The Performance Investigation on a Solar Still Distillation System Combined with PV-DC Heater System

By

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15509

Dissertation submitted in partial fulfilment of

the requirements for the

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Certification of Approval

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Approved by,

____

(AP DR. HJ. KHAMARUZAMAN WAN YUSOF)

Universiti Teknologi PETRONAS

Certification of Originality

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

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(MUHAMMAD IZZAT BIN AZMI)

ABSTRACT

Water scarcity and pollution pose critical situation in all walks of life especially in the developing countries. Among the available purification technologies, solar distillation process proves to be a suitable solution for resolving this existing crisis. This renewable energy technology operates on a basic principle of which the solar radiation enters through the glass surface inside a closed chamber touching the black surface generating heat energy, which gets trapped inside. This gradually raises the temperature of the liquid resulting in evaporation process and further condensation, which is drained out for use. However, the distilled water produced by the solar still system is very limited. Hence, this paper presents the experimental results of the performance of the solar still system using the combination of PV-DC heater. This experiment will be conducted in Universiti Teknologi PETRONAS (UTP) solar field testing facility. The weather forecast and solar radiation intensity data will be obtained from Ipoh Meteorological Department for the experiment. The parameters of the basin size, cover material and water depth are fixed. Generally, 3 types of experiments will be conducted;

- Active solar still system combined with PV-DC heater
- Passive solar still system with black painted basin
- Conventional passive solar still

From this experiment, data of the water basin temperature, inner glass cover temperature, and ambient temperature will be collected and tabulated hourly. Theoretically, the more temperature differences between the water basin temperature and inner glass temperature, the more evaporation rate will be produced.

ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratefulness to Allah SWT for giving me the strength, motivation and good health during the completion of my project. Without His blessing, I would not be able to complete my FYP.

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Not to forget to my beloved parents, family, beloved soul mate and friends for the continuous prayers throughout my FYP completion. Without them, I would not be as fortunate as I am today.

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CHAPTER 1

INTRODUCTION

Introduction

Freshwater is perhaps the most crucial resource for humans and all other living creatures on earth. Our life revolves around water, and sufficient clean water is essential for our healthy living as well as the health of the environment.

Malaysia receives abundant rainfall averaging 3,000mm annually that contributes to an estimated annual water resource of some 900 billion cubic metres.

About 97% of our raw water supply for agricultural, domestic and industrial needs are derived from surface water sources primarily rivers. Malaysia has 189 river basins - 89 in Peninsular Malaysia, 78 in Sabah and 22 in Sarawak. All the rivers originate and flow from the highlands (Jabatan Meteorologi, 2014).

The highland forests and wetlands (including forested wetlands and water bodies such as river systems) constitute key freshwater ecosystems in the country that deliver a multitude of benefits, from providing natural resources, gene pools, and habitats for flora and fauna, to enabling water purification and flood control.

These freshwater ecosystems are facing numerous threats and challenges. In fact, the extreme climate nowadays also becomes a huge contributing factor to the eruption of freshwater supply in Malaysia. The eruption supply of fresh water will give a major impact to the living in the remote area, where there are no piped water supply especially in remote of Sabah and Sarawak. This will give a huge impact to all living thing and ecosystems especially humans.

Recognising this, a research and study have been developed on producing the potable water using solar still distillation process. A solar still is a simple way of distilling water, using the heat of the sun to drive evaporation from humid soil, ambient air or any source of untreated water to collector plate. The water collected is clean and fresh. Aezzah (2013) stated that the water produced from solar still system meet all the standard requirement of World Health Organisation (WHO) for drinking water quality.

To achieve this, a high intensity of solar radiation is needed, and our country has a good potential in that area. Being a maritime country close to the equator, Malaysia naturally has abundant sunshine and thus solar radiation. However, it is extremely rare to have a full day with completely clear sky even in periods of severe drought. The cloud cover cuts off a substantial amount of sunshine and thus solar radiation. On the average, Malaysia receives about 6 hours of sunshine per day. There are, however, seasonal and spatial variations in the amount of sunshine received. Alor Setar and Kota Bharu receive about 7 hours per day of sunshine while Kuching receives only 5 hours on the average. On the extreme, Kuching receives only an average of 3.7 hours per day in the month of January. On the other end of the scale, Alor Setar receives a maximum of 8.7 hours per day on the average in the same month (Jabatan Meteorologi, 2014).

Solar radiation is closely related to the sunshine duration. Its seasonal and spatial variations are thus very much the same as in the case of sunshine. Therefore, it has been a great challenge to this research, on how to generate the high scale of potable water, with the high rate of the production by the evaporation process. There are many previous research that have done before regarding the solar still system, but to increase the production rate, external sources is needed instead of solar energy alone. In this research, author will use the combination of PV-DC heater and solar flat plate collector as the external sources to increase the productivity of potable water collected.

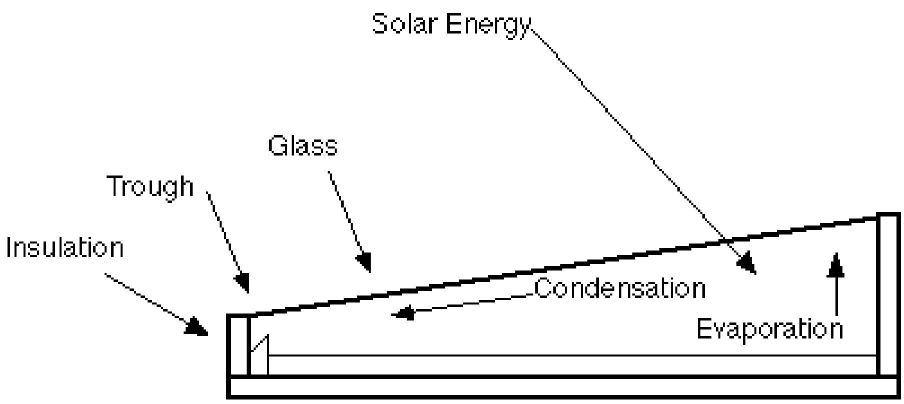


Figure 1: Basic Solar Still System

Problem statement

Clean and fresh waters production is decreasing globally, due to the pollution and several global issues. Though, to increase the productivity of the fresh and clean water is important to the mankind. On top of that, supplying the clean and fresh water to the rural areas has become a critical problem that we need to overcome. As clean and fresh water is important for human being, solar energy can help in order to solve this problem, in order to purify the water to ensure the water supply is clean and fresh. During dry season, water interruption will occur. Thus, the solar energy that available especially during the dry season will be used as a solution to the problem. Therefore the solar system can produce potable water, the problem occurs when the productivity of the potable water is very low. Though, this research also focuses on how to increase the productivity of the potable water of the solar still system using the combination of PV-DC heater.

Objectives

Based on the problem statement, we realize that to produce the potable water using the solar still distillation system is possible but this research will emphasize on how to increase the rate of production of the potable water by the evaporation process. This research is giving an overview of the impact of the using of PV-DC heater in order to get the maximum production rate of potable water collected. This research also can provide community service for the farmers and the population of the remote area by providing potable water during dry season in a big scale via solar still farm.

Listed below are the objectives of the project:

1. To evaluate the impact of solar still system using the PV-DC heater towards the production rate of potable water system through the evaporation process in solar still system.
2. To determine the amount of potable produced.

Relevancy & Impact of Research

With references to the Problem Statement section, we know that clean and fresh water or so called potable water has become a global problem, where due to the pollution and other global problem such as war, and socio economic related problems. Nowadays, to get a potable water becomes a problem, including Malaysia.

With the high rate of population growth, demand of the potable water constantly increased, but at the same time, the supply is constantly decrease due to the extreme weather, excessive solar radiation and high intensity of heat. In July 2014, Malaysia has gone through a disaster where the water level of the ponding area all over the country gets lower due to extreme hot weather.

This research is focusing on how to produce the potable water by evaporation using solar still system towards the big scale, by high production rate to cater the needs of the end user. To achieve this, a PV-DC heater will be used to support the production rate by heating up the water ponded in the basin. The water that usually absorb heat from the sun in conventional passive solar still system, will increase the heat by the heater. That is what we call the active solar still system. However, according to Badran (2007), the night production in the absence of solar radiation contributed to 16% of the daily output due to the differences in temperature between the cover and water, and the decrease of heat capacity. In terms of the research conduct of the project, it is not feasible for the student to conduct the experiment during night time. However, the feasibility of the overall project is within the students' grasp, where all the feasibility elements discussed later is provided. Therefore, the main significant of this research project can be summarized to effectively produced the potable water by increasing the evaporation rate, to ensure it can be implemented in a big scale, for the benefit of the mankind.

Feasibility & Scope of Study

This study will be focused on solar still system design and fabrication in order to get the maximum evaporation rate to produce the maximum potable water collected. All the parameters that affecting the solar still productivity and the potable water collected will be taken into consideration in order to vary the method used to achieve the objective stated.

Generally, this experiment will be conducted using 2 types of solar still distillation system which is:

a) Active solar still system
b) Passive solar still system

The active solar still system will be enhanced by the using of PV-DC heater, while the passive solar still system will use 2 types of different basin, one is black painted and the other is non-painted. The performance of the solar still distillation system itself will be compared with the added PV-DC heater in the system. This experiment will help to determine how efficient the evaporation will be by using the external sources towards the system in order to increase the production of the potable water by evaporation process. Besides, different type of the basin will also determine the production rate in the passive solar still system. Therefore this research project is definitely feasible and scope of study in processing and interpreting the results is achievable within the conduct of Final Year Project I (FYP I) and Final Year Project II (FYP II).

CHAPTER 2

LITERATURE REVIEW

Solar Still System

Wilson (1972), a Swedish engineer, was the first scientist who developed a solar still for supplying pure water to a nitrate mining community in Chile, which was very popular and was in operation for more than 40 years. A solar still is a simple way of distilling water, using the heat of the sun to drive evaporation from humid soil, ambient air and any source of water. The solar still distillation system is environmental friendly and it can save a lot of money and time, in term of producing clean and fresh water. It is supported by Kumar et al., (2009) where he stated that solar distillation is one of the good options to obtain fresh water at reasonable cost. Furthermore, solar distillation is an attractive alternative because of its simple technology, non-requirement of highly skilled manpower for maintenance, low energy need and can be used at any place without much problem. The water that evaporated will be collected in the collector plate. Tiwari et al., (2008) has stated that solar still are working on the process of distillation of brackish/saline water by utilizing solar thermal energy. Basically, solar still distillation system has two general types which are single slope and double slope. There are several factors that affecting the performance of the solar still distillation system, which is the water depth in the basin, basin size, and the basin material. Tiwari et al., (2008) stated that the thermal performance of solar still is affected by several design parameters like water depth, thickness of glass cover, insulation thickness, condensing cover material, type of solar collector, number of collectors, and also affected by climate change. Nafey et al., (2000) had conducted a study on different material used as a basin to store the water in the solar still distillation system. He found that the productivity increased by 20% when using black rubber (10mm) thick as the basin material whereas the productivity also increase by 19% when using black gravel (15-20mm) size as the basin material. Solar still system divided into two, which is the active solar still system and passive solar still system. Passive solar still system is a system that fully utilizes the energy from the sun, whereas the active solid still system is a system that using other equipment to produce heat.

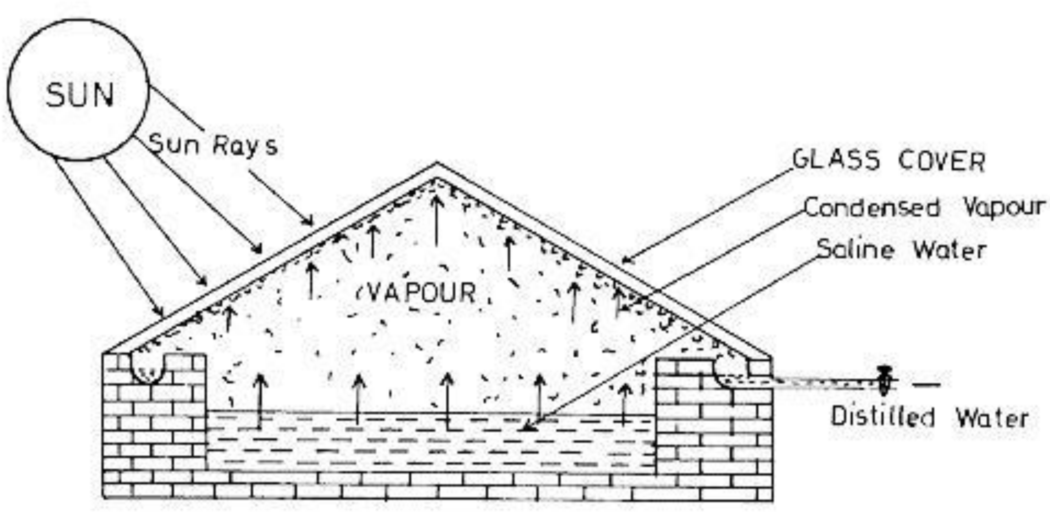


Figure 2: Sample of Double Slopped Solar Still Distillation System

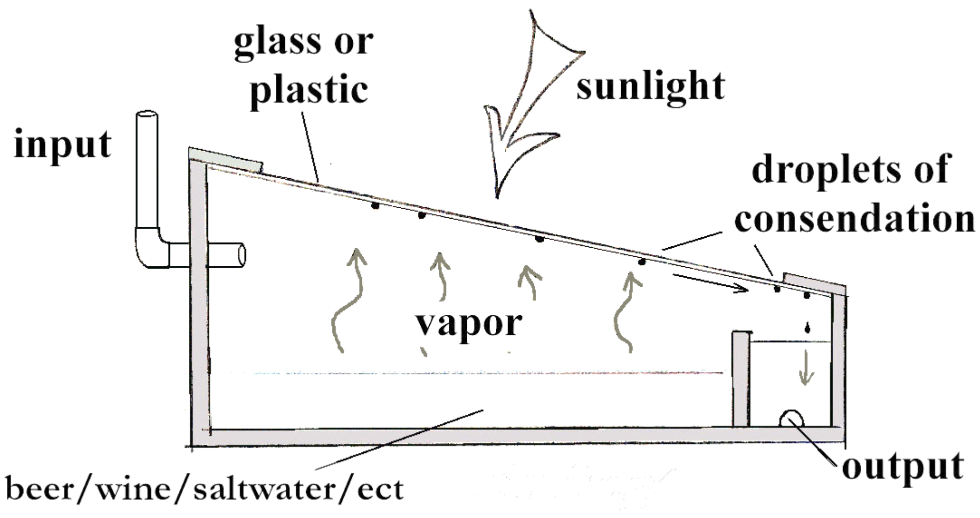


Figure 3: Sample of Single Slope Solar Still Distillation System

Performance of Solar Still Distillation System

Kumar et al., (1998) stated that the performance of solar distillation system is governed by the rate of evaporation from the water surface in the basin. This depends on water and inner glass cover temperature differences. This is supported by Vinoth et al., (2007) where he found that the condensation occurs due to the temperature difference not only on the glass surface but also on the four sidewalls, which can be cooled by water circulation through tubes attached on the wall surface for efficiency enhancement

Table 1
Rate of Evaporation for Different Sample

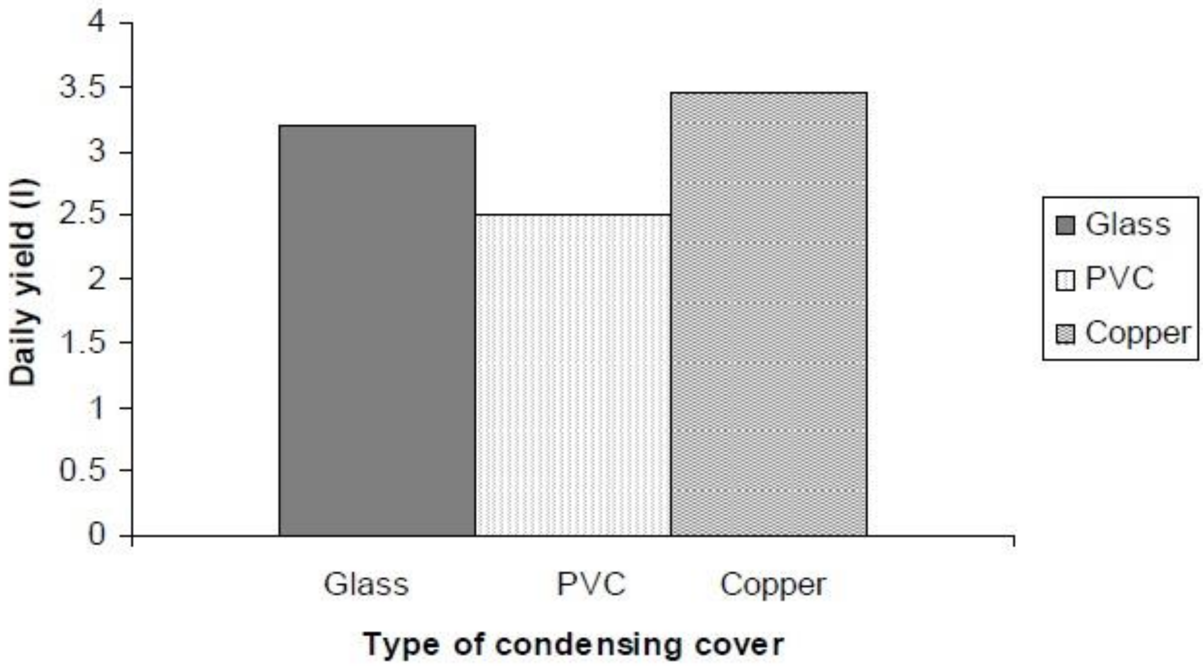
Sml. no.	Time (s)	Avg. ambient temp. (°C)	Avg. water temp. (°C)	Avg. solar ins. (W/m^2)	Avg. wind speed (m/s)	Avg. relative humidity (%)	Rate of evap. (%)	Conditions
1.	6300	36.5	41.75	969.7	1.8	74	80.40	Tap water (with cooling)
2.	6300	36	40.58	940.5	1.8	73	82.83	Tap water (with cooling)
3.	7500	34	40.93	668.8	1.4	73	97.86	Tap water (without cooling)
4.	8400	33.7	38.87	508.87	1.2	72	98.32	Tap water (without cooling)
5.	9600	35	41.35	915.58	2.1	74	55.62	Seawater (with cooling)
6.	9900	34.5	41.17	844.86	2.4	75	58.27	Sea water (with cooling)
7.	11400	34.0	40.25	583.3	1.2	71	90.96	Seawater (without cooling)
8.	12300	33.0	38.33	468.67	1.1	69	97.93	Seawater (without cooling)
9.	9900	35	39.17	538.3	1.8	73	41.03	Dairy effluent (with cooling)
10.	7400	34.9	38.28	934.9	2.4	75	69.88	Dairy effluent (with cooling)
11.	11200	35.01	41.56	594.99	1.2	70	82.74	Dairy effluent (without cooling)
12.	7400	35.32	42.57	909	1.1	74	91.91	Dairy effluent (without cooling)

Table 1 is the tabulated data obtained by Vinoth et al., (2007). The table shown that the rate of evaporation will increase with the increase of the temperature differences.

Passive Solar Still

Passive solar still system is a system that fully utilizes the energy from the sun, whereas the active solid still system is a system that using other equipment to produce heat. Tiwari et al., (2008) stated that the thermal performance of solar still is affected by several design parameters like water depth, thickness of glass cover, insulation thickness, condensing cover material, type of solar collector, number of collectors, and also affected by climate change. However, Kumar et al., (1998) stated that the performance of solar distillation system is governed by the rate of evaporation from the water surface in the basin. This depends on water and glass cover temperature differences.

The other parameters that will be taken into consideration are the cover material of the solar still system. According to Tiwari et al,. (2008), it is predicted that the maximum yield of solar still occurs for copper as cover material while the lowest yield happen when using the PVC as the cover material.



Active Solar Still

This research will focus on active solar still system. Previous studies shown that there are several studies on active solar still system. Some of the previous research used several method and external source including the using of flat plate collector. Kumar et al., (1998) has conduct an experiment of solar still system using the flat plate collector and it is clear that yield increase with increase of number of collected, as expected due to more heat transfer from the collector to the basin.

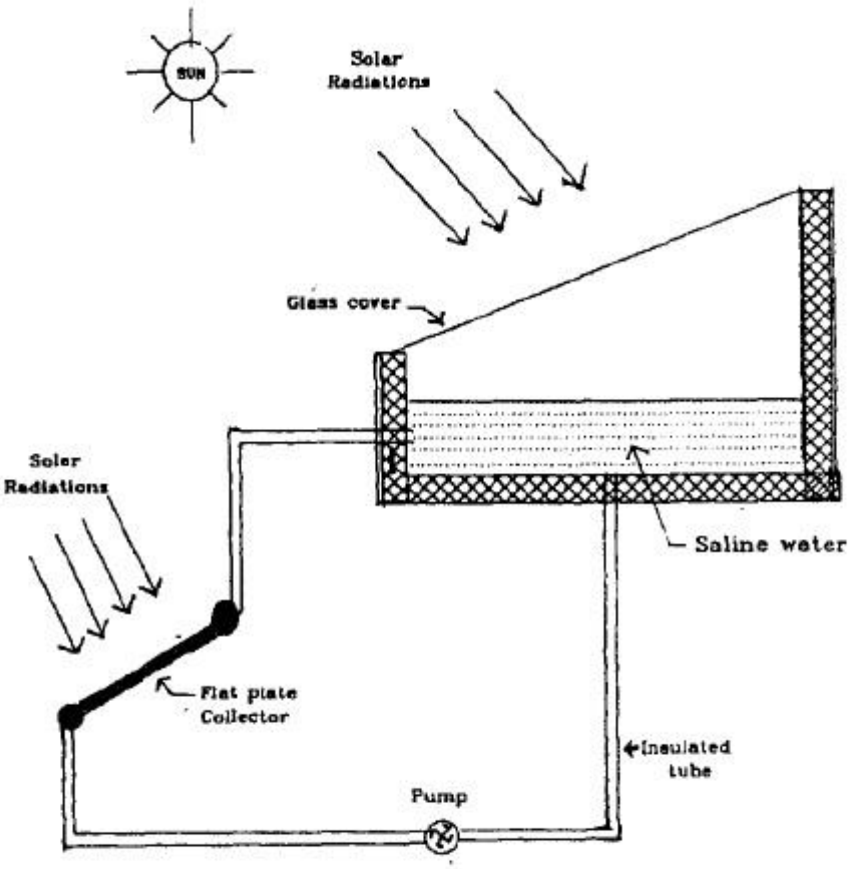


Figure 4: Sample of Active Solar Still Distillation System

However, no optimization of heat capacity from the combination of heater and flat plate collector was carried out by any authors. Therefore, this research will focus on the effect of using that combination in the solar still system toward the evaporation rate. Table below shows the previous research on active solar still that using several type of outsource to enhance the productivity of potable water from solar still distillation system.

Table 2:
Types of Outsource and Maximum Water Production

Authors	Study area and date	Enhancement method	Maximum water production (L/m²)
F. F. Tabrizi and A. Z. Sharak [5].	Iran, 2010	Sandy heat reservoir was added to a solar still basin.	3.00 L/m² During 16 hours
V. Velmurugan et al [6].	India, 2008	Fin, sand, sponges, pebbles and black rubber were added in the basin of single slope solar still.	2.77L/m² During 10 hours
A. Ahsan et al [7].	Malaysia, 2014	Solar still using black painted Perspex sheet basin and transparent Polythene film cover	1.55L/m² During 12 hours
G.N. Tiwari et al [8].	2009, India	Parametric study of an active solar still integrated with a flat plate collector (FPC)	2.85L/m² During 24 hours
Gajendra Singh et al [9].	2011, India	Experimental study of an active solar still integrated with 2 solar flat plate collectors (FPC)	7.54L/2m² During 24 hours
Saettone. E [10].	2012, Peru	Active solar still using parabolic-trough concentrator (PTC)	6.36L/m² During 24 hours

CHAPTER 3

METHODOLOGY

Project Flow

The research methodology is planned and scheduled properly to ensure all the plan of activities performed efficiently. Basically, the process flow started with review of the past research called the literature review and followed by the experimental process.

Basically, this research is divided into two, which is :

- Preliminary Research (FYP 1)
  - Literature review – past research
  - Studying and understanding the concept of solar still
  - Brainstorming on how to conduct the experimental activities at the next stage of methodology

- Secondary Research (FYP 2)
  - Fabrication of solar still system model
  - Data collection and analysis

In general, the research methodology flow is shown the chart below. The time planning is also shown in the Gantt chart below.

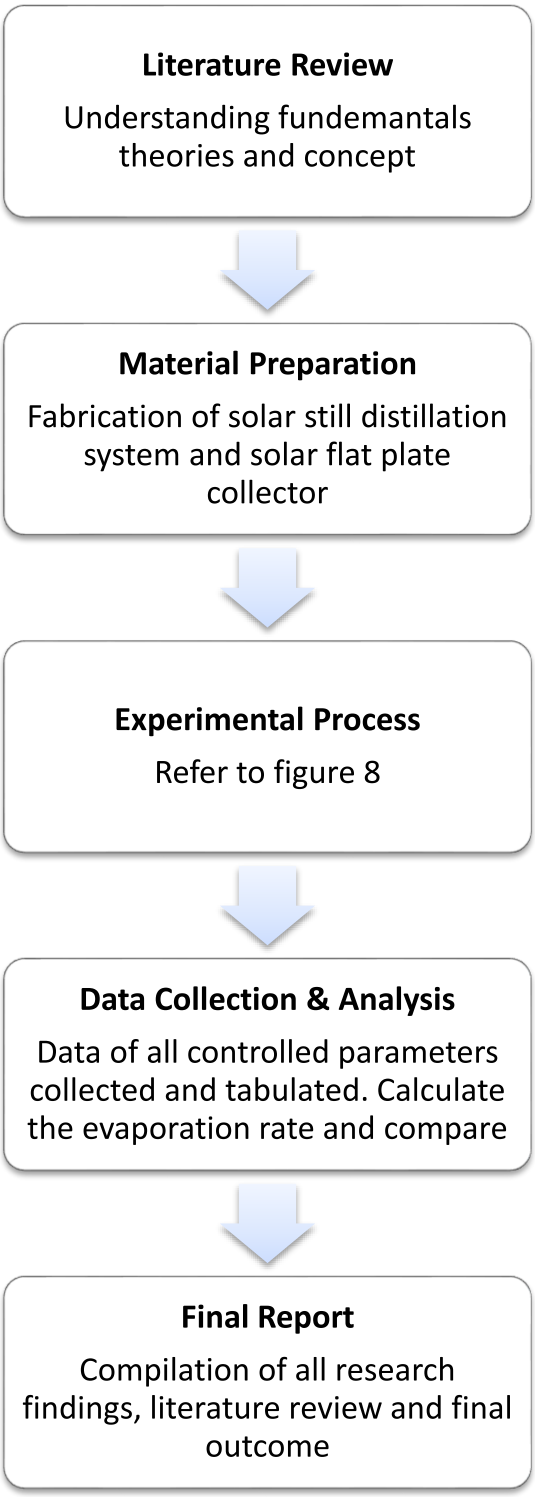


Figure 5: Flow Chart of the project research

Gantt Chart and Milestone

Table 2:
FYP 1 Gantt Chart

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■												
2	Preliminary Research Work		■	■	■	■									
3	Submission of Extended Proposal						●								
4	Proposal Defence								■	■					
5	Project work continues										■	■	■		
6	Submission of Interim Draft Report													●	
7	Submission of Interim Report														●

● Suggested milestone
■ Process

Table 3:
FYP 2 Gantt Chart

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■								
2	Submission of Progress Report							●								
3	Project Work Continues								■	■	■	■	■			
4	Pre-SEDEX										●					
5	Submission of Draft Final Report											●				
6	Submission of Dissertation (soft bound)												●			
7	Submission of Technical Paper												●			
8	Viva													●		
9	Submission of Project Dissertation (Hard Bound)															●

● Suggested milestone
■ Process

Experimental Methodology

There are 3 experiments will be conducted, which is:

a) Passive solar still system with non-painted basin
b) Passive solar still distillation system with black painted basin
c) Active solar still distillation system with additional PV-DC heater

Passive solar still system is a basic solar still system, which the system works, depends only on the solar radiation. In this research, author conduct 2 experiments involved the passive solar still, which the controlled parameters are the basin type.

The difference of the basin type is:

a) Non-painted basin
b) Black painted basin

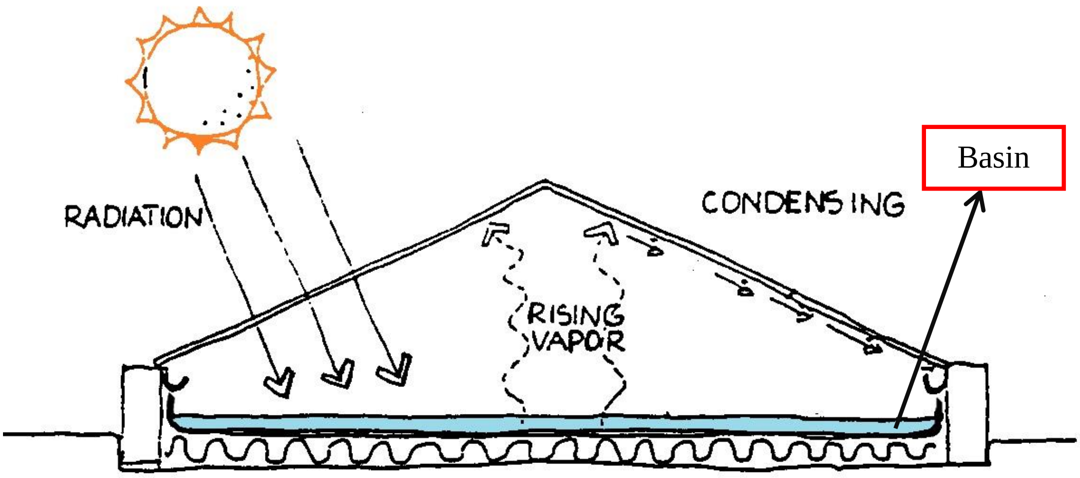


Figure 6: Passive Solar Still Distillation System

Active solar still distillation system is a system where a conventional solar still is assisted by another heat source. In this case, the source is a PV-DC heater.

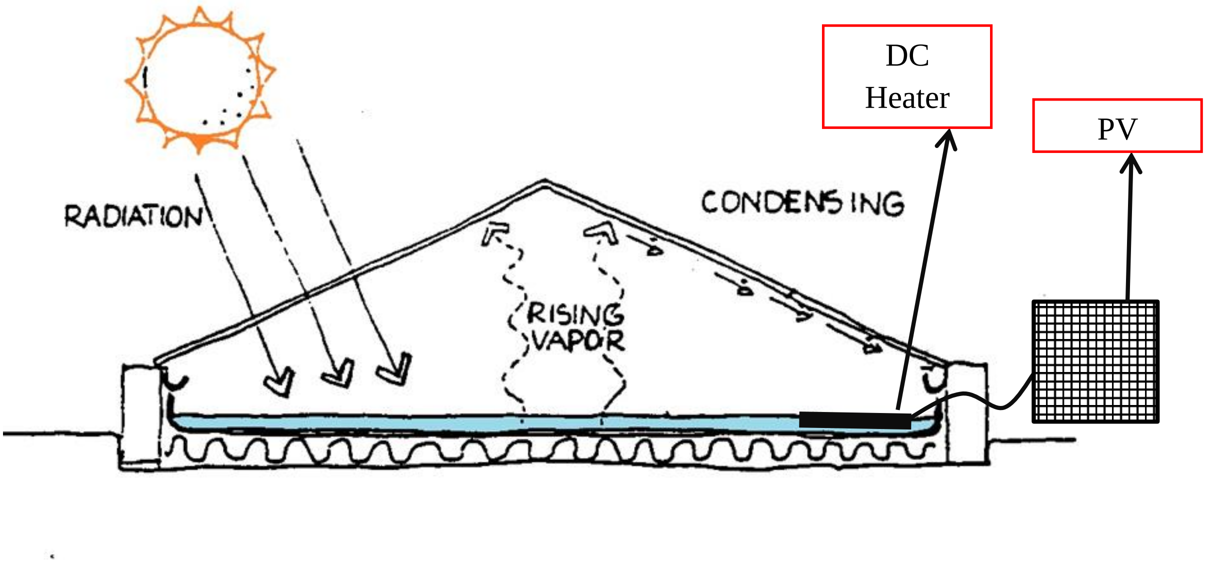


Figure 7: Active Solar Still System with PV-DC Heater

Figure shows that the conventional passive solar still distillation system is combined with PV-DC heater which made it an active solar still distillation system.

Theoretically, existence of the heat source is to heat up the water in the basin to create a bigger temperature difference between the water in the basin and the inner surface of the cover.

Below is the propose experimental methodology in order to investigate the performance of the solar still distillation system using the combination of solar flat plate collector and PV-DC heater.

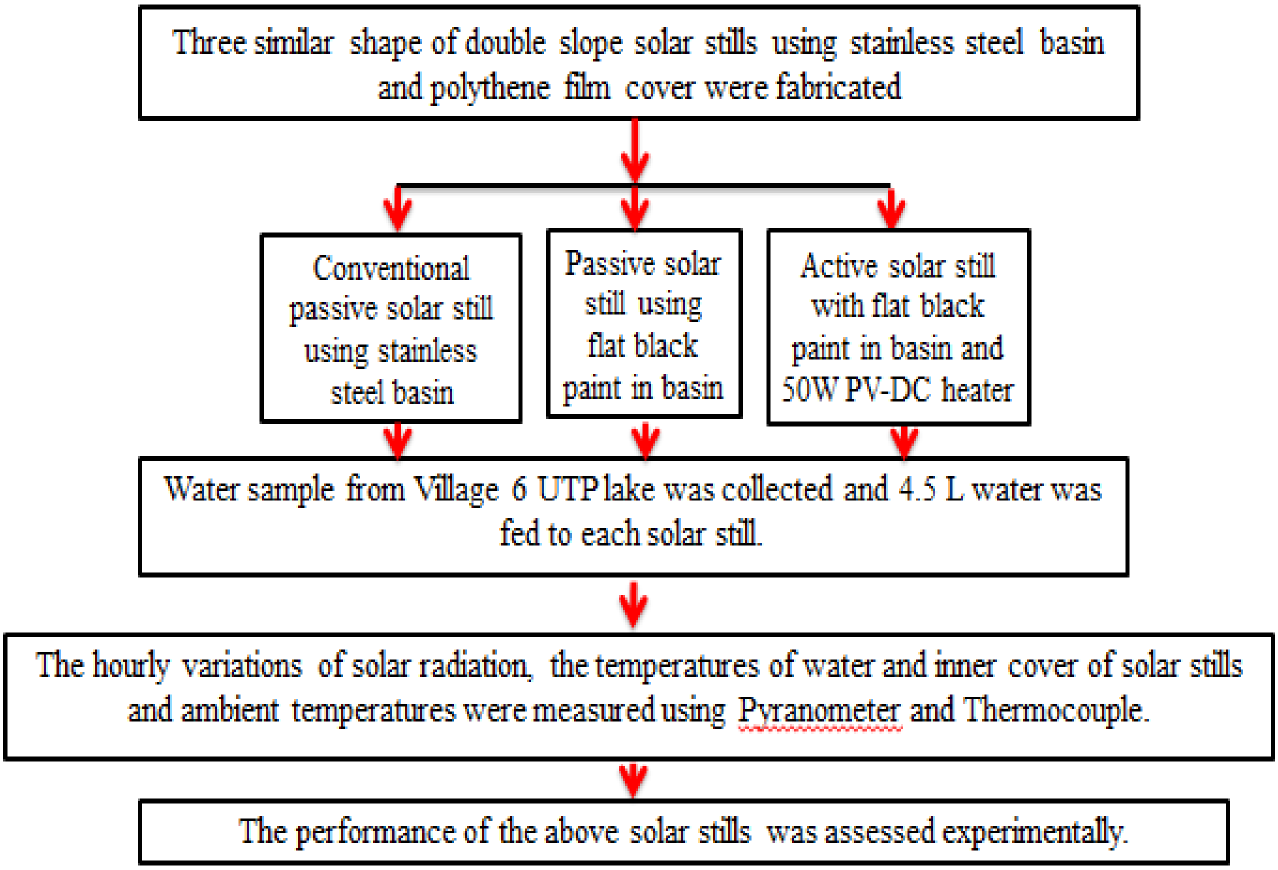
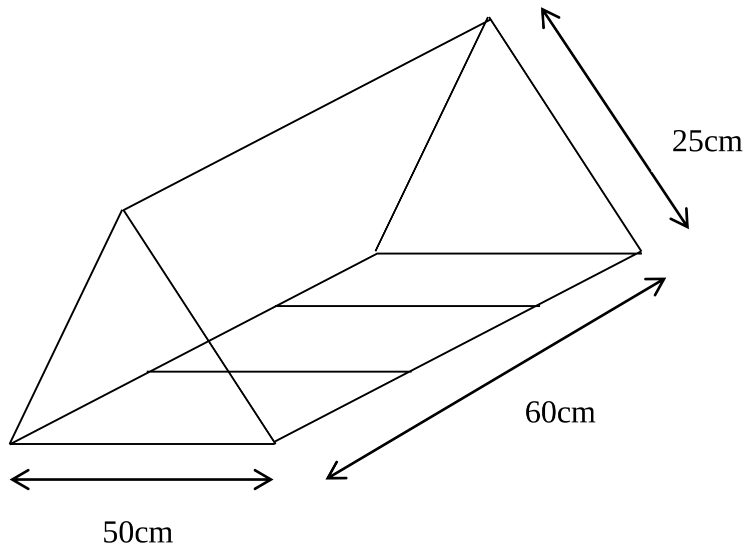


Figure 8: Experimental Methodology

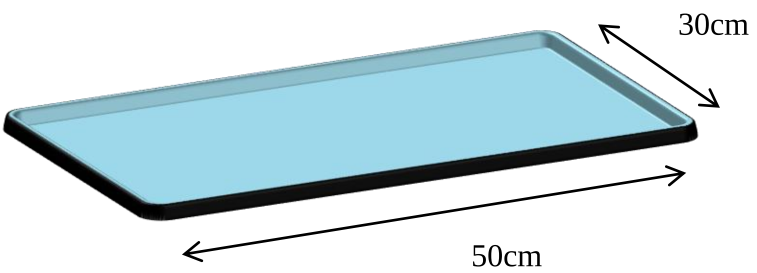
Material Preparation

In order to conduct the experiment, the solar still system was fabricated precisely according to the correct dimension. The solar still system consists of:

a) Frame – Polyvinyl chloride (PVC)



b) Stainless Steel Basin



c) Cover – Plastic

Figure 9: Fabrication of Solar Still System

For active solar still system, there are additional of PV-DC heater to the passive solar still system. The PV producing 45.9 Watt to fixed the requirements of the heater which is 12 Volts 50 Watt.

Figure 10: PV 50 watt

The experiments conducted in the solar field testing facility where it is an open space and receive highest amount of solar radiation in UTP.

To measure the solar radiation, pyranometer were used in this experiment. Besides, the temperature of inner cover and the temperature of the water were measured using thermocouple.

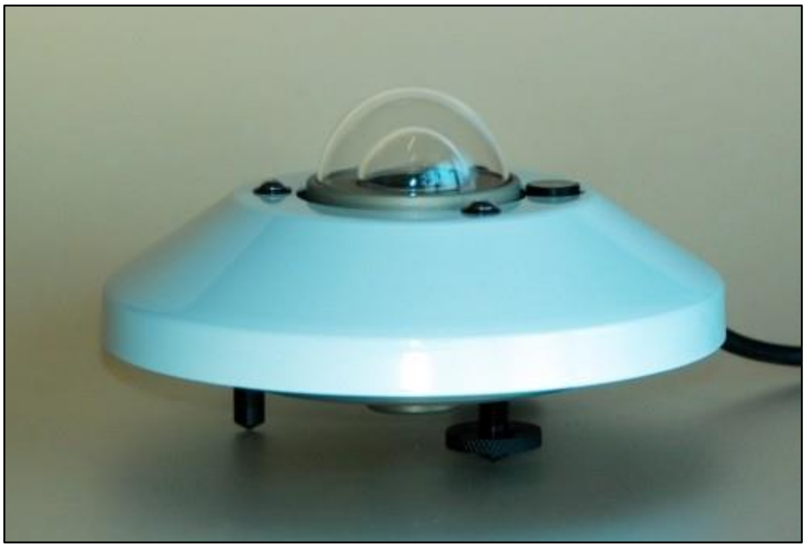


Figure 11 : Pyranometer

Figure 12: Thermocouple

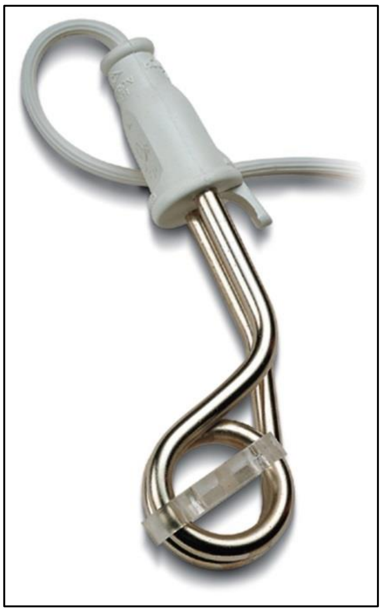


Figure 13: DC Heater

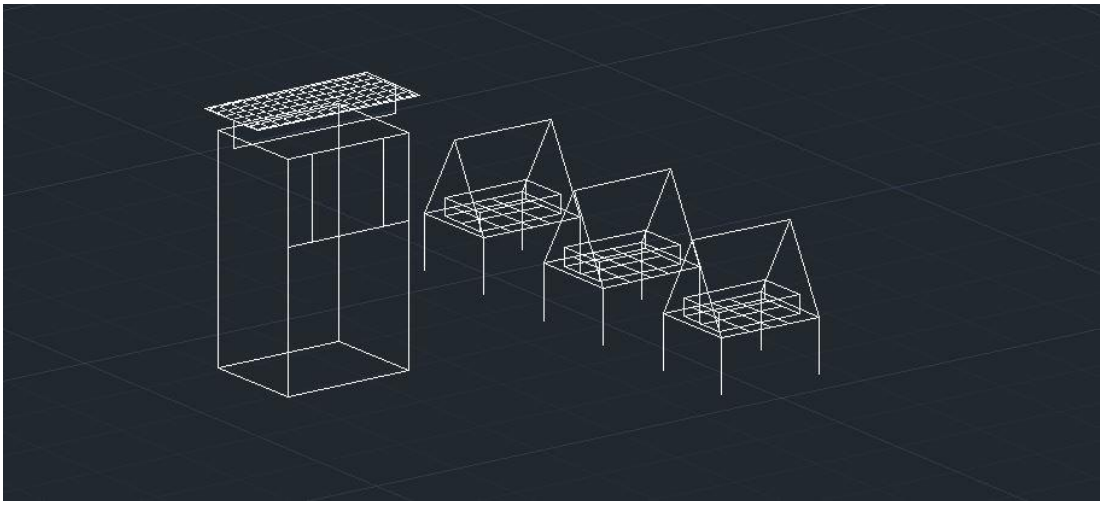


Figure 14: 2D Wireframe Drawing of the Arrangement of the Experiment

CHAPTER 4

RESULT AND DISCUSSION

The experiment was done on the 23 February 2015, at the solar field, Universiti Teknologi PETRONAS, Tronoh, Perak.

All the data obtained had been interpreted in the graph as per below.

Solar Radiation Intensity

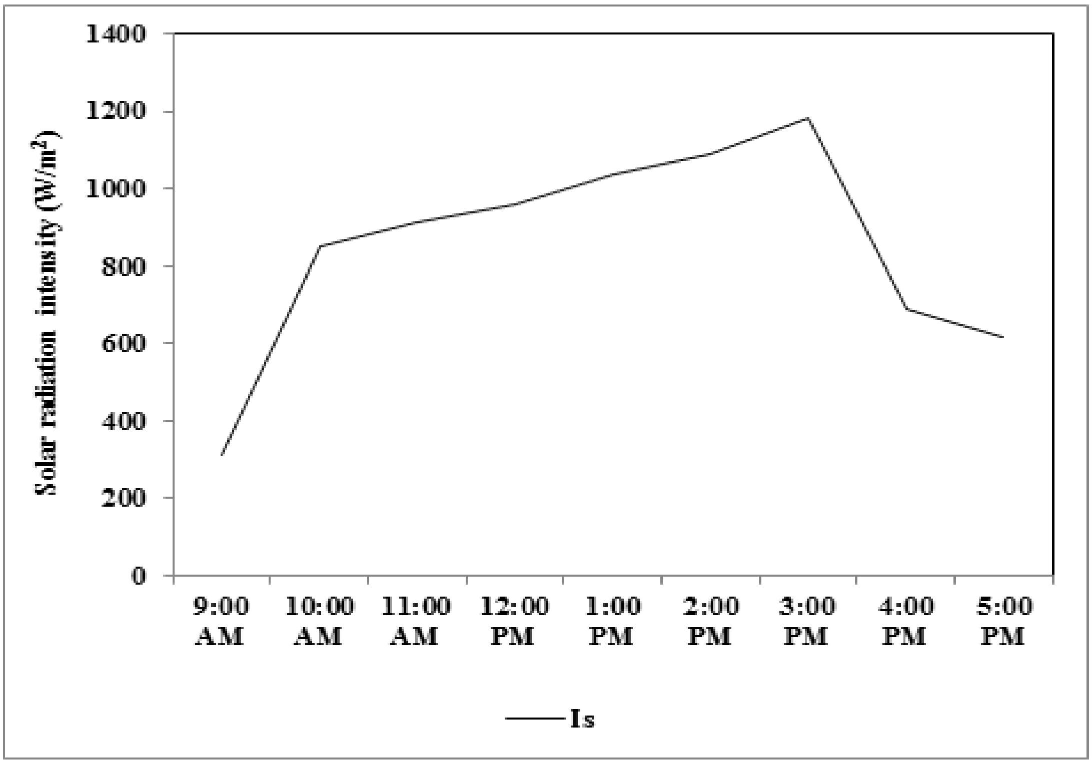


Figure 15: Hourly variations of solar radiation intensity on 23 February 2015 from 9 am to 5 pm

Figure 15 shows that the lowest solar radiation is at 9am, 313 W/m^2 and the highest value is at 3pm, where the radiation is at 1183W/m^2. The solar radiation intensity is increasing until it reaches the peak point and start to reduce.

The increasing of solar intensity is directly proportional to the temperature of the solar still inner cover and the temperature of water. Below is the graph from the result obtained on field.

Conventional Solar Still

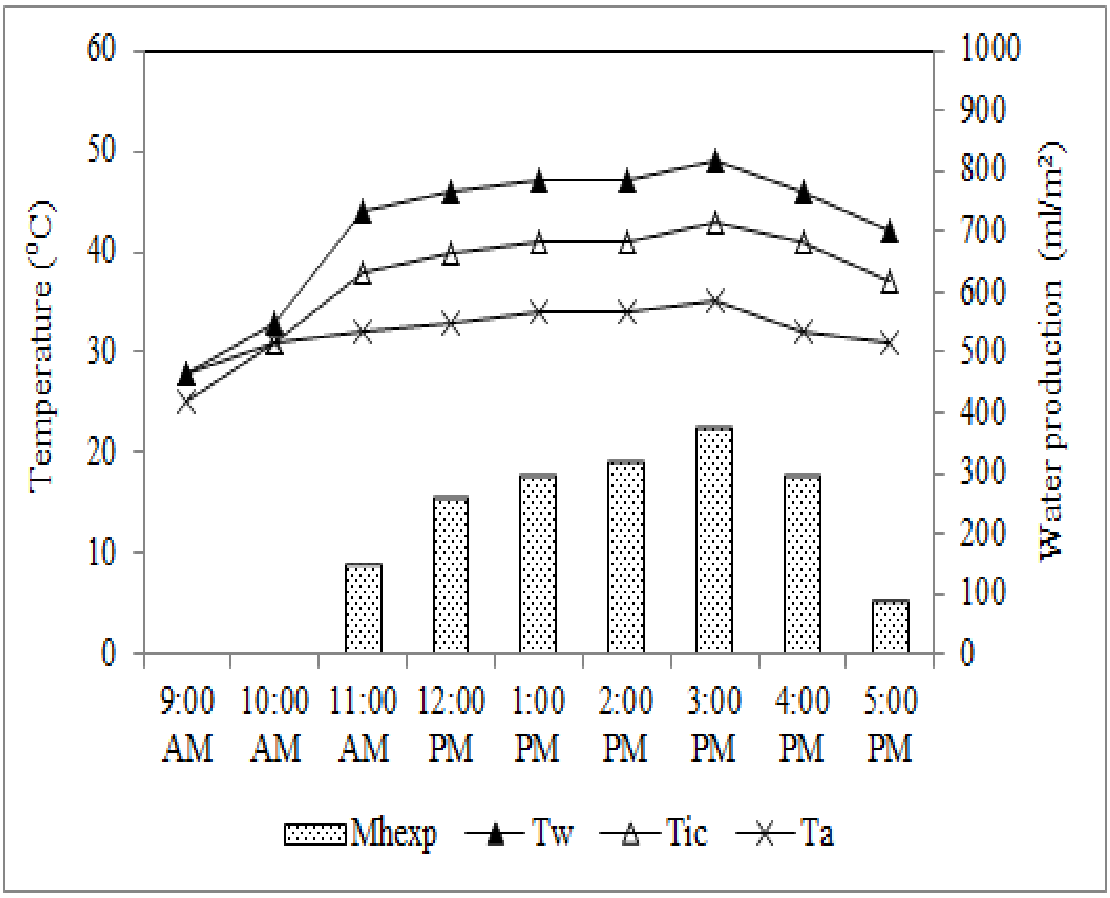


Figure 16: Hourly values of temperatures of water, inner cover of solar still and ambient temperature versus the hourly values of water production of conventional solar still on 23 February 2015 from 9 am to 5 pm

The graph contains the information of:

- Ambient Temperature (Ta)
- Inner Cover Temperature (Tic)
- Water Temperature (Tw)
- Water Production (Mhexp)

Based on Figure 16, the curve shows that the temperatures of water, inner cover, and ambient are directly proportional to the solar radiation intensity. Though, the production of the water also has the peak value at 3pm, 400ml/m^2 where the water, inner cover, and ambient temperature are highest.

Solar Still with Black Painted Basin

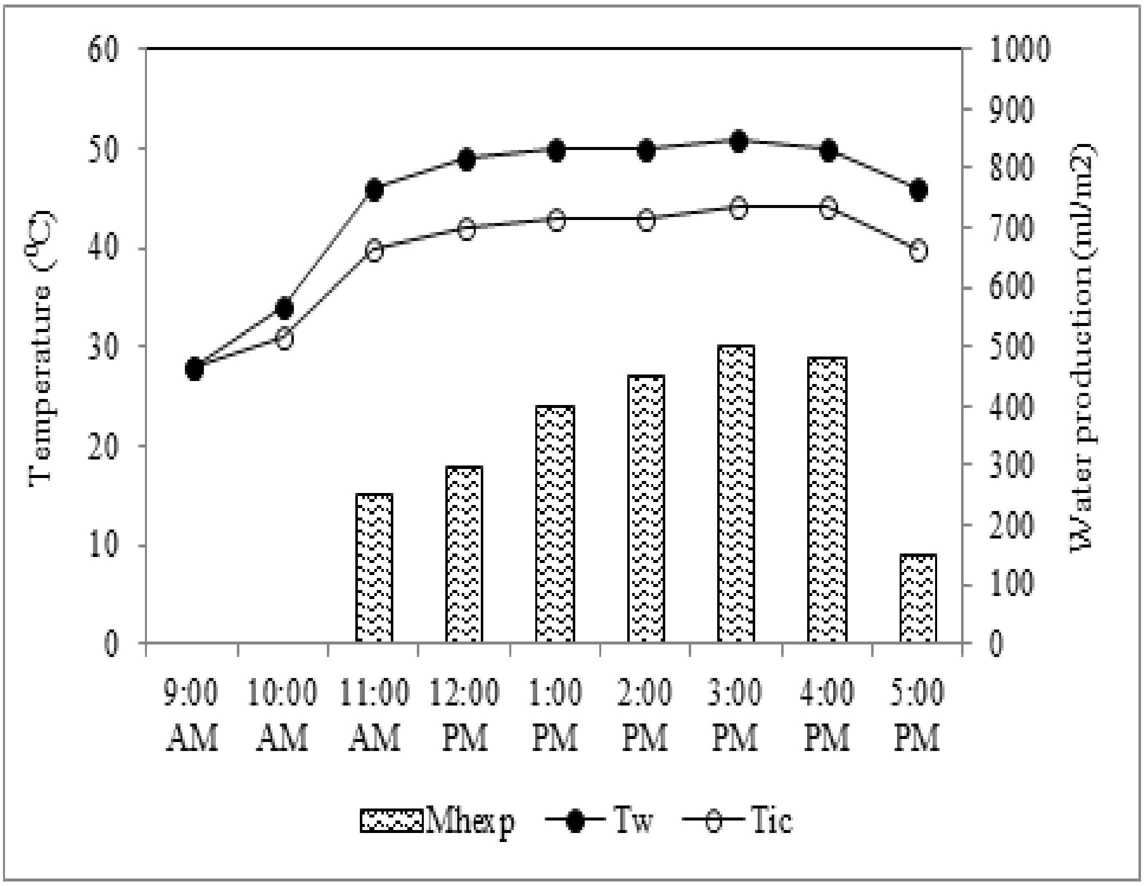


Figure 17: Hourly values of temperatures of water, inner cover of solar still and ambient temperature versus the hourly values of water production of solar still with black paint basin on 23 February 2015 from 9 am to 5 pm

The graph contains the information of:

- Inner Cover Temperature (Tic)
- Water Temperature (Tw)
- Water Production (Mhexp)

Based on Figure 17, the curve also shows that the temperature of water and inner cover are also directly proportionate to the solar radiation intensity. The highest production of water is at 3pm, 500ml/m^2.

Solar Still Combined with 50 watt PV-DC Heater

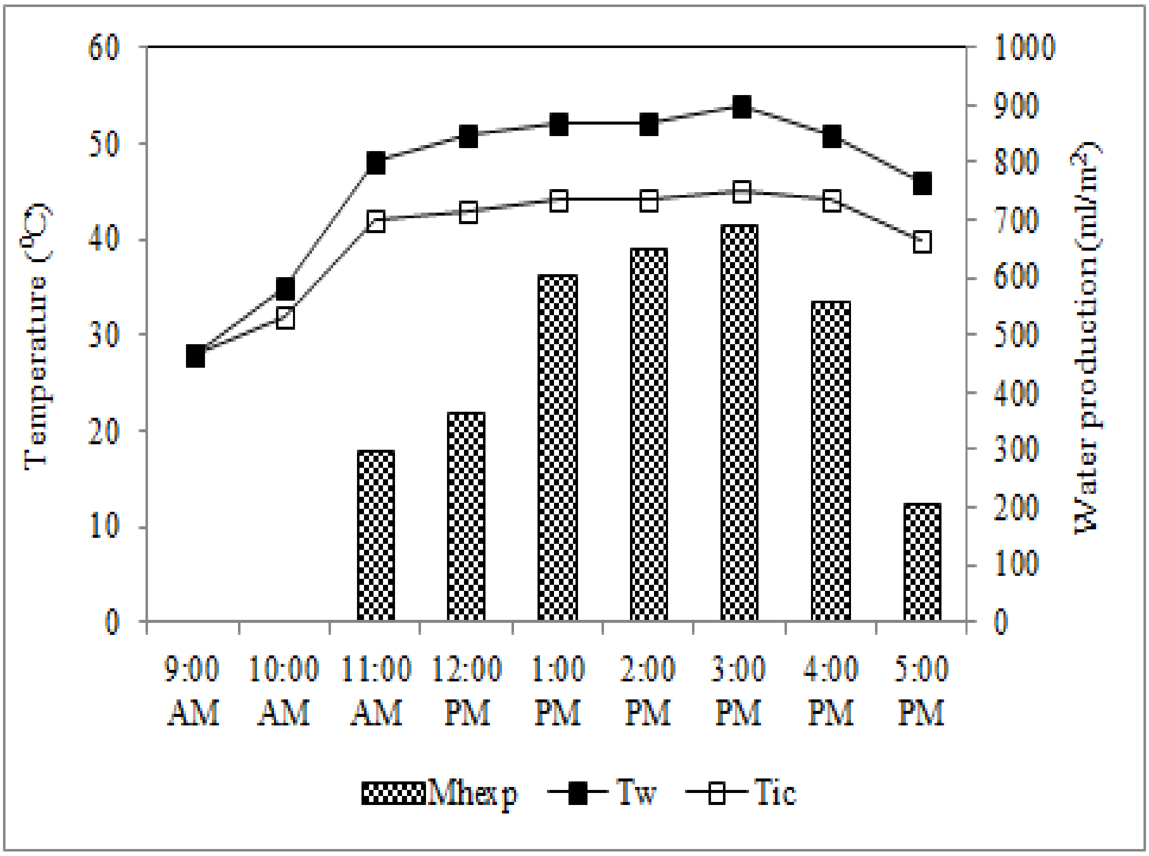


Figure 18: Hourly values of temperatures of water, inner cover of solar still and ambient temperature versus the hourly values of water production of solar still with black paint basin using 50 W PV-DC heater on 23 February 2015 from 9 am to 5 pm

The graph contains the information of:

- Inner Cover Temperature (Tic)
- Water Temperature (Tw)
- Water Production (Mhexp)

Based on the Figure 18, the curve also shows that the temperature of water and inner cover are also directly proportionate to the solar radiation intensity. The highest production of water is at 3pm, 690ml/m^2.

Cumulative Water Production

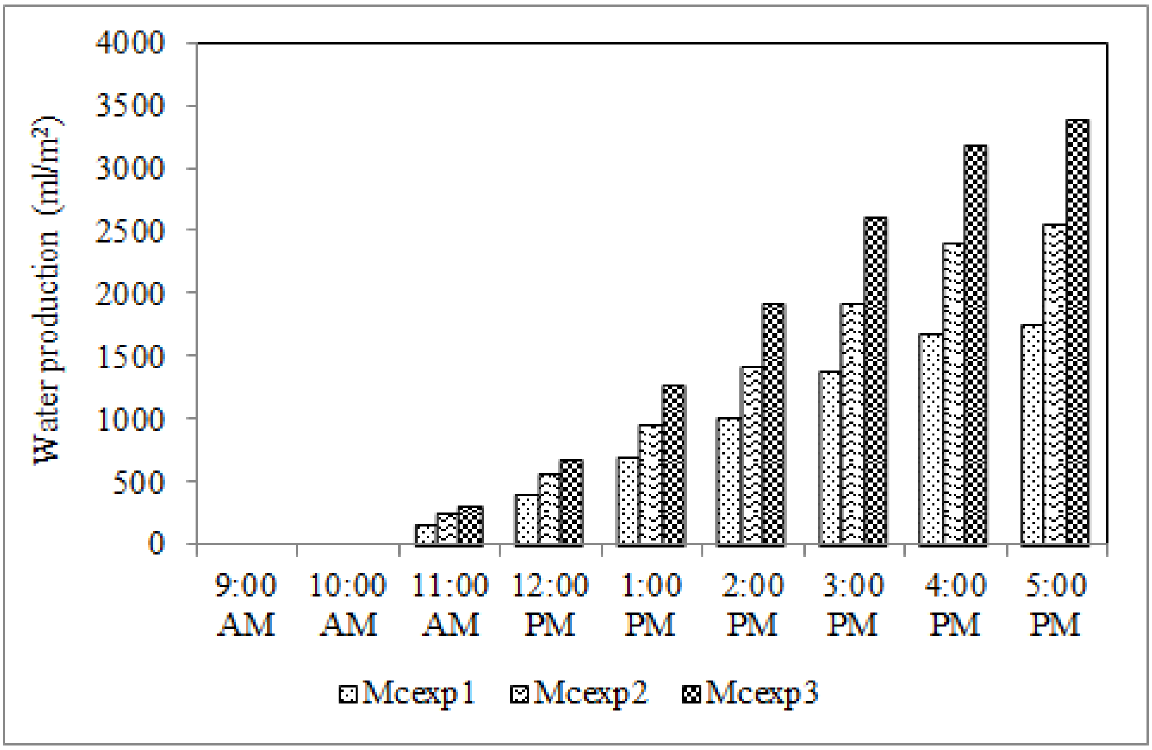


Figure 19: Hourly values of cumulative water production of conventional solar still, solar still with black painted basin and black painted basin solar still using 50W PV-DC heater respectively on 23 February 2015 from 9 am to 5 pm

The graph contains the information of:

- Water Production 1 (Mhexp1)
- Water Production 2 (Mhexp2)
- Water Production 3 (Mhexp3)

Based on the previous graph, we can see that Water Production 1 (Mhexp1) indicates the water production of conventional solar still. Same with water production 2 (Mhexp2), it indicates water production from solar still that have black painted basin. For water production 3 (Mhexp3), it is from solar still system combined with 50watt PV-DC Heater system.

Figure 19 shows that the cumulative production of the water from all solar still. Solar still system that combined with 50watt PV-DC heater system produces the highest amount of potable water, compared to the other two, while conventional solar still system produce the lowest.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This study is mainly to investigate the performance of solar still system using the additional of PV-DC heater towards the conventional passive system. Throughout the experiment, it is expected that the performance of the system will increase, with the increase of the evaporation rate. The evaporation rate basically increases because of the increasing of the temperature difference between the water and the inner cover temperature because of the additional of the mentioned outsources.

Based on the result obtain, it is shows that the performance of solar still system combined with PV-DC heater system is obviously increase up to 50% of the conventional solar still. The water produced from the combination system produce 690ml/m^2 while conventional solar still produce 390ml/m^2 at 3pm, where the solar radiation intensity is at the highest value with 1183W/m^2. With the highest value of solar radiation intensity, the ambient temperature is also highest at that particular time, and this will give a good impact towards temperature of the inner cover and the water temperature. When inner cover and water temperature increase, the water production will increase. In combination system, the heat was extra from the other two systems, where it comes from the heater, makes the evaporation rates increased and water production also got increased.

This investigation experiment has proved that the external heat source added to the conventional system can improve the productivity of potable water, compared to the conventional/passive system. Though, author would suggest that comparison from active solar still that using heater are compared to other type of heat outsource like Flat Plate Collector (FPC) or Parabolic Through Concentrator (PTC) for future investigation and improvement.

This project will solve a global issue – lack of potable freshwater. In a big scale, this enhanced system can produce high volume of freshwater at one time, and possibly can cater the needs of big scale of area especially remote and rural area where there is no source of freshwater. This system can be considered one of the most reliable option to obtain freshwater because of the production and maintenance cost is lowest compared to other option like water transportation by piping or tanker.

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