MED desalination plants along with a summary of features of these plants. Based on Table 2.5, developed countries such as Japan and USA have installed MED plant. The energy source which is sunlight is harvested using solar pond and evacuated solar collector. The highest capacity produced by MED is up to 3000 m^3/d.

Location	Year	Energy source	Feed water type	Energy source details	Capacity (m^3/d)	SEC (kWh/m^3)	Specific plant details
Takami Island, Japan [63]	1977	ETC-FPC	Seawater	336 m^2 ETC, 185 m^2 FPC, 38 m^3 stratified hot water storage and 25 m^3 mixing type water storage	20		16 effect horizontal tube, air-bubbling type ED, ETC used for MED and FPC for ED, RR 24.5%
Abu Dhabi, UAE [55]	1984	ETC	Seawater	1862 m^2, 300 m^3 of stratified hot water storage	80	50	18 effect with preheating in each stage, GOR 12.4, RR 12%, water cost 7–10$/$m^3$
El Paso, USA [64]	1987	Solar Pond	Seawater	3000 m^2 with 3.75 m depth			24 stages falling film MED
Plataforma Solar De Almeria, Spain [56]	1988	PTC	Seawater	2672 m^2, 115 m^3 thermocline hot water storage	72	3.3–5 (electric) 57.5–70.4 (thermal)	14 effect vertical stack, hydro-ejectors vacuum system, GOR 9.3 to 10.7 at low pressure steam 0.28 bar and increases to 12–14 if use high pressure steam 16–26 bar, RR37.5%, Absorption pump addition resulted in 44% and 12% reduction in thermal and electric consumption respectively
Le Desired Island, France [65]		ETC			40		14 effect
University Of Ancona, Italy [58]	1997	Solar Pond	Seawater	625 m^2 with 3.5 m depth	30	8 (electric) 194 (thermal) for MED, 2.5 (electric) 111 (thermal) for TVC	GOR 5.73 for TVC, RR 5.7% for MED and 11.4 for TVC
Near Dead Sea, Israel [66]		Solar Pond			3000		
Plataforma Solar De Almeria, Spain [57]	2004	CPC	Seawater	500 m^2, gas boiler back up with 30% continuous operation	72	3.3–5 (electric) 57.5–70.4 (thermal)	14 stages, double-effect absorption heat pump to enhance system efficiency, hydro-ejectors vacuum system, PR 11, water cost 2.86$/$m^3$

Figure 2.15: List of solar MED desalination plants along with a summary of features (Ali M.T. et al., 2011)

2.2.2.3Thermal Vapor Compression (TVC)

The thermal vapor compression is a key system to enhance the performance of thermal desalination processes such as multiple effect distillation (MED) and multi stage flash (MSF). In thermal vapour compression, motive steam at higher pressure is withdrawn from another process such as a steam power cycle and industrial process steam (Review of CSP and Desalination Technology, n.d). The MSF and MED require steam at low pressure meanwhile the TVC need high-pressure steam. The performance of the TVC system can be enhanced at higher motive steam pressures (Hassan A.S. and Darwish M.A., 2015). Figure 2.16 shows the thermal vapor compression which is known steam jet ejector.

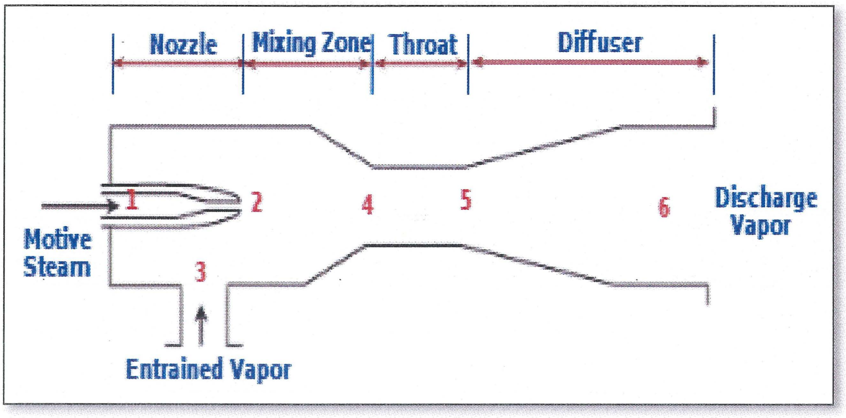


Figure 2.16: Thermal vapor compression (Hassan A.S. and Darwish M.A., 2014).

2.2.2.4 Reverse Osmosis (RO)

Reverse osmosis (RO) is a membrane separation process which has semi-permeable membrane that recovers water from saline water when it is pressurized to a point higher than the osmotic pressure of the solution. In simply means that the semi-permeable membrane forces the water with a higher concentration of contaminants (source water) to flow into a tank that contains low concentration of contaminants (processed water). The role of high water pressure at source water is mainly to reverse the natural osmotic process. The factors affectiong the RO membranes are pH value, oxidizers, organics, algae, bacteria, particulate deposition and also fouling (Review of CSP and Desalination Technology, n.d). Figure 2.17 shows how the the semi-permeable membrane is allowing the water to pass while trapping most of the other contaminants. This specific process is known as ion exclusion (Alkhatib A., 2014).

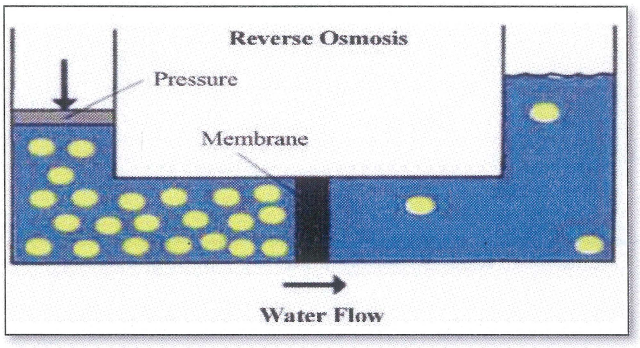


Figure 2.17: Reverse Osmosis (RO) process (Alkhatib A., 2014).

Among all the desalination technologies, RO is rapidly overtaking thermal desalination in terms of market shares (Fritzmann C. et al., 2007). In fact, the solar-driven RO has become favourable in the late seventies (Petersen G. et al., 1979). This is because solar-driven RO can potentially break the dependence on fossil fuels thus reduce operational costs, and improve environmental sustainability (Ghermandi A. and Messalem R., 2009). Solar-driven RO desalination systems is an integration of RO membranes and arrays of photovoltaic (PV) modules. In PV–RO desalination, the direct current (DC) electricity generated in the solar cells either by silicon or other semi-conductors can be used directly or after regulation to power the pumps that supply sufficient amount of pressure required for the feed water to fill the RO membranes. Figure 2.18 shows the simple photovoltaic reverse osmosis system which has few components such as PV array, high pressure pump, control electronics, reverse osmosis membranes and energy recovery device.

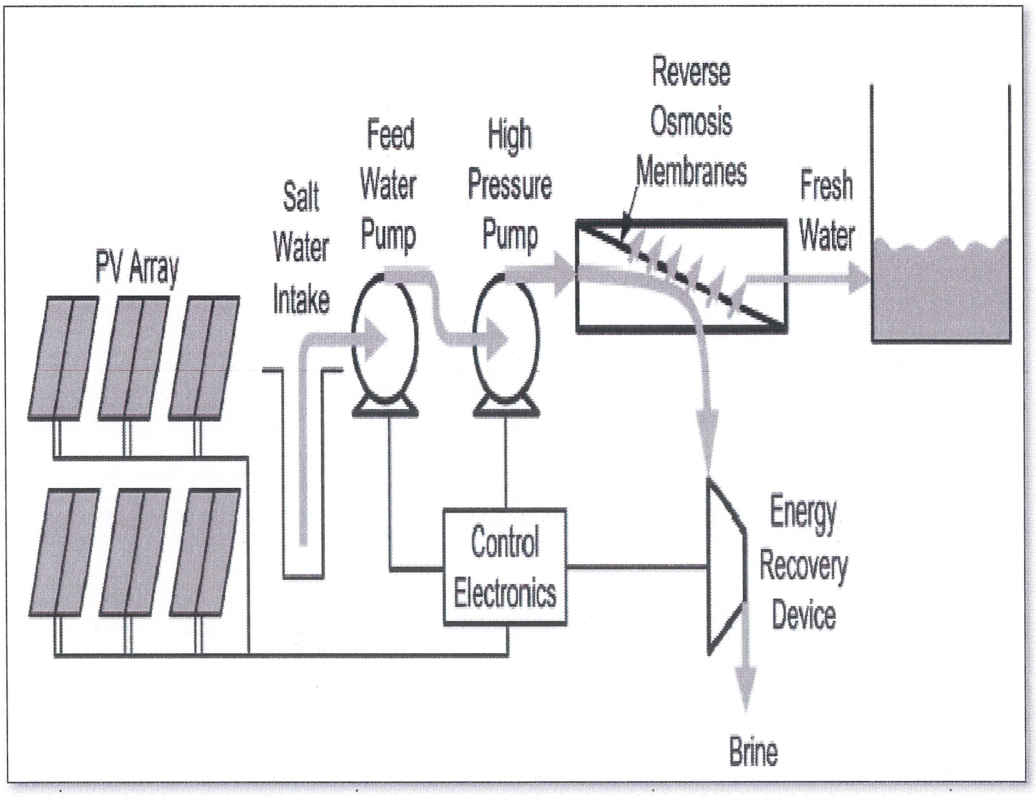


Figure 2.18: Simple photovoltaic reverse osmosis system (Bilton A.M., 2011).

Unlike thermal desalination which works well for large communities but do not scale well for smaller communities, PV-RO desalination system can be scaled more easily for the demands of smaller communities (Harold D. and Neskakis A., 2001). The other advantage is PV-RO desalination system has a significant contribution in reduction of carbon dioxide (CO_2). Moreover, batteries are widely used in PV systems to store the energy during the day and utilize it at night (Thomson A.M., 2003). However, there are few drawbacks of PV-RO desalination system. RO membranes are prone to fouling and scaling where pre-treatment is required which eventually results in higher maintenance cost (Ali M.T. et al., 2011). On top of that, cost of membrane replacement and membrane performance degradation are high. These membranes were too inefficient, expensive, and unreliable for practical applications.

However, modern advances in synthetic materials have found solution for these problems by enhancing the efficiency of membranes in rejecting contaminants and making them strong enough to withstand the higher pressures necessary for efficient operation (Alkhatib A., 2014). Many researches have been done in order to improve the process by modifying the characteristics of the process or improving membrane efficiency or adding chemical reactions to ease the passage of water through the membrane or the separation of salt from it (Moridpour S., 2014). In fact, the design or type of solar collector can be improve to harvest the maximum amount of sunlight either by installing solar tracker or using concentrating solar collector. Soon, PV-RO desalination plants with different scales and capacities were built all around the world (Gocht, W. et al., 1998). PV-RO plant was first commercialized in Saudi Arabia in 1981. This system successfully desalinated seawater of 42,800ppm at a production rate of $3.2m^3/d$ (Boesch W.W., 1982). Table 2.6 shows the list of PV-RO desalination plants along at different locations with a summary of features of these plants.

Location	Year	Energy source	Energy source details	Feed water type	Capacity (m³/d)	Specific energy consumption (kWh/m³)
Canary Island, Spain [86]	1998	PV	Seawater	4.8 kWp PV, 59.52 kWh battery storage	0.8–4.2	18–19
Lisbon, Portugal [75,87]	2000	PV	Brackish Water	0.15 kWp PV	0.08	25.6–32.4
Haifa, Israel [88]	2000	PV, wind	Brackish Water	3.5 kWp PV, 0.6 kWp wind, 36 kWh battery	3	
Ceara, Brazil [75]	2000	PV	Brackish Water	1.1 kWp PV, 9.6 kWh battery	6	3
White Cliffs, Australia [89]	2002	PV	Brackish Water	0.34 kWp PV	0.5	8
Keratea, Greece [68,69]	2003	PV-wind	Seawater	3.96 kWp PV, 0.9 kWp wind, 44.4 kWh battery	3.12	16.5
Massawa, Eritrea [90]	2003	PV	Seawater	2.4 kWp PV with single-axis tracking	3	
Baja California Sur, Mexico [51]	2003	PV	Seawater		19	2.6
Canary Island, Spain [91]	2004	PV	Seawater	5.6 kWp PV with tracking, 41 kWh battery	10	2.54
Agricultural University Of Athens, Greece [57,69]	2004	PV-wind	Seawater	0.846 kWp PV, 1 kWp wind, 7.56 kWh battery	2.2	3.3–5.2
Canary Island, Spain [91]	2005	PV-wind	Seawater	0.6 kWp PV, 0.89 kWp wind, 21 kWh battery	1	3.74
North West Of Sicily, Italy [92]	2005	PV	Seawater	125 kWp PV, 160 kVA diesel generator, 1236 kWh battery	36	4.86
Agricultural University Of Athens, Greece [33,93]	2005	ETC-heat engine	Seawater	162 m² ETC, 100 kW heat engine, R-134a as working fluid	1.8	2–3
Cooper Pedy, Australia [94]	2005	PV	Brackish Water	3.2 kWp PV	0.764	3.2
Rajasthan, India [95]	2006	PV	Brackish Water	2.5 kWp PV	3.6	

Figure 2.19: Summary of PV-RO desalination plants (Ali M.T. et al., 2011)

2.3 LIMITATIONS OF SOLAR DESALINATION

Desalination facilities may curtail the dependence of local water agencies on climate sensitive sources of supply. However, desalination proposals should evaluate the long-term climatic risks and benefits. A major concern that should be considered while increasing productivity is to maintain economic feasibility and simplicity. Rabadia acclaims that the system components and hardware used to enhance productivity are still expensive often impeding commercialization. Even though solar energy is free, the equipment required for capturing, converting it to useful forms and storing it can be expensive (Rabadia, 2015). Another limitation of desalination is that it may introduce biological or chemical contaminants into water supply (Cooley et. al., 2006). Hence, initiatives should be implement to filter and separate chemical containments such as oil from the saline water in order to produce quality potable water.

In conclusion, solar desalination is already a vitally important option as it is renewable source and eco-friendly. The current project is intended to design and fabricate a stand-alone point-focus parabolic solar still for the desalination of brackish water and purification of non-potable water. The reason for choosing PPSS among others is because PPSS can produce higher yield with lower cost of installation. Compare to the parabolic trough which is use for large scale and require higher cost of installation, PPSS can be used for lower scale and it has a simpler design. Even though passive solar stills are cheaper and have lower cost, the productivity is no very significant compare to PPSS. However, to have a better productivity, the need for strong and direct sunlight is essential and it is fragile in nature. Improvements can be done in the material selection by selecting non-fragile and long-lasting material.

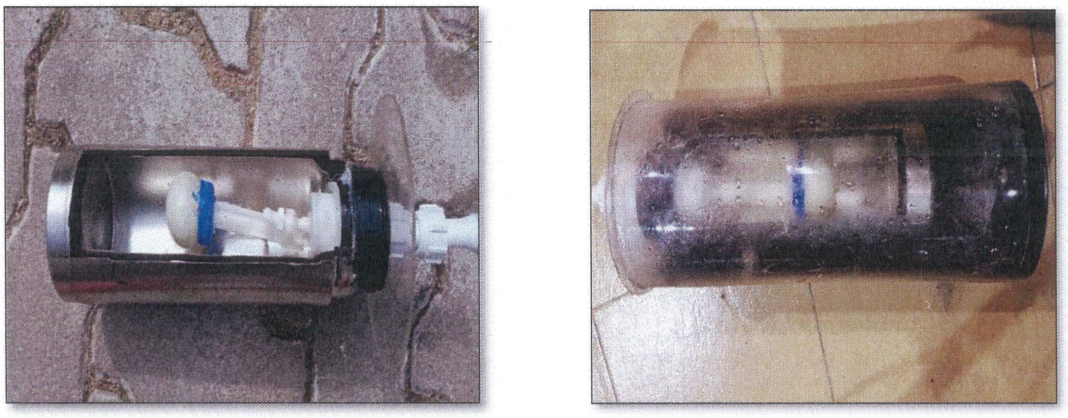
CHAPTER 3

PROJECT IMPLEMENTATION & METHODOLOGY

3.1 MATERIALS

3.1.1 Insulated Absorber

A high graded vacuum flask and cylindrical glass were used as insulated absorber. This is because the vacuum flask has the ability to trap heat which will increase the rate of evaporation in insulated absorber. The capacity of the vacuum flask is 1L. The insulated absorber was mounted at the focal point of the parabolic dish concentrator. The outer surface was surrounded with tempered glass in cylindrical shape where the vapour condensed at the upper part of glass forming droplets. The insulated absorber was integrated with an inlet linked to a saline water tank and an outlet to fresh water tank. In the vacuum flask, a float ball with valve was incorporated to control the water level in the insulated absorber. A ping-pong ball was used as the float ball as it has floating capacity. Figure 3.1 (a) and (b) shows the float ball with valve inside the vacuum flask and the insulated absorber which consists of vacuum flask surrounded by glass respectively.



(a) (b)

Figure 3.1: (a) the float ball with valve inside the vacuum flask and (b) insulated absorber which consists of vacuum flask surrounded by glass

3.1.2 Parabolic Dish Concentrator

An ASTRO dish was re-used as the parabolic dish solar concentrator to meet the objective of this thesis which is to design low cost parabolic dish solar concentrator. The parabolic dish solar concentrator with 0.66m was mounted with a thin aluminium foil covered on it to increase the reflectivity of the radiation. Then, silver spray was spray on it to enhance the reflectivity and for neatness purpose. The role of the parabolic dish concentrator is to focus the incident solar radiation which will be reflected onto the focal point of the absorber. Two slots with the length of 0.1m and width of 0.03m were made in the parabolic dish where the frame is built in between the slots which hold the insulated absorber. Moreover, the slots were made so that there is a space for the parabolic dish to move at a certain angle in relative with direction of sunlight. This will enhance the efficiency of parabolic dish in harvesting more solar radiation as it moves to the direction of the solar position. Figure 3.2 shows the parabolic solar dish concentrator with thin aluminium foil on it.

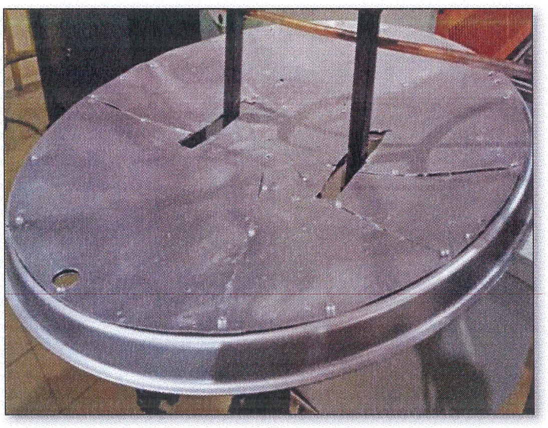


Figure 3.2: The parabolic solar dish concentrator

3.1.3 Piping system

The piping system can be divided mainly into two parts which are inlet and outlet flow of the water. Galvanized steel pipe was used for the inlet which carries saline water to the insulated because it has the ability to resist corrosion due to the presence of salt in water and at the same time it is economical. Meanwhile for the outlet pipe, copper pipe which carries the freshwater was connected to the fresh water tank.

3.1.4 Heat exchanger

The heat exchanger used is known as Power-pipe copper heat exchanger. Its function is to transfer the latent heat from freshwater to inlet saline water. In this case, counter-current heat exchange mechanism is applied. Countercurrent heat exchange is a common mechanism that utilizes parallel pipes of flowing fluid in opposite directions in order to save energy. Thin copper strips surrounding the stainless steel pipe that carries the fresh water at higher temperature was used. So the heat from the freshwater was transferred to the supply pipe which preheated the saline water before entering the insulated absorber to further get heated by the solar radiation. Therefore, waste of heat could be reduced and the efficiency of the process could be increased. Figure 3.3 shows the Power-Pipe Copper Heat Exchanger.

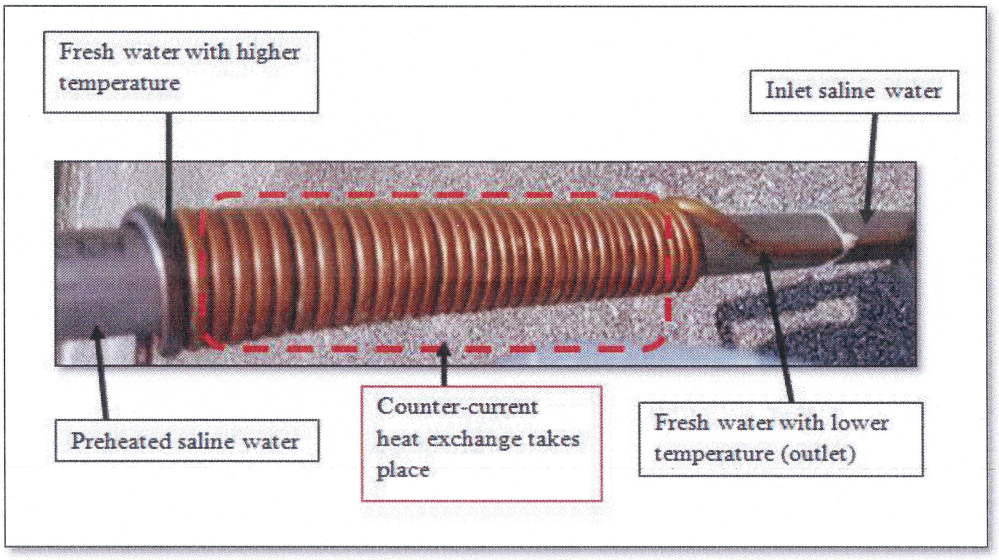


Figure 3.3: Mechanism in Heat Exchanger

3.1.5 Single Axis Sun Tracking System

A solar tracker is a device that orients a payload toward the Sun. In other words, solar tracker which is known as sun tracking system is a device which follows the movement of the sun as it rotates from the east to the west. In this design, single axis sun tracking was installed. A single-axis can only pivot in one plane either horizontally or vertically. Moreover, the trackers function is to keep the parabolic solar dish oriented directly towards the sun as it moves through the sky every day. Trackers work with assist of motor and gear trains to direct the tracker as commanded by a controller responding to the solar direction. The main purpose of sun trackers in this design is to harvest the maximum amount of solar energy that will help to improve the output of the process.

3.1.6 Stepper Motor

The stepper motor as shown in Figure 3.4 is an electromagnetic device that converts digital pulses into mechanical shaft rotation. In this design, 3 gears and a chain were integrated with stepper motor. The stepper motor is used to control the movement of the parabolic solar dish. Generally, the shaft or spindle of a stepper motor rotates one step at a time when electrical command pulse is applied to it in the proper sequence. The direction of motor shaft rotation is directly influenced by the sequence of the applied pulses. Furthermore, the speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

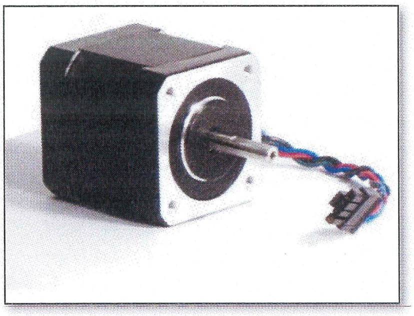


Figure 3.4: Stepper motor (Eva Robotics, 2011)

3.1.7 Water Pump

Water pump is a mechanical device that is used to move or push the fluid. Water pump is needed in this design because the insulated absorber was placed at the higher position and also far away from the supply tank. Therefore, water of high pressure is required in order to reach the absorber with the aid of water pump. In this design, water pump was installed and submerged in the saline water tank. There are few specifications of water pump that has been used in this design. For instances, the submersible pump requires 30W to operate and the maximum flow rate is 3000L/h. In order to prolong the life span of the pump, we ensured that the debris surrounded was washed frequently.

During installation, we make sure that the power plug of the pump was inserted to the power socket outlet at higher point. This is to ensure that the water will not flow back via the wire to the socket outlet. Figure 3.5 shows the water pump used in this design.

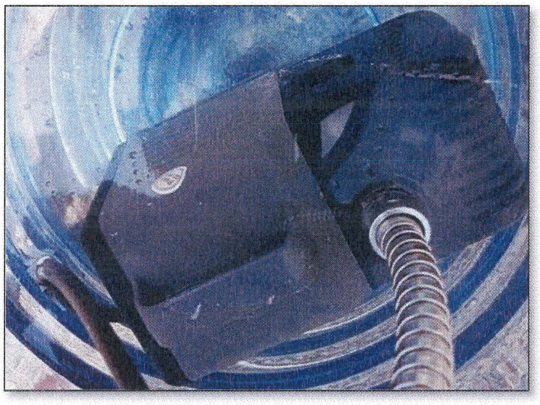


Figure 3.5: Water pump

3.1.8 Light Dependent Resistor (LDR)

As shown in Figure 3.6, Light Dependent Resistor (LDR) is a component that has a variable resistance which changes with the light intensity that falls on it. LDR is commonly used in light sensing circuits. In this design, two LDR were fixed in parabolic solar dish in order to detect the sunlight fall on the dish. Thus, the parabolic dish will move according to the position of sunlight and able to harvest more sunlight.

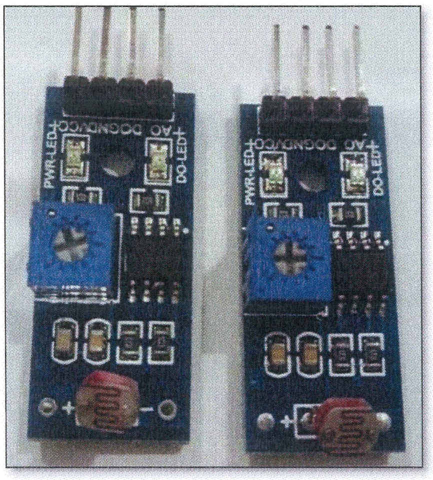


Figure 3.6: Light dependent resistor (LDR)

3.2 WORKING PRINCIPLE OF STAND-ALONE POINT-FOCUS PARABOLIC SOLAR STILL (PPSS)

Stand-Alone Point-Focus Parabolic Solar Still (PPSS) operation cycle mainly undergoes two processes which are evaporation and condensation. The desalination starts when the saline water is feed into the insulated absorber which is connected using galvanized steel pipe meanwhile the outlet of the absorber is connected to fresh water tank using copper pipe. The water flow rate for the PPSS circulation was controlled by the water pump. The purpose of water pump is to ensure sufficient amount of saline water is fed into the insulated absorber and also to prevent saline water level exceeds the highest point of the absorber. Moreover, continuous flow of saline water tends to decrease the creation of the sediment inside the circulation pump due to the reason of reduction of heat shock. A float ball with valve is used to control the water level in the insulated absorber.

The trackers will rotate the collector towards the sunlight direction. When the sunlight rays falls on the reflective concentrator surface of the parabolic concentrating dish, it will be reflected and converged to the focal point of the insulated absorber. Subsequently, the insulated absorber will absorb the sunlight and heat up the saline water which causes saline water to vaporize and thus generates steam. Then, the generated steam rises up and condenses at the upper part of the glass forming freshwater which will eventually flows down. The cylindrical glass (insulated absorber) is slanted slightly to ease the flow the freshwater to the outlet pipe. The outlet pipe here act as heat exchanger which is designed as helical coils around the inlet pipe. The heat from freshwater will be transfer to inlet saline water due to latent heat of vaporization in the heat exchanger. Thus, the temperature of the feed saline water will increase slightly before entering the insulated absorber which increases the efficiency as well.

Finally, the excess salt pumped out of the absorber to avoid sedimentation in the absorber which will reduce the absorption rate of the incoming salt water. Then, the flow of the salt water is pumped again into the insulator absorber after the accomplishment of the salt removal process. The working principal of stand-alone point-focus parabolic solar still (PPSS) is shown in Figure 3.7.

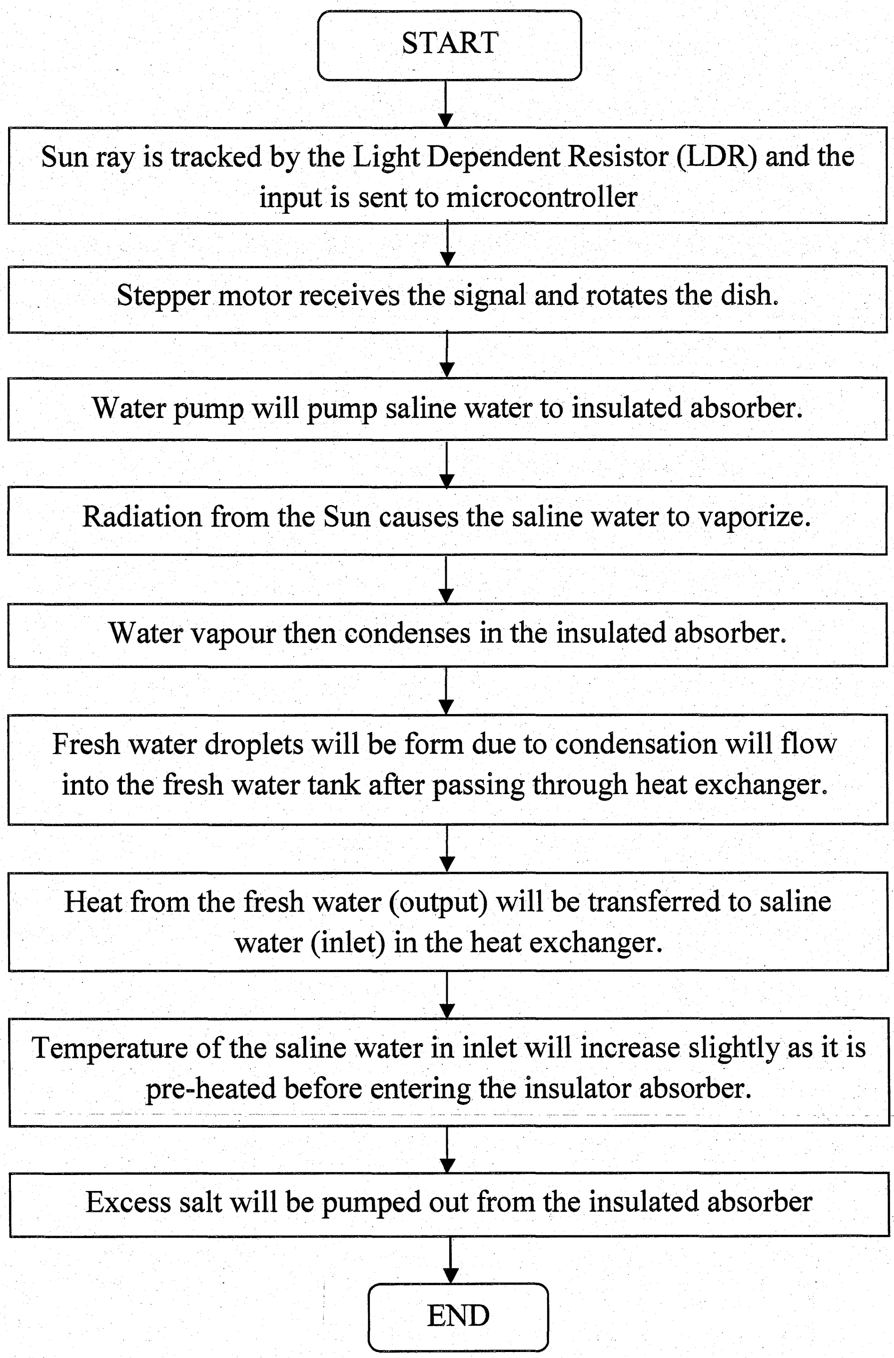


Figure 3.7: Working principle of stand-alone point-focus parabolic solar still

3.3 THEORETICAL ANALYSIS OF THE PARABOLIC DISH CONCENTRATOR

3.3.1 Prototype Geometry

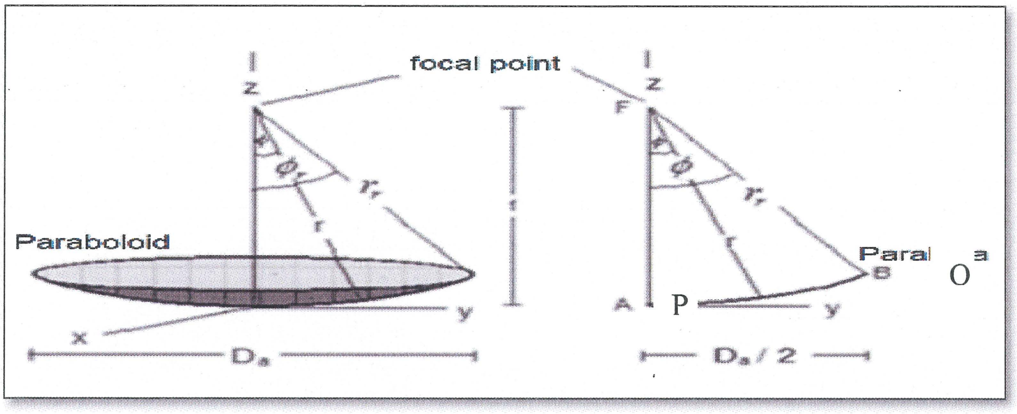


Figure 3.8: The geometry and dimension of the parabolic dish concentrator (Jorge et al., 2013)

Mathematical analysis uses the Figure 3.8 to perform and calculate the design criteria of the parabolic dish concentrator. The design criteria involve diameter of aperture, focal length from centre of aperture to the absorber, aperture angle, concentration ratio, optical efficiency and thermal efficiency. Table 3.1 show the dimension used to design the parabolic dish concentrator. Then, the diameter of aperture and depth of the parabolic dish are applying in the following equation to find the focal length from centre of aperture to the copper tube which acts as absorber. (Paul, 1998) The focal length is use to determine the location of precise and accurate focal point of the cylinder shaped copper tube wrapped with tempered glass. The accuracy of the focal point can direct influence the efficiency and productivity of the fresh water.

Calculation of the focal length from centre of aperture to the copper tube, *f*

Table 3.1: Dimension of the parabolic dish concentrator

Description	Value
Diameter of aperture, D_a (m)	0.66
Depth of the parabolic dish, h (m)	0.135
Radius of the cylinder, a (m)	0.06

$f = (D_a)^2 / 16h$

$f = (0.66)^2 m^2 / [16 \times (0.135 m)]$

$f = 0.2017 m$

Hence, the focal length from centre of aperture to the copper tube is 0.2017 m.

$\emptyset = 2 arctg\, D_a / 4f$ defines the relationship between the maximum angle with the diameter of the aperture and focal length (Jorge et al., 2013). Data such as focal length and diameter of aperture are required in calculating the maximum angle located between focal length with the diameter of the aperture is tabulated in Table 3.2.

Calculation of the maximum angle located between focal length with the diameter of the aperture

Table 3.2: Data required in calculation the maximum angle located between focal length with the diameter of the aperture

Description	Value
Diameter of aperture, D_a (m)	0.66
Focal length, f (m)	0.2017

$\emptyset = 2 arctg \frac{Da}{4f}$

$\emptyset = 2\, tan^{-1} \left(\frac{0.66}{4(0.2017)}\right)$

$\emptyset = 78.57°$

Thus, the maximum angle located between focal length with the diameter of the aperture is 78.57°.

Edge radius (r_r) or maximum distance value existing between the focal point and the parabolic extreme represented by the following equation: (Jorge et al., 2013). Table 3.3 recorded that information and values used to calculate edge radius, r_r.

Calculation of the edge radius, r_r at parabolic dish solar concentrator

Table 3.3: Data of focal length and maximum angle located between focal length with the diameter of the aperture

Description	**Value**
Focal length, *f* (m)	0.2017
Maximum angle located between focal length with the diameter of the aperture, $\emptyset$ (°)	78.57°

$$r_r = \frac{2f}{1+\cos\emptyset}$$

$$r_r = \frac{2(0.2017)}{1+\cos 78.57°}$$

r_r = 0.3367m

Therefore, edge radius (r_r) existing between the focal point and the parabolic extreme is 0.3367m.

There have a closer relationship between the concentration index and temperature that absorber by the copper tube wrapped with glass. The higher the concentration ratio, the temperature to be reached with the solar concentrator system will be also higher. Concentration index defines as ratio between the aperture area (A_a) and the area curved surface of the receiver (A_r) can be define as concentration index. (Jorge et al., 2013) $A_a = \pi r^2$ are the formula used in order to obtain the area of the aperture area and diameter of aperture, D_a is tabulated in Table 3.4.

Calculating concentration index, *C* of the PPSS system

$C = A_a / A_r$

Step 1: Find the area of aperture, A_a

Table 3.4: Diameter of aperture, D_a

Description	**Value**
Diameter of aperture, D_a (m)	0.66

$$A_a = \pi r^2 = \pi(\frac{0.66}{2})^2$$

A_a = 0.3421 m^2

The area of aperture, A_a is 0.3421 m^2.

Step 2: Find the area curved surface of the receiver, A_r

Aperture angle, radius of the absorber, edge radius, and 32' or 0.53° α angle supported by the sun seen from the earth are the data that require in calculating the area of the absorber. The angle supported by sun seen from the earth is constant because the sun receiving rays from the sun are not parallel to each other and induce a finite radius. Radius of the absorber is design and set in 0.06m for the prototype of the parabolic dish solar collector. While, c in Figure 3.9 is the hypotenuse formed between the focus and point B with Ø=78.57° and then is solve through Pythagorean Theorem. (Jorge et al., 2013). Table 3.5 shows the necessary value required in calculating hypotenuse, *c*.

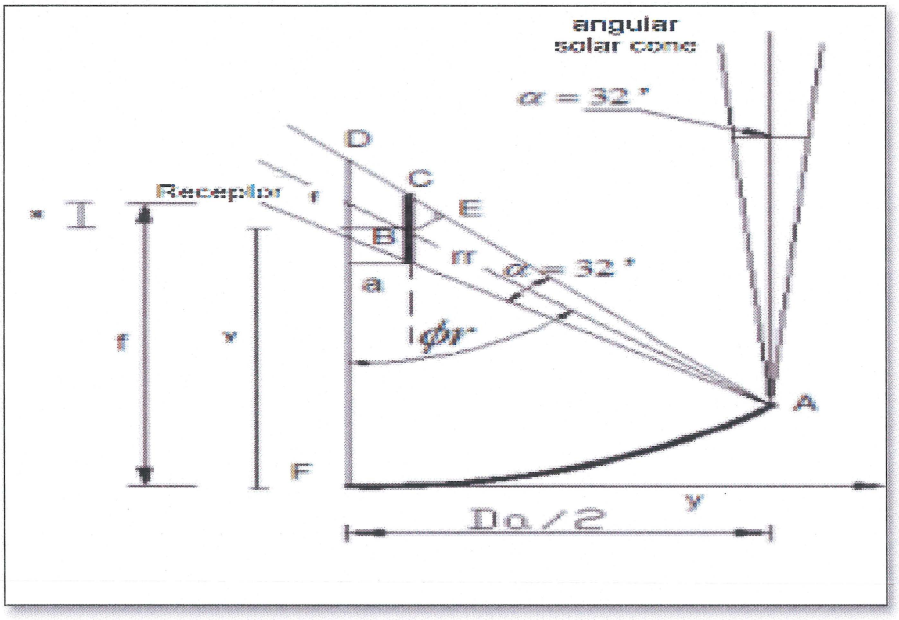
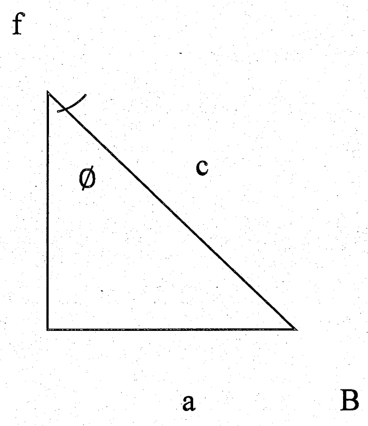


Figure 3.9: The geometry and dimension of the parabolic dish concentrator with angle reflected by the sun on the parabolic dish (Jorge et al., 2013)

Step 2a: Find hypotenuse, *c* formed between the focus point and point B with Ø=78.57°

Table 3.5: Necessary values in calculating hypotenuse, *c*

Description	Value
Radius of the absorber , a (m)	0.06
Maximum angle located between focal length with the diameter of the aperture, *Ø* (°)	78.57°



$$\sin \emptyset = \frac{a}{c}$$

$$c = \frac{a}{\sin \emptyset}$$

$$c = \frac{0.06m}{\sin 78.57°}$$

$$= 0.0612\text{m}$$

Hypotenuse, *c* formed between the focus point and point B is 0.0612m.

Now, we can obtain the length from point B to A by minus the edges radius that existing between focal point and parabolic extreme, r_r with the value of c. (Jorge et al., 2013) and these data is tabulated in Table 3.6.

Step 2b: Find length from point B to A

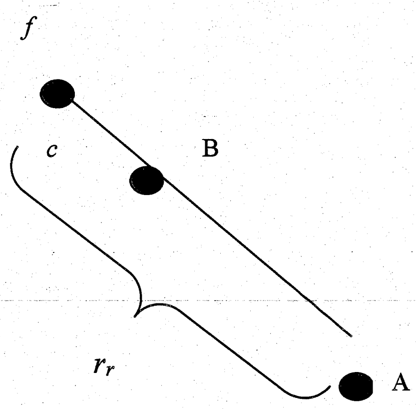


Table 3.6: Necessary values to calculate length from point B to A

Description	Value
Edge radius, r_r (m)	0.3367
Hypotenuse formed between the focus point and point B, c (m)	0.0612

Length from point B to A = r_r - c

Length from point B to A = 0.3367m – 0.0612m

Length from point B to A = 0.2755m

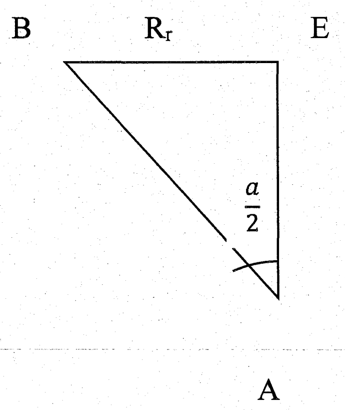
Length from point B to A is 0.2755m.

Step 2c: Find the radius of the receptor, R_r

Receptor radius, R_r can be obtained by using $sin\ \frac{a}{2} = \frac{Rr}{BA}$ that extracted from Figure 3.11 above. (Jorge et al., 2013). Necessary values to calculate radius of the receptor, R_r is recorded within Table 3.7.

Table 3.7: Necessary values to calculate radius of the receptor, R_r

Description	Value
Length from point B to A, (m)	0.2755
Angle supported by the sun seen from the earth, α (°)	0.53°



$$sin\ \frac{a}{2} = \frac{Rr}{BA}$$

$$R_r = BA\ sin\ \frac{a}{2}$$

$$R_r = 0.2755\text{m}\ sin\ \frac{0.53°}{2}$$

$$R_r = 1.2742 \times 10^{-3}\ \text{m}$$

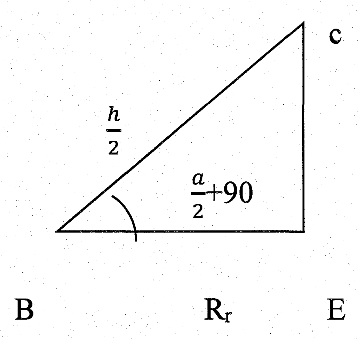
Radius of the receptor, R_r is 1.2742×10^{-3} m.

Step 2d: Find the contact surface of the cylinder shaped copper tube absorber, h

The value of the contact surface of the cylinder shaped copper tube absorber, h can be also obtained by using value of the absorber's radius, R_r and the angle located between CBE with the aid of the Pythagorean theorem and those data is recorded in Table 3.8. (Jorge et al., 2013)

Table 3.8: Necessary values to calculate contact surface of the cylinder shaped copper tube absorber, h

Description	Value
Radius of the receptor, R_r (m)	1.2742×10^{-3}
Angle supported by the sun seen from the earth, α (°)	0.53°
Maximum angle located between focal length with the diameter of the aperture, $\emptyset$ (°)	78.57°



$$cos\,(90° + \frac{a}{2} - \emptyset) = R_r / (\frac{h}{2})$$

$$h = 2\,\frac{1.2742 \text{ x } 10{-}3 \text{ m}}{cos\,(90° + \frac{0.53°}{2} - 78.57°)}$$

$$h = 2(1.30 \text{x} 10^{-3})$$

$$h = 2.60 \text{x } 10^{-3} \text{m}$$

The contact surface of the cylinder shaped copper tube absorber, h is 2.60x 10^{-3}m.

Step 2e: Area of the curved surface absorber, A_r

The area of the curved surface absorber can be determined through equation $A_r = 2\pi a h$. Table 3.9 tabulated the data necessary in calculating area of the curved surface absorber, A_r.

Table 3.9: Necessary values in calculating area of the curved surface absorber, A_r

Description	Value
Radius of the absorber , a (m)	0.06
contact surface of the cylinder shaped copper tube absorber, h (m^2)	2.60x 10^{-3}

$A_r = 2\pi ah$

$A_r = 2\pi(0.06)\ (2.60 \times 10^{-3})\ m^2$

$A_r = 9.8018 \times 10^{-4}\ m^2$

The area of the curved surface absorber, A_r is $9.8018 \times 10^{-4}\ m^2$.

Step 3: Find the concentration ratio, C of the parabolic concentration dish

The concentration ratio, C of the parabolic concentration dish can be calculated with the value of aperture area, A_a and area of curved surface of the absorber, A_r. (Jorge et al., 2013). The value of the aperture diameter and area of the curved surface absorber are recorded within Table 3.10.

Table 3.10: Necessary values in calculating concentration ratio, C of the parabolic concentration dish

Description	Value
Area of aperture, A_a (m^2)	0.3421
Area of the curved surface absorber, A_r (m^2)	9.8018×10^{-4}

$C = A_a / A_r$

$C = 0.3421\ m^2 / (9.8018 \times 10^{-4}\ m^2)$

$C = 349.0175$

The concentration ratio, C of the parabolic concentration dish is 349.0175. This means that the higher the concentration ratio, the temperature to be reached with the solar concentrator system will be also higher. However, the maximum concentration ratio which related to the area of the absorber and area of the curved surface cylinder tube absorber is inaccurate due to the reason of does not consider angular dispersion in the absorber during the calculation process. To obtain an accurate maximum concentration ratio, we should consider angular dispersion during finding the value of the contact surface of the cylinder shaped copper tube absorber through the below equation. Theoretical value of 3° for the specular deviation σ is given (Jorge et al., 2013). Information and data used to calculate accurate value of the contact surface of the cylinder shaped copper tube absorber,h_l is recorded in Table 3.11.

Calculation for determining the accurate concentration ration with considering angular dispersion

Step 1: Find accurate value of the contact surface of the cylinder shaped copper tube absorber, h_l

Table 3.11: Necessary values to calculate accurate contact surface of the cylinder shaped copper tube absorber, h_l

Description	Value
Radius of the receptor, R_r (m)	1.2742×10^{-3}
Angle supported by the sun seen from the earth, α (°)	0.53°
Maximum angle located between focal length with the diameter of the aperture, Ø (°)	78.57°
Specular deviation, σ (°)	3°

$h_l = 2R_r / [\cos(\theta - \emptyset + \frac{\sigma}{2})]$

$$h_l = \frac{2(1.2742 \, x \, 10{-}3)}{\cos(90° + \frac{0.53°}{2} - 78.57° + \frac{3}{2})}$$

$h_l = 2.6175 \times 10^{-3} m^2$

The accurate contact surface of the cylinder shaped copper tube absorber, $h_l = 2.6175 \times 10^{-3} m^2$.

With the value of the contact surface of the cylinder shaped copper tube absorber, h_l, we can use value of h_l to find the accurate maximum concentration ratio. The area of curved surface of the absorber will change according to the value of the contact surface of the cylinder shaped copper tube absorber, h_l. Nevertheless, the area of the aperture does not influence by the value of h_l and remain as 0.3421 m^2. Then, the concentration ratio, C of the parabolic concentration dish can be calculated with the value of aperture area, A_a and area of curved surface of the absorber, A_r with data tabulated in Table 3.13. While, Table 3.12 recorded the radius of the absorber and new value of the contact surface of the cylinder shaped copper tube absorber, h_1.

Step 2: Calculate new and accurate area of curved surface of the absorber, A_r.

Table 3.12: Necessary values in calculating area of the new and accurate curved surface absorber, A_r

Description	Value
Radius of the absorber , a (m)	0.06
contact surface of the cylinder shaped copper tube absorber, h (m^2)	2.6175×10^{-3}

$A_r = 2\pi ah$

$A_r = 2\pi(0.06)\ (2.6175 \times 10^{-3})\ m^2$

$A_r = 9.8677 \times 10^{-4}\ m^2$

The new and accurate curved surface absorber, A_r is $9.8677 \times 10^{-4}\ m^2$.

Step 3: Calculate accurate concentration ratio, C of the parabolic concentration dish

Table 3.13: Necessary values in calculating accurate concentration ratio, C of the parabolic concentration dish

Description	Value
Area of aperture, A_a (m^2)	0.3421
Area of the curved surface absorber, A_r (m^2)	9.8677×10^{-4}

$C = A_a / A_r$

$C = 0.3421\ m^2 / (9.8677 \times 10^{-4}\ m^2)$

$C = 346.6867$

C= 346.6867 is the accurate maximum concentration ratio of the solar collector parabolic dish. (Jorge et al., 2013) Next, the value of the diameter of the aperture and the focal length from centre of aperture to the absorber can be clarified by using the accurate maximum concentration ratio, C and the necessary data applied during the calculation is tabulated in Table 3.14.

Calculation for sizing the diameter of the aperture, D

Table 3.14: Necessary values in calculating the diameter of the aperture, D

Description	Value
Radius of the absorber , a (m)	0.06
contact surface of the cylinder shaped copper tube absorber, h (m^2)	2.6175×10^{-3}
Accurate maximum concentration ratio of the solar collector parabolic dish, C	346.6867

$C = A_a / A_r$

$C = (\pi D^2 /4) / 2\,\pi a h$

$D^2 = \frac{4C \times 2\pi a h}{\pi}$

$D = \sqrt{\frac{4C \times 2\pi\, a h}{\pi}}$

$D = \sqrt{\frac{4(346.6867) \times 2\pi \times 0.06 \times (2.6175 \times 10{-}3)}{\pi}}$

$D = 0.6600\text{m}$

The diameter of the aperture is 0.6600m and there is no different from the previous diameter of the aperture after clarifying. Thus, the focal length also can be found by using the equation stated below with the clarified diameter of the aperture. (Paul, 1998)The depth of the aperture is remaining the same with the value of 0.135 m.

Calculation for determining the new focal length from centre of aperture to the insulated absorber

$f = (\frac{Da}{2})^2 / 4h$

$f = (\frac{0.66}{2})^2 / (4 \times 0.135\text{m})$

$f = 0.2017\text{m}$

$f = 0.2017$ is the new and most accurate focal length from the centre of aperture to the cylinder shaped copper tube absorber after clarifying with the consideration of the angular dispersion. As compare to the previous reading, reading of the focal length remain unchanged and this gives a strong support and evidence on the dimension of our prototype after consideration on other factor such as angular dispersion.

3.3.2 Thermal and Optical Calculation

3.3.2.1 Optical Efficiency

The first thermal and optical analysis is regarding to the optical efficiency of the collector. The optical efficiency of the parabolic dish solar collector can be calculate through $n_o = P_c\ T_v\ \rho\ S$. (Jorge et al., 2013) The values of the receptor absorptance, transmittance of the aluminium coating, reflectivity of the aluminium coating on concentrator and shape factor are tabulated in Table 3.15.

Table 3.15: Information and values used to calculate optical efficiency

Description	Value	Reference
Receptor absorptance , P_c	0.93	Madhukeshwara et al, 2012
Transmittance of the aluminium coating, T_v	1	Jorge et al., 2013
Reflectivity of the aluminium, ρ	0.98	Flemming, 2009
Shape factor, S	0.9996	Jorge et al., 2013

Calculate optical efficiency of the parabolic dish solar collector

$n_o = P_c\ T_v\ \rho\ S$

n_o=0.93 x 1 x 0.98 x 0.9996

n_o= 0.9110 x 100%

n_o= 91.10%

After calculation, we can have 91.10% of the optical efficiency of the parabolic dish solar collector.

3.3.2.2 Average Temperature in the Absorber of the Parabolic Disc Solar Collector

Information regarding to the ambient temperature, temperature of the sun, emissivity of the copper tube, maximum efficiency range of the solar collector, maximum concentration ratio and optical efficiency of the parabolic disc solar collector are needed in calculating the average temperature in the absorber of the parabolic disc solar collector, T_{rm} and tabulated in Table 3.16.

Table 3.16: Information and values used to calculate average temperature of absorber

Description	Value	Reference
Ambient Temperature, T_{amb}	20°C or 293.15K	Blumberg, 2004
Temperature of the sun, T_{sun}	5526.85°C or 5800K	John, 2009
Emissivity of the copper tube, Σ_r	0.09	Mayank et al., 2014
Maximum efficiency range of the solar collector (80%-100%), n	0.80	Jorge et al., 2013
Maximum concentration ratio, C	346.6867	-
optical efficiency, n_o	0.9110	-

Calculating average temperature in the insulated absorber of the parabolic disc solar collector, T_{rm}

Temperature in the absorber of the solar collector can be found through the necessary value given and equation given below: (Jorge et al., 2013)

$$T_{rm} = \frac{Tamb + Tsun * \left[(1-n) * \left(\frac{no * C}{46311 * \Sigma r}\right)\right]}{2}$$

$$T_{rm} = \frac{20°C + 5526.85°C * \left[(1-0.8) * \left(\frac{0.9110 * 346.6867}{46311 * 0.09}\right)\right]}{2}$$

$$T_{rm} = \frac{103.76°C}{2}$$

$$T_{rm} = 51.88°C$$

The average temperature in the insulated absorber of the parabolic dish solar collector is 51.88°C.

3.3.2.3 Energy Absorber

$Q_{opt} = A_a\, P_c\, T_v\, \rho\, S\, I_b$ is the equation that used to calculate energy absorbed by the cylinder shaped copper tube receptor. (Jorge et al., 2013) The information regarding to the energy absorber is listed in the Table 3.17.

Table 3.17: Information and values used to calculate energy absorber, Q_{opt}

Description	Value	Reference
Area of the aperture, A_a (m^2)	0.3421	-
Receptor absorptance , P_c	0.93	Madhukeshwara et al, 2012
Transmittance of the aluminium coating, T_v	1	Jorge et al., 2013
Reflectivity of the aluminium, ρ	0.98	Flemming, 2009
Shape factor, S	0.9996	Jorge et al., 2013
Mean Direct Radiation from the sun,I_b (W/m^2)	450	Aghil et al., 2013

Calculation to find the energy absorbed by the cylinder shaped copper tube receptor, Q_{opt}

$Q_{opt} = A_a\, P_c\, T_v\, \rho\, S\, I_b$

Q_{opt} =0.3421 m^2 x 0.93 x 1x 0.98 x 0.9996 x 450 W/m^2

Q_{opt} = 140.2494 W

The energy absorbed by the insulated absorber, Q_{opt} is 140.2494 W

3.3.2.4 Receptor's Energy Loss to the Environment

Receptor's energy loss to environment must be consider the area of the receptor, the mean coefficient of the heat loss and the temperature difference between the average temperature in the cylinder shaped copper tube receptor with the ambient temperature and the information regarding these are tabulated in Table 3.21. Firstly, the mean coefficient of the heat loss, U_L must be calculated by using the equation that stated below: (Jorge et al., 2013)

Calculation to determine the energy loss from the receptor to environment

Step A: Find the mean coefficient of the heat loss

$U_L = h_w + h_r$

h_w represented the convection coefficient and h_r represented the radiation coefficient

There have two equations used to solve and calculate the convection and radiation efficient. These two equations are listed below:

Radiation coefficient, h_r $= 4\sigma \varepsilon r T_{air}^3$ (Jorge et al., 2013)

Convection coefficient, h_w $= (K_{air} / D_{out}) \times Nu$ (Jorge et al., 2013)

Step 1: Find the radiation coefficient, h_r

Table 3.18 shows the information and value used to evaluate and calculate the radiation coefficient for the receptor.

Table 3.18: Information and values used to calculate radiation coefficient

Description	Value	Reference
Stephan-Boltzmann Constant, σ ($W/m^2 *K^4$)	$5.67\text{x } 10^{-8}$	John, 2009
Emissivity of the copper tube, Ɛr	0.09	Mayank et al., 2014
Ambient temperature(°C)	20	Blumberg, 2004
Ambient temperature (K)	293.15	-

$h_r = 4\sigma\varepsilon r T_{air}^3$ (Jorge et al., 2013)

$h_r = 4 \text{ x } 5.67\text{x } 10^{-8} W/m^2 *K^4 \text{ x } 0.09 \text{ x } (293.15K)^3$

$h_r = 0.5142 \ W/ K.m^2$

The radiation coefficient, h_r is $0.5142 \ W/ K.m^2$.

Step 2: Find the Convection coefficient, h_w

Thermal conductivity of the air, diameter of the receptor and the Nusselt number are the information required to calculate convection coefficient of the receptor. Before further calculation on convection coefficient, Reynold number, Re is used to calculate Nusselt number. Different equation of the Nusselt number will be performed according to the categories of the Reynold number like Re range between 0.1 and 1000 or Re range between 1000 and 50000. The formula that applied for the Reynold number, Re calculation is stated below and its required information is shown in Table 3.19. (Jorge et al., 2013)

Step 2a: Calculate the Reynold Number, Re

Table 3.19: Information and values used to calculate Reynold Number, Re

Description	Value	Reference
Wind Velocity in Malaysia, V_{air} (m/s)	1.7	Tetsu et al., 2006
Diameter of the receptor, D_{out} (m)	0.03	-
Kinematic Velocity of air, Y_{air} (m^2/s)	1.568 x 10^{-5}	Konakav et al., 2015

$Re = (V_{air}\ x\ D_{out})\ /Y_{air}$

$$Re = \frac{\frac{1.7m}{s} \text{x } 0.03\ m}{1.568\text{x}10{-}5\frac{m2}{s}}$$

$Re = 3252.55$

The Reynold Number, Re is 3252.55

When Re range between 0.1 with 1000, then $Nu = 0.40 + 0.54Re^{0.52}$ is used to calculate Nusselt Number. While, $Nu = 0.30Re^{0.6}$ is applied for Nusselt Number calculation when Re is located between 1000 to 50000. (Jorge et al., 2013) When $Re = 3252.55$, then $Nu = 0.30Re^{0.6}$ is used in the calculation part for the convection coefficient. (Jorge et al., 2013)

Step 2b: Calculate the Nusselt Number, *Nu*

$Nu = 0.30Re^{0.6}$

$Nu = 0.30\ (3252.55)^{0.6}$

$Nu = 38.4110$

The Nusselt Number, Nu is 38.4110.

Step 2c: Calculating value of the convection coefficient, h_w

After the calculation of the Nu, then convection coefficient is represented by the following equation: (Jorge et al., 2013)

$$h_w = (K_{air} / D_{out}) \times Nu$$

The information regarding to the convection coefficient is listed in the Table 3.20 and encompass the thermal conductivity of the air, diameter of the receiver and the Nusselt Number.

Table 3.20: Information and values used to calculate convection coefficient

Description	Value	Reference
Thermal conductivity of the air, K_{air} (W/(m.K)	0.0257	Andras, 2008
Diameter of the receptor, D_{out} (m)	0.03	-
Nusselt Number, Nu	38.4110	-

$h_w = (K_{air} / D_{out}) \times Nu$

$h_w = \frac{0.0257 \text{ W/(m.K)}}{0.03m} \times 38.4110$

$h_w = 32.9054\ W/K.\ m^2$

The value of the convection coefficient, h_w is 32.9054 $W/K.\ m^2$.

Step 3: Find the mean coefficient of the heat loss, U_L

Based on the value of the radiation coefficient, h_r = 0.5142 W/ K.m^2 and convection coefficient value, h_w = 32.9054W/K. m^2, then the mean coefficient of the heat loss can be calculated by using the equation that stated below: (Jorge et al., 2013)

$U_L = h_w + h_r$

$U_L = 32.9054 + 0.5142\ W/K.m^2$

$U_L = 33.4196\ W/m^2.\ K$

Mean coefficient of the heat loss, U_L is 33.4196 $W/m^2.\ K$

Step B: Calculate receiver's energy loses to the environment, Q_{Loss}

Thus, 33.4196 W/m^2.K is the coefficient of the heat losses that will be used in calculating the receiver's energy loses to the environment, Q_{Loss}. Table 3.21 tabulated the data require in calculating the receptor's energy loss.

Table 3.21: Information and values used to calculate receptor's energy loss

Description	Value	Reference
Area of the absorber, A_r (m^2)	9.8677 x 10^{-4}	-
Mean coefficient of the heat loss, U_L (W/m^2. K)	33.4196	-
Average temperature in the receptor, T_{rm}	73.48°C or 346.63K	-
Ambient temperature, T_{amb}	20°C or 293K	Blumberg, 2004

Receiver's energy loses to the environment, Q_{Loss} (Jorge et al., 2013)

$= A_r\, U_L\, (T_{rm} - T_{amb})$

$= 9.8677\text{x}10^{-4}\, \text{m}^2 \text{ x } 33.4196\ W/m^2.\ K \text{ x } (346.63\text{-}293)\text{K}$

$= 1.7686\ W$

Receiver's energy loses to the environment, Q_{Loss} is 1.7686 *W*.

3.3.2.5 Useful Energy in the Absorber, Q_{out}

Calculating the useful energy in the absorber, Q_{out}

The useful energy delivered in the absorber can be calculated by minus the energy absorbed by the absorber with the absorber's energy loses. (Jorge et al., 2013). Energy absorbed and loss by the insulated absorber is recorded in Table 3.22.

Table 3.22: Information and values used to calculate useful energy in the absorber, Q_{out}

Description	Value	Reference
Energy absorbed by the insulated absorber, Q_{opt} (W)	140.2494	-
Receiver's energy loses to the environment, Q_{Loss} (W)	1.7686	-

$Q_{out} = Q_{opt} - Q_{Loss}$

Q_{out} = 140.2494 W – 1.7686 W

Q_{out} = 138.4808 W

The useful energy in the absorber, Q_{out} is 138.4808 W.

3.3.2.6 Thermal Efficiency, η_{inst}

The data about the useful energy delivered in the absorber, the area of the aperture and the mean direct radiation from the sun are applied in the equation list down to calculate the parabolic dish solar collector and is tabulated in the Table 3.23

Table 3.23: Information and values used to calculate thermal efficiency, η_{inst}

Description	Value	Reference
Useful energy delivered in the absorber, Q_{out} (W)	138.4808	-
Area of the aperture, Aa(m^2)	0.3421	-
Mean Direct Radiation from the sun,I_b (W/m^2)	450	Aghil et al., 2013

Calculating the thermal Efficiency, η_{inst} of PPSS system

$\eta_{inst} = Q_{out} / (A_a \times I_b)$ *(Jorge et al., 2013)*

$$\eta_{inst} = \frac{138.4808W}{0.3421m2 \; x \; 450\frac{W}{m2}}$$

η_{inst} =0.8995 x 100%

η_{inst} = 89.95%

The thermal efficiency, η_{inst} of PPSS system is 89.95%.

3.3.3 Pressure of the Pump

Pressure of the pump plays an important role in delivering the sufficient amount of the salt water to the absorber for the desalination process. The pressure of the pump can determine by using:

$$\text{Pressure, } P = \rho g\, h$$

Data of the density of saltwater, gravity and height of the parabolic dish solar collector is stated in the Table 3.24.

Table 3.24: Information and values used to calculate pressure of the pump

Description	Value	Reference
Density of saltwater, ρ (kg/m^3)	1030	Beicher et al.,2000
Gravity , g (m^3/s)	9.81	-
Height of the parabolic dish solar collector (m)	0.92	-

Calculation of the pressure of water pump

Pressure, $P = \rho g h$

Pressure, $P = 1030 kg/m^3$ x 9. 81m^3/s x 0.92m

Pressure, $P = 9295.956 \frac{\text{kg.m}}{s} \text{ x } \frac{1Pa}{1\frac{\text{kg.m}}{s}} \text{ x } \frac{1KPa}{1000Pa}$

Pressure, $P = 9.2960\ KPa$

Hence, 9.296 KPa is the pressure of water pump.

3.3.4 Productivity of the fresh water

Based on the survey done before, the productivity of the fresh water is 3.56L/m^2 per day (Arunkumar et al., 2013). After some modification on the design, the productivity can be improve by installing heat exchanges, single axis sun tracking system and coated the copper tube with black paint. In addition, the efficiency of the absorption with increase by 10% through coating the copper tube with black paint. (Abdullah et al., 2009) Thus, 4L/m^2 per day is the expected outcome of the point focus parabolic solar still.

Expected outcome for productivity of the fresh water:

= 3.56L/m^2 per day x $\frac{110}{100}$

= 3.916 L/m^2 per day

≈ 4 L/m^2 per day

3.4 PROTOTYPE

The design of the point-focus parabolic solar still (PPSS) is shown in Figure 3.10 with labels for every part of the solar still and the dimensions for every material are shown in Table 3.25.

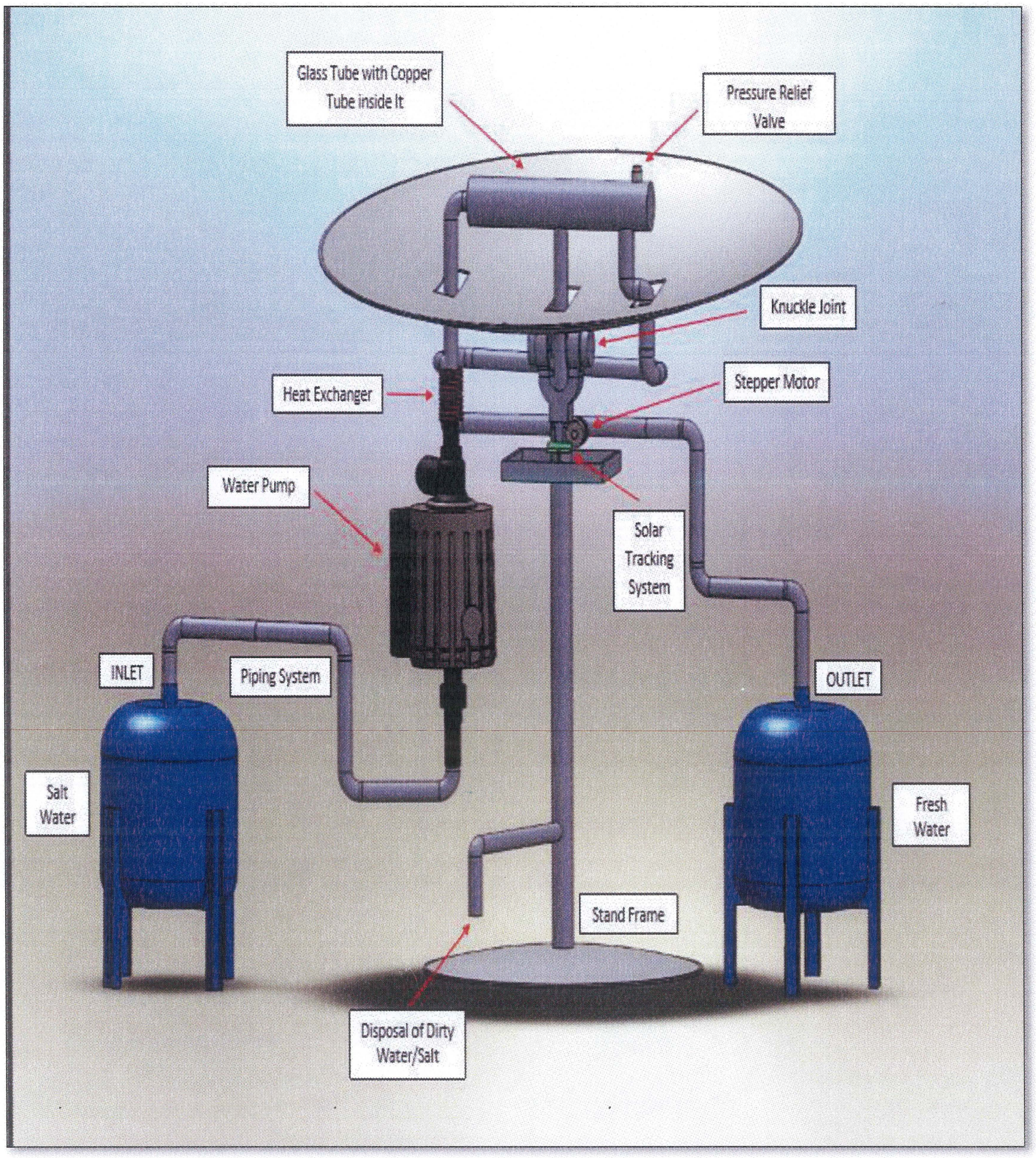


Figure 3.10: The prototype of point focus parabolic solar still (PPSS)

Table 3.25: The dimensions of the materials for point-focus parabolic solar still (PPSS)

Parameter	Value
Solar Collector Diameter	0.66 m
Solar Collector Thickness	0.0025 m
Slot Length	0.1 m
Slot Width	0.03 m
Stand Inner Diameter	0.023 m
Stand Outer Diameter	0.03 m
Glass Envelope Outer Diameter	0.12 m
Glass Envelope Inner Diameter	0.10 m
Length of Glass Envelope	0.4 m
Thickness of Glass Envelope	0.01m
Outer Absorber Diameter	0.03 m
Inner Absorber Diameter	0.028 m
Galvanized Pipe Outer Diameter	0.05 m
Galvanized Pipe Inner Diameter	0.048 m
Copper Pipe Outer Diameter	0.02 m
Copper Pipe Inner Diameter	0.018 m
Stand Frame Diameter	0.4 m
Stand Frame Height	0.5 m
Coil Diameter (Heat Exchanger)	0.007 m
Water Pump Power	12 V
Stepper Motor Power	12 V
Water Tank Capacity	10 L

3.5 OBSTACLES FACED UPON COMPLETION OF PROTOTYPE

We have many difficulties and problems when completing our prototype. However, we managed to overcome the problems with a good solution or finding other alternatives. Firstly, the weather which is not as favourable as it was raining frequently in that month. Even if it is sunny, that weather does not remain sunny for the whole day. Thus, it may affect the productivity of PPSS due to cloudy day. However, we have a backup plan which is using spotlight instead of sunlight if the weather is too bad. Next, we faced problem in sun tracking system connections. The parabolic dish is difficult to move as it stuck at a point because the frame of our prototype blocked the chain in the gear. Hence, we decided to remove the frame from its original position and welded it lower so that it will not disturb the movement of the chain. Besides that, there is lack of equipment in workshop and some part of fabrication should be handled carefully by the experienced person. So, we outsourced some parts of fabrication.

Apart from that, the parabolic dish does not look neat and clean after the aluminium foil is coated on top. We sprayed it using silver colour for aesthetic purpose as well as to increase the reflectivity. Meanwhile, the frame of the prototype is sprayed with black colour for aesthetic purpose too. In addition, we have difficulties to place the plate which is initially made up of Perspex inside the insulated absorber. This is because the plate should have enough space to place the float ball with valve inside. Then, we come up with other alternative where we bought a vacuum flask and cut it into half and replaced it with the Perspex plate. The vacuum flask has the ability to retain heat and has appropriate space to place the float ball with valve in it.

3.6 ECONOMIC ANALYSIS

The economic analysis helps to decide whether a project or technology is worth implementing by taking into account few factors such as supply and demand in the goods, services, and maintenance. Cost analysis is essential in determining the PPSS is cost effective or not. Few parameters are determined in order to carry out economic analysis such as capital cost, operation cost, maintenance cost, and the cost of fresh water produced.

i) Capital Cost

Capital cost is the total cost of PPSS which encompasses of purchasing main components and complete fabrication. Table 3.12 shows the capital cost of prototype which is RM 865.49 depending on the material used and size.

Table 3.26: Total Cost of Prototype

NO	ITEMS	QUANTITY	PRICE (RM)
1	Fabrication Cost (Outsourced)	N/A	90.00
2	Silicone Glue	1	36.00
3	Aluminium Foil	N/A	13.50
4	Mild Steel Tube (For Parabolic Stand And Glass Holder)	N/A	70.00
5	DC Gear Motor + Roller Chain	1	100.00
6	Light Sensor Module	1	4.50
7	Arduino Kit	1	80.00
8	LDR Sensor	8	2.40
9	Stainless Steel Pipe	N/A	32.00
10	Galvanized Pipe	N/A	8.00
11	Copper Pipe	N/A	90.00
12	DC Water Pump	1	100.00
13	Gallon Tong	2	79.80
14	Flexible Hose Pipe	2	19.00
15	Plastic Wheel	4	10.50
16	Cylinder Glass	1	25.90
17	Vacuum flask	1	33.90
18	Socket	1	8.30
19	Copper Connector	3	6.60
20	PVC Arm Connector	2	15.40
21	B.S 9.5 Drill	1	15.73
22	20mm Hole Saw	1	9.96
23	Spray Paint	2	14.00
	TOTAL		**RM 865.49**

ii) Annual Fresh Water Production and Payback Period

It is assumed that the PPSS is operated 10 hours per day for 340 days (which is estimated to be sunny). The average volume of fresh water obtained per day is ml which is equivalent to

Annual fresh water production = 0.1483L x 340 days

= 50.42 L per year

Since the fresh water from the PPSS can be used to replace the filtered RO water, the cost of RO water in bottle for 1 L is used to calculate the payback period. Given the cost for RO water in bottle is RM1.64 for 1 L.

Annual cost saving = 50.42 L x RM 1.64

= RM 82.69

Hence, Payback Period = Investment Cost / Annual Saving

= RM 865.49/ RM 82.69

= 10.5 years $\simeq$ 11 years

The capital cost of this prototype is considered low because the total cost is less than RM 1000. The annual saving obtained was approximately RM83 and the payback period is 11 years. The payback period is quite long due to some factors such as weather and solar radiation received. The solar irradiance for each country is not the same and it varies according to location and angle. Besides, Kuantan areas are experiencing cloudy day and raining season now. Due to the small scale of the prototype, the lower productivity leads to longer payback period. Therefore, by increasing the size of the collector and absorber, the annual saving can be increased.

ii) Operating and Maintenance costs

The Operating and Maintenance (O & M) costs encompasses the cost related to regular cleaning of the water tank, replacing or mending the broken parts, protecting the pump, heat exchangers and piping system from corrosion. Approximately, 20% of the capital investment can be taken for O & M.

(20/100) x RM 865.49= RM 173.10

iii) Energy cost

Energy cost is also important because water pump and solar tracker system requires electricity to perform. Since the power consumption is not much, 10% of capital investment can be taken for electricity cost.

(20/100) x RM 865.49= RM 173.10

3.7 PROJECT TIMELINE FOR SENIOR DESIGN PROJECT 2

ACTIVITY	WEEK																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Short briefing with Dr. Che Ku	■								■									
Meeting with project supervisor		■			■					■								
Materials or costing listing	■	■	■															
Preparation of quotation letter for material purchasing		■	■															
Fabrication of prototype – parabolic dish concentrator and base frame support			■	■														
Testing on the performance and efficiency of the evaporation rate				■	■	■												
Discussion on the project and task distribution						■												
Fabrication of prototype – glass drilling process						■	■											
Preparation for individual thesis report						■	■	■	■	■	■	■	■	■				
Fabrication of prototype – piping and welding process									■	■								
Fabrication of prototype – motor, LDR and sun tracker installation process										■	■							
Fabrication of prototype – water pump and damper installation process											■	■						
Fabrication of prototype – insulated absorber											■	■						

ACTIVITY	WEEK																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Fabrication of prototype – Piping process																		
Testing on the performance of prototype																		
Data Recording																		
Investigation experimentally on the quality of the fresh water produced																		
Task distribution on the group report and poster																		
Submission of individual thesis report																		
Submission of log book																		
Submission of group report																		
Submission of peer evaluation form																		
Poster Printing																		
Mock-presentation of project																		
Presentation of project																		
Improvisation of the final individual thesis report																		
Submission of the final individual thesis report																		

MILESTONES FOR SENIOR DESIGN PROJECT 2

Week 1 : Briefing for Senior Design Project 2.

Week 2 to 3 : Materials listing to be purchased for fabrication process.

Week 3 to 4 : Material arrival and start fabrication.

Week 4 to 6 : Conduct experiment and distribution of task.

Week 6 to 14 : Preparation of individual thesis report.

Week 9 to 10 : Piping and welding process.

Week 10 to 11: Sun tracking system installed and tested.

Week 11 to 12 : Water pump installed and tested.

Week 12 to 13 : Final touching and adjustment of prototype.

Week 13 to 14 : Testing and data collected.

Week 14 : Data analysis and thesis correction.

Week 15 : Submission of first draft thesis and extended abstract.

Week 16 : Correction of thesis.

Week 17 : Preparation of poster for presentation and a mock presentation is conducted.

Week 18 : Presentation of Senior Design Project 2 and final individual thesis report submission.

3.8 ETHICAL CONSIDERATION

Upon completion of our project, there are some ethical considerations included especially matters pertaining to materials purchasing and designing the solar desalination plant. Firstly, in designing stage, we took into account the aspects of modifications so that is has the ability to easily modify for future purposes. Besides, some materials such as water pump and copper pipe are expensive. Therefore, a systematic and proper usage of material has been given high priority as damages on these materials cannot be mended. Especially, the water pump is very sensitive to debris. Thus, good care is needed in order to prolong the lifespan of water pump. Furthermore, we have outsourced some parts of the fabrication due to lack of equipment in workshop. The fabrication outsourced includes the welding of copper pipe to heat exchanger. During the journey of completion of project, we seek advice and guidance from JP's and lab assistant. They are people who allocated to assist us by faculty. Each time when doing fabrication in workshop or experiment in lab, we always follow safety measures and precaution to avoid accidents. Lastly, the task for each team member is distributed equally and fairly depending on capabilities of the member. In addition, each of the team members has the right to voice out their opinion. In order to coordinate well with the project advisor, we had meeting often with the advisor to update the progress so that both sides will have common understanding about the project.

3.9 GROUP INTERACTION

The members of this group worked together since early of year 2016. The members of this project are from three different backgrounds; three from Energy & Environmental, one from Electrical & Electronic and another one from Manufacturing. We held meeting and discussion for few times among us to discuss about the project's progress and task distribution. We also did fabrication together in workshop. Meeting with project advisor as well as the supervisors is held once in a week.

Dr Samson Mekbib Atnaw is our project advisor for this project whereas Madam Siti Aishah and Dr. Roshahliza are supervisors. On top of that, our faculty has guided us by setting a proper timeline for the team to follow and support us in administrative issues, purchasing related matters and knowledge sharing.

Thaneissha a/ p Marimuthu responsible to do the analysis for the sample collected including testing the conductivity and salinity of fresh water. Meanwhile, Sim Shu Yi did calculations for energy analysis of point focus parabolic solar concentrator. Priyatharishini a/p Mardarveran are in charge for the measurement of solar irradiance and cost analysis. Muhammad Khairi bin Md Gapar main contribution was programming the solar tracking and fabrication whereas Mazlin Azura binti Usop in charge of material selection, fabrication, and drawing. Overall, each of us has done equal research through online, journals and books to support the project's execution. Even though each of us has different task to perform, we still managed to work in team and respect each other's opinion.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

For this thesis, we required to collect some data and make analysis to determine the productivity of PPSS. One of the parameters that need to be measured is solar irradiance. Solar irradiance is the power per unit area received from the Sun in the form of electromagnetic radiation. It varies with the geographical location. Besides that, it is measured perpendicular to the incoming sunlight. In the case of solar irradiance, it is usually measure the power per unit area, so irradiance is typically quoted as W/m^2 that is Watts per square meter. Table 4.1 shows tabulation of data for the solar irradiance (W/m^2) measured every 1 hour. Using the data in Table 4.1, a graph to illustrate the pattern of solar irradiance is plotted as shown in Figure 4.1.

Table 4.1: The average solar irradiance (W/m^2) measured for three consecutive days

Time	Solar Irradiance (W/m^2)		
	Day 1	**Day 2**	**Day 3**
8.30 a.m.	575.7	470.7	350.7
9.30 a.m.	821.5	891.5	413.5
10.30 a.m.	845.7	940.7	448.7
11.30 a.m.	895.5	975.5	690.5
12.30 p.m.	910.5	1012.9	710.5
1.30 p.m.	917.7	995.7	717.7
2.30 p.m.	895.2	870.2	595.4
3.30 p.m.	307.2	507.2	307.2
4.30 p.m.	191.8	396.8	190.3
5.30 p.m.	192.7	295.7	187.9
Average	**655.35**	**735.69**	**461.24**

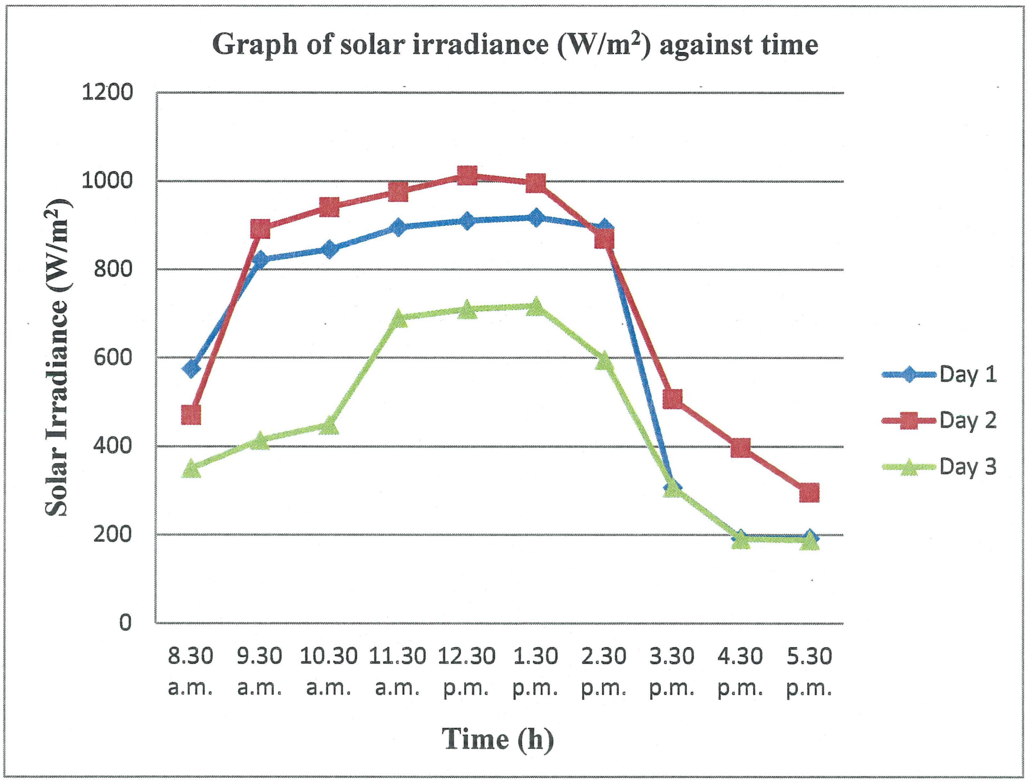


Figure 4.1: Solar Irradiance (W/m^2) against time (h)

From the graph above, Day 2 shows the highest solar irradiance received by the PPSS throughout the day whereas Day 3 shows the lowest solar irradiance due to cloudy day. Basically, the pattern of solar radiation seems to be increasing every hour from 8.30 a.m. till it reaches the peak at noon. From 12 p.m. to 2 p.m. the solar radiation is quite high and almost consistent. After 2.30 p.m., the trend shows that solar irradiance decreases drastically because it is the time for sunset. For Day 1, 2 and 3 the amount of fresh water collected is measured and tabulated in Table 4.2.

Table 4.2: The amount of fresh water produced (ml) for three consecutive days

Amount of fresh water (ml)	Day 1	Day 2	Day 3	Average
	155	170	120	148.3

A graph is plotted to determine the relationship between the solar irradiance and the volume of freshwater collected for point focus parabolic solar still as shown in Figure 4.2. Based on the Figure 4.2, the amount of fresh water increases when the solar irradiance increases. As the evaporation takes place using solar energy it is a given fact that productivity increase with solar intensity. The more intense the solar radiation, the faster the rate of evaporation takes place which results in higher productivity. Based on Figure 4.2, it is found that for an increase in solar irradiance from 655.35 W/m^2 to 735.69 W/m^2, the production of fresh water also increased from a value of 155 ml to 170 ml. Meanwhile, for a decrease in solar irradiance from 735.69 W/m^2 to 461.24 W/m^2, the fresh water production decreased sharply from a value of 170 ml to 120 ml. Thus, it is proven that the solar irradiance is the major factor that influence the volume of fresh water produced which also affects the productivity of PPSS.

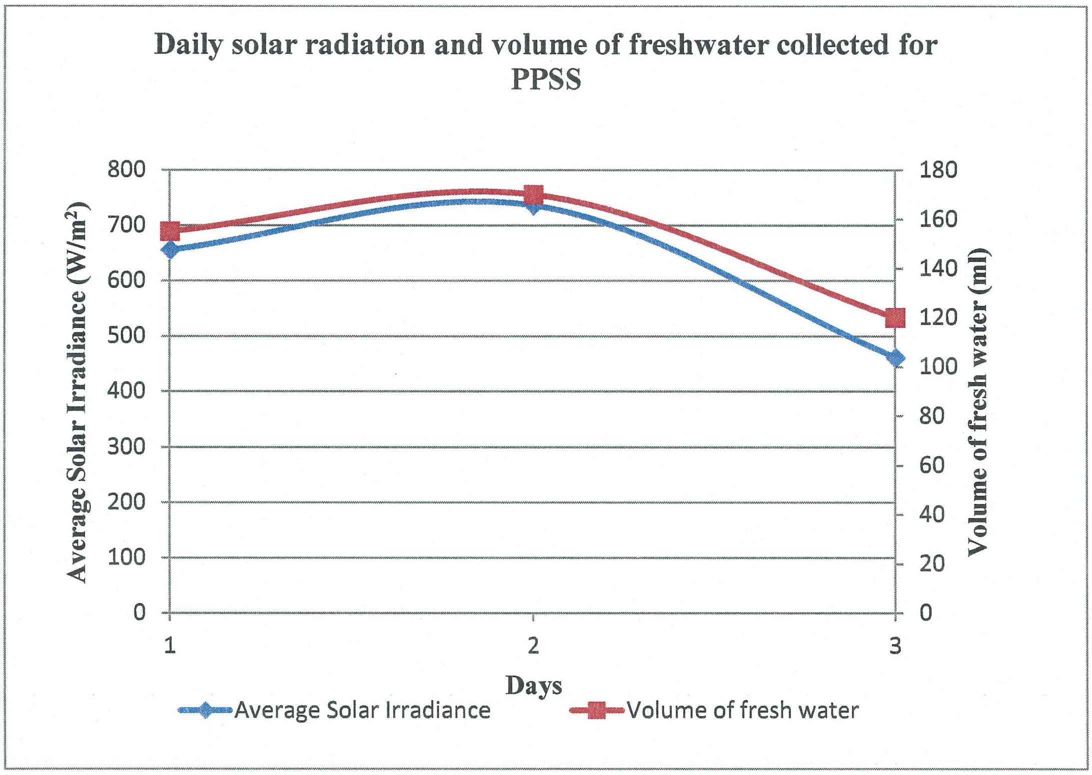


Figure 4.2: Daily solar radiation and volume of freshwater collected for PPSS

Table 4.3: The comparison of salinity and conductivity of distilled water, seawater and fresh water for three consecutive days

Type of Water	Conductivity (mS)				Salinity (ppt)			
	Day 1	Day 2	Day 3	Average	Day 1	Day 2	Day 3	Average
Distilled water	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Seawater	40.80	40.70	40.80	40.77	20.40	20.30	20.10	20.37
Fresh water (output)	2.85	2.54	2.67	2.69	1.42	1.45	1.53	1.47

Table 4.3 shows the comparison of salinity and conductivity of distilled water, seawater and fresh water for three consecutive days. This is done by using conductivity meter where the sample is tested for the concentration of salt (parts per thousand) before and after the desalination process. The seawater contain high amount of salt. In order to produce freshwater through solar desalination process, the salinity in water need to be reduced. Figure 4.3 shows the comparison for concentration of salt in seawater (before solar desalination) and fresh water (after solar desalination) for three consecutive days. In other words, it also represents the percentage reduction of salt through solar desalination process.

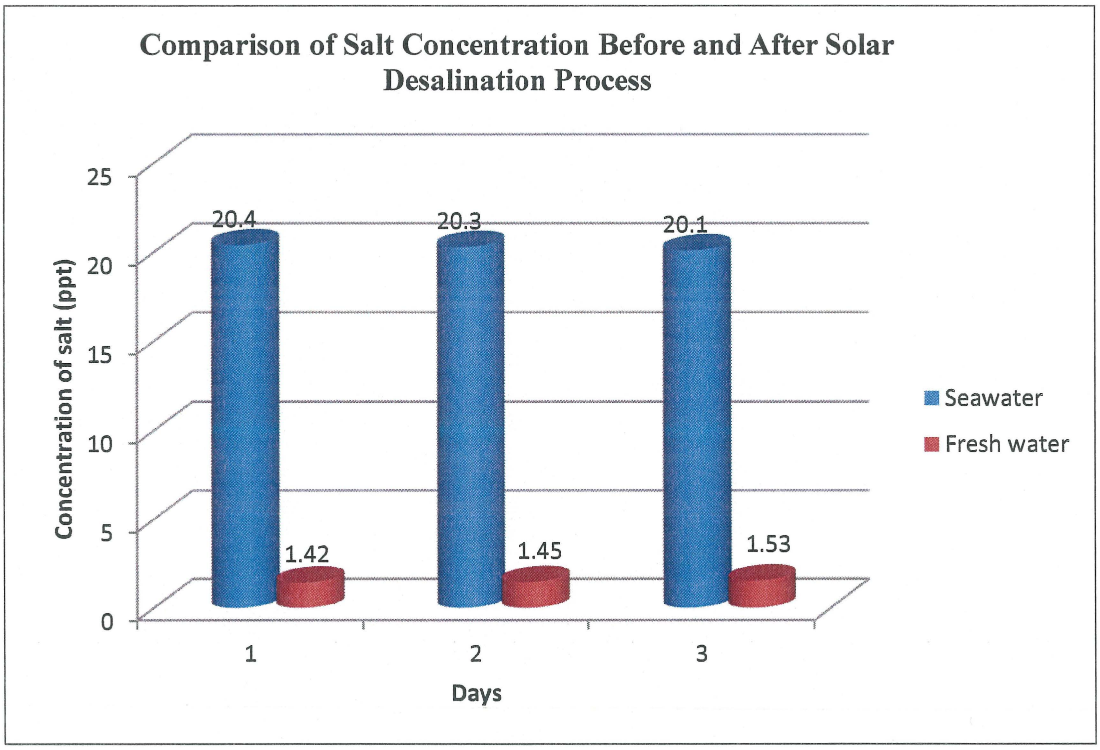


Figure 4.3: Percentage Reduction of Salt through Solar Desalination

From Figure 4.3, it is obvious that the salt concentration in reduces significantly after undergoing desalination process. On day 1, 93.0% of salt concentration is reduced whereas on day 2 and day 3, 92.9% and 92.4% of salt concentration is reduced respectively. From the Table 4.3, the conductivity of fresh water is found to be lower compared to the seawater. This is because only water will be evaporated and the salt and other inorganic matters will be left behind. So, there is no ions exist in freshwater to enable it to conduct electricity. This show that the solar desalination using point focus parabolic solar still is an effective method to reduce the salinity and conductivity in seawater.

4.2 DISCUSSION

In order to achieve our objective, the productivity of PPSS is calculated to make comparison with the existing PPSS.

The productivity of PPSS = Average volume of fresh water obtained / Area of Aperture

$= 0.1483 \text{ L} / 0.3421 \text{ m}^2$

$= 0.433 \text{ L/m}^2$

The productivity of PPSS obtained after testing our prototype is 0.433 L/m^2 where it is very much lower than the existing PPSS which has productivity of 3.56 L/m^2 per day (Arunkumar et al., 2013). It is due to certain limitations which will be explained further. Basically, the productivity of the PPSS is affected by certain factors. They are solar intensity, ambient temperature, size of the solar collector, size of the insulated absorber and etc. In this case, we focused more on the variation of solar radiation which influence the performance of PPSS. The solar irradiation is measured using Solar Power Meter as shown in Figure 4.4. Based on the results, it is found that the volume of fresh water increases as the intensity of solar radiation increases. This is because solar radiation has the ability to convert the saline water to water vapour by using heat from the sun through evaporation process. So, if the intensity of sunlight is high, the heat absorbed by the water also will be high and thus more water molecules will evaporate as water vapour leaving the salt behind. However, intermittent solar irradiance due to cloud and lower solar intensity may have played a factor in our experiment. Due to cloudy day, the productivity of this PPSS is not so high compared to existing one.

In addition, the parabolic dish in our prototype is designed to concentrate the solar radiation at one point which helps to increase the temperature of insulated absorber indirectly and we also utilized the direct sunlight by using glass as insulated absorber. Unlike other desalination process, the disinfection stage can be skipped in this solar desalination process because the direct sunlight can kill the microorganisms in the water providing fresh water supply. However, the parabolic dish and surface area of absorber were made in small scale in our prototype. This may also consider as one of the limitations which causer low productivity of PPSS. In the existing PPSS, the parabolic dish has diameter of the aperture of 2m and the absorber has a receiving surface of 0.031 m^2 whereas for our PPSS, the parabolic dish has diameter of the aperture of 0.66m and the absorber has a receiving surface of 9.8018×10^{-4}m^2

which are very small compared to existing PPSS. The parabolic dish with larger diameter has the ability to reflect more incoming solar radiation to the absorber and the absorber with bigger receiving surface area allow the water to get heated up easily. Thus, it is proven that PPSS with smaller scale of parabolic dish and absorber may lead to lower productivity.

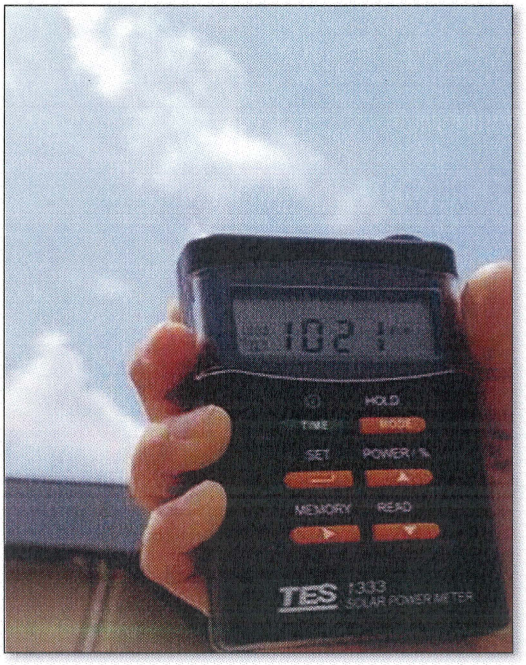


Figure 4.4: Solar Power Meter

On top of that, the concentration of salt is reduced significantly through solar desalination process. Seawater is known to be rich with salty water. In order to produce fresh water, it is crucial to remove the salt concentration. We tested the sample using Conductivity meter as shown in Figure 4.5. We analyzed three parameters using this equipment which are temperature, salinity and conductivity. For the salinity test, the percentage reduction of salt concentration exceeds 90% for all three days which means that this PPSS is effective enough to be used for domestic purpose. Next is conductivity test which is done to measure the water's ability to conduct electricity. Usually, distilled water or pure water is a poor conductor of electricity whereas water with salts or other inorganic chemicals dissolved in it is known as a good conductor of electricity. This is because the salt or inorganic chemicals can break into tiny particles which have electrically charged known as ions. These free moving ions have the ability to conduct electricity. From the results obtained, the conductivity has also been successfully reduced as much as 90%.

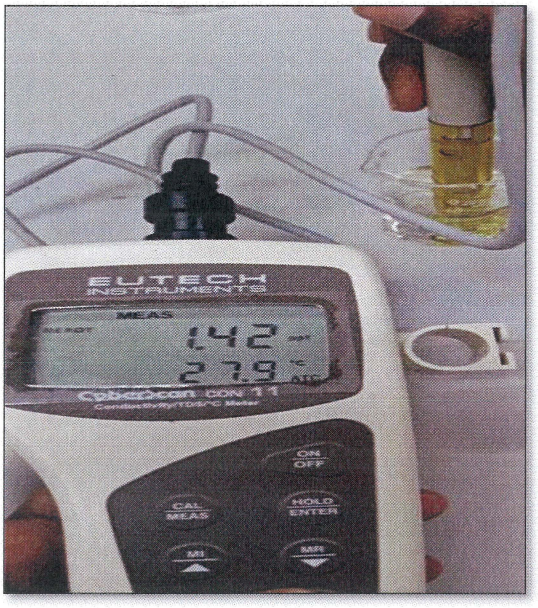


Figure 4.5: Conductivity meter

In this design, we made two main modifications which are installing sun tracking system and heat exchanger. Sun tracking system in order designed is made up of low cost materials and compatible which is in accordance to our second objective. The trackers used are two LDRs which direct solar collector toward the sun. These devices have the ability to change their orientation throughout the day relative to the sun's path to maximize energy capture. Besides, the trackers help minimize the angle of incidence (the angle that a ray of light makes with a line perpendicular to the surface) between the incoming light. It is essential for all the concentrated solar systems to have trackers because the systems do not produce energy unless it is directed correctly toward the sun. A single-axis solar tracker rotate on one axis moving back and forth in a single direction is used in our prototype which works well in capturing maximum sunlight.

Finally, the heat exchanger efficiency is calculated to determine the heat is loss or gain during desalination process. The heat exchanger used is counter current heat exchanger. Since there is no shaft work in heat exchangers, the energy balance equation for heat power emitted from the hot freshwater becomes;

$$Q_E = \dot{m}_e \, C_{p,e} \, (T_{in,e} - T_{o,e})$$

where, $\dot{m}_e$ is the hot fluid flow rate, $C_{p,e}$ is the specific heat capacity for freshwater, $T_{in,e}$ and $T_{o,e}$ are the inlet and outlet of freshwater temperatures respectively. Given the mass flow rate of freshwater, $\dot{m}_e = 0.03$kg/h, $C_{p,e} = 4187$ J/kg.K, $T_{in,e} = 338$ K and $T_{o,e} = 333$ K.

Whereas the heat rate of heat absorbed (saline water) is given by,

$$Q_A = \dot{m}_a C_{p,a} (T_{in,a} - T_{o,a})$$

where, $\dot{m}_a$ is the hot fluid flow rate, $C_{p,a}$ is the specific heat capacity for freshwater, $T_{in,a}$ and $T_{o,a}$ are the inlet and outlet of freshwater temperatures respectively. Given the mass flow rate of freshwater, $\dot{m}_a = 0.03$kg/h, $C_{p,a} = 3993$ J/kg.K, $T_{in,a} = 299$ K and $T_{o,a} = 301$ K

$Q_E = (0.03\text{kg/h}) \times (4187 \text{ J/kg.K}) \times (338 \text{ K} - 333 \text{ K})$

$= 628.05$ J/h

$Q_A = (0.03\text{kg/h}) \times (3993 \text{ J/kg.K}) \times (26 \text{ K} - 28 \text{ K})$

$= -239.58$ J/h

If the insulation of the heat exchanger is perfect, the heat power emitted from the hot freshwater is equal to the heat power absorbed by the saline water. From the calculation above, only 239.58 J/h is absorbed. Since the perfect insulation is not achieved, heat power lost is calculated by,

$= |QE| - |QA|$

$= |628.05| - |-239.58|$

$= 388.47$ J/h (heat loss)

Finally, the percentage gain of heat power is given by,

$$P = [\,|QA| / |QE|\,] \times 100$$

$P = [239.58 / 628.05] \times 100$

$= 38.15$ % of heat gain.

Based on the calculation above, it is found that the heat gain is 38.15% which means that more than half of total heat emitted is loss to the surroundings. This may be due to no proper insulation for the heat exchanger as it is left open without any insulation. In order to improve the heat transfer, a black insulation box can be fixed surrounding the heat exchanger to reduce the heat loss to surrounding and avoid its exposure from wind.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

In a nutshell, issues related to scarcity of water have inspired us to develop a solar desalination system which uses naturally occurring resources to produce freshwater. Uniquely, point focus parabolic solar still (PPSS) that we made is environmental friendly, made up of non-fragile materials and low cost. Our PPSS can be beneficial to those who are staying at seaside, marine militaries and engineers at offshore. The freshwater from this plant can be used instead of using seawater for domestic purpose. This will reduce the burden for plenty of people because they do not have to search for freshwater whenever they are in ocean. As long as they have this plant, freshwater can be gained especially for marine militaries and offshore engineers in Malaysia who spend most of the time in ocean. Our desire is to fulfill their need as they are also the asset of our country.

Our PPSS entails of sun tracking system and heat exchanger which helps to enhance the productivity of the plant. The productivity of our PPSS is 0.433 L/m^2 which is lower compared to existing one due to some limitations as mentioned previously. However, these problems can be solved using alternate solutions as recommended in next subtopic. This PPSS gives a lot of benefit to the Earth. The utilization of solar energy instead of non-renewable energy actually combats global warming and reduces the emission of greenhouse gases. On top of that, the groundwater depletion can be prevented since we are consuming the water from ocean for this plant. By considering pros and cons, PPSS is found to be effective and eco-friendly technology.

5.2 LIMITATIONS AND RECOMMENDATIONS

There are some limitations and drawbacks in our study which can be further improved in future. Firstly, there is no particular pipe or exit hose for the excess salt to be sucked out. So, it has to be done manually for the current prototype. In future, a pipe which is resistance to corrosive can be connected to the vacuum flask to suck out the excess salt in it by using valve. Next, the vacuum flask surface a silver surface which may cause the sunlight received to reflect back. Due to time limitation, we did not paint the surface with black colour since we have to import the food-graded black paint as it is not available in Malaysia. By coating the surface with food graded black paint, the heat in absorber can be retain as well as enhance the rate of evaporation. On top of that, we faced obstacles when carrying out the test during December month because it was raining season in Kuantan and most of the time the sky will be cloudy. So, it is difficult to obtain accurate reading. This factor cannot be prevented as our final year project timeline has been set at this period of time. More testing can be done during sunny day in order to obtain accurate results. It will be even better if the testing is done beside the sea. Apart from that, the productivity can be increased by enlarging the surface area of collector and installing a wiper to wipe out all the water droplets as it has difficulties to flow down at certain time. Finally, the fresh water obtained can be used for domestic purposes but not for drinking purposes since not all the parameters of water quality is measured. Hence, research can be done on how to improve the fresh water quality to be used as drinking water.

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