SOLAR-STILL WATER PRODUCTION UNDER MALAYSIAN CONDITIONS

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

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May 2013

CERTIFICATION OF ORIGINALITY

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

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(BELDEN CHIN CHUNG YEW)

ABSTRACT

In many parts of the world, fresh water is unavailable to people. The worldwide rapid growth in industry has greatly increased the demand for fresh water. Early advancements in providing such solutions have come up with desalination plants to convert sea water into drinking water through distillation system. However, the operational and maintenance costs are high and energy demanding which is a practical option only in rich countries. Solar distillation is an expanding alternative to desalination, that is distilling water using solar energy. Solar distillation is environmentally safe and uses solar radiation to evaporate saline water into potable water. This project aims to discuss solar-still water production under Malaysian conditions in terms of ambient temperature, solar radiation and wind effects. The first method involved using three solar still basins - with black paint, sand layer, and conventional to compare solar capture with water production. The second method emphasizes on increasing the effects of evaporation by using a Parabolic Trough Collector (PTC) connected to a solar still basin. The present investigation showed the black paint basin has productivity up to 2.36 $kg/m^2/d$ which is 70% more than conventional stainless steel basin. PTC system produced up to 439 $ml/m^2/d$ with much areas to improve on. It is projected that the finding of this research can widen the research field of solar distillation especially in areas where fresh water is scarce.

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CHAPTER 1

INTRODUCTION

1. PROEJCT BACKGROUND

1.1 Background Studies

Solar stills were originally introduced in military and survival exercises as a means of obtaining potable water from surrounding materials that hold undrinkable water. The main concept was to evaporate the undrinkable water by heat from solar energy which would then condense by cooling of surrounding air and the collected water would be distilled water. The solar still would be useful in the long run for sustainable energy if expanded to community uses such as in countries or areas where potable water is scarce or difficult to find. Water is growing to be an indispensable resource around the world as 96.54% of the water resources in the world are seawater and 2.53% is fresh water [1] , while only a portion around ~0.36% is available to the people [2].

Desalination systems are viable for production of fresh water, however are considered costly to construct and operate as well as requiring high energy consumption. Hughes BR et al. [31] reports that the United Arab Emirates make use of reverse osmosis (RO) and multiple-effect distillation (MED) technology, together with district cooling (DC) in their desalination systems. The power consumption required per individual technology of RO-DC and MED-DC systems are 5.65 MW and 6.65 MW respectively, whereas for the desalination water cost of RO and MED is reported to be $0.30/m^3 and $0.15/m^3 respectively. Though there has been a drop in the cost over the years [32] , it is still more expensive than the conventional method of treating water where it would only cost a few pennies per cubic meter.

The increasing effects of global warming towards the weather as well as pollution of rivers and groundwater caused by industrial and agricultural wastes have also stimulated interests in finding environmental friendly alternatives to obtain fresh water. This is also a case in both developed and developing countries where people are unable to acquire clean water due to dry weather or pollution causes. Countries around the globe that implemented desalination system are New Mexico, Italy, USA, North Africa [33], members of the Gulf Cooperation Council (GCC) which includes Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates [34], and many more. This shows that communities are in search of obtaining fresh water despite being a developed or under developed nation.

For desalination using solar stills, the simple type of solar still can produce about 2-5 $kg/m^2/d$ only [36], which makes the system not very attractive in terms of economical gains and may not suffice for large scale development to meet the required daily needs of water supply. Nevertheless, the different types of designs explored by researchers help to develop the knowledge of the functions of various ambient conditions affecting the rate of obtaining distilled water. The various factors that affect the productivity of solar still include solar intensity, ambient temperature, wind velocity, water–glass temperature difference, free surface area of water, absorber plate area, temperature of inlet water, glass angle and depth of water [26,28,37]. Of course the solar intensity, ambient temperature and wind velocity are meteorological parameters and are beyond our control, but other parameters can be varied to improve the production capacity of distilled water in solar stills. Many of the times, solar stills are more effective in temperate and dry countries as more sunlight can be obtained throughout the year.

1.2 Problem Statement

Fresh water is diminishing around the globe and alternatives to increase its sources are of primary importance. The abundance of seawater would provide much of an alternative to replace the search for new fresh water sources. However, the refining process of changing seawater to potable water can be rather costly such as through desalination plants. The energy consumption of such plants could also pose a threat to the environment itself, especially those that use fossil fuels to operate. As of such, environmentally friendly alternatives are to be explored and studied further. One potential alternative would be the use of solar stills.

1.3 Objectives

The main objective of this work is to test a specific design of a solar still for production of potable water under Malaysian conditions.

Other objectives include:

- to determine how much energy of solar radiation per square meter in a day in UTP.
- to measure the daily ambient temperature and temperatures of the solar still basins and solar still coupled with parabolic trough collector.
- to determine the amount of distilled water production of the solar still per square meter in a day.
- to determine the efficiency of the solar distillation system.

CHAPTER 2

LITERATURE REVIEW

The solar still is an environmentally friendly device capable of producing pure water from distillation. The water that is usually put into the distillation is seawater or brine, which contains salt. Distillation method differs from other forms of water purification as water is removed from the impurities instead of impurities removed from water. Water undergo phase changing processes during distillation, which is from liquid to vapor and back to liquid form. It is the change from liquid to vapor where the impurities are separated. When vapor condenses back to liquid, only water and a few substances that boil at lower temperatures remains in the distilled water.

With sunlight being free for collection, it just requires space to harness the energy in terms of solar radiation. The basic design of a solar still contains a base where water is filled to be evaporated and a roof for condensation to take place and a container to obtain the output. Xiao et al. [3] categorized six types of designs explored in solar stills by various researchers aside from the basic solar still.

The basic solar still ranges from double-slope glass roof to semi-sphere glass. A standard design consist of a frame with insulation materials, glass cover and pipes for connection. Solar radiation passes through the glass cover which would be mostly absorbed by the bottom surface of the still, usually coated with black paint. From there, solar radiation is converted to heat and gradually evaporates the water into vapor. The vapor condenses into distilled water droplets and flow into a collector placed at the lower side of the inclined glass cover. Among the many basic still designs explored, the house-like frame solar still produced better results compared to dome shaped stills. Tayeb [4] experimented with 4 types of stills with different glass covers and reported that the inclined flat glass cover is preferred as it produced ~1.25 $kg/m^2/d$ over an absorption area of $0.24m^2$ and condensation area of $0.267m^2$.

Thermal efficiency is recorded to be 21.8%. Under similar conditions, other three stills - one with semi-sphere cover, a bilayer semi-sphere cover and an arch cover - produced ~1.1 kg/m^2/d, ~1.2 kg/m^2/d and ~0.83 kg/m^2/d distilled water, respectively. The solar stills have the same area of evaporation but different shapes which lead to different area of condensation. Cappelletti [38] reported that the conventional solar still can produce approximately between 5 kg/m^2/d (on bright sunny summer days) and 2 kg/m^2/d (on winter days). Kabeel and El-Agouz [39] mentioned that basin solar stills under optimized operating conditions have reported efficiencies in the range of 30-45%, with production less than 5 L/m^2/d. The reason for low efficiency studied is due to the loss of latent heat of condensation of water vapor on the solar still glass cover.

A common design to enhance solar stills is by installing reflectors. Tanaka [5] made use of installing internal and external reflectors in a basin still. More solar radiation is amplified into the basin through the reflectors when compared to the basic design of a solar still. Tanaka [6] also pointed out that the angle of vertical external reflector should be modified to suit the seasons in order to enhance efficiency and productivity all year round. This also applies to the latitude of the placed solar still. Results also showed optimum glass cover inclination to be 10° in summer and 50° in other seasons at 30°N latitude. It is observed that the optimum inclination of external reflector from vertical would increase in winter and decrease in summer while the glass cover inclination increases. Expanding to curved reflectors seem to be effective in directing solar concentration into the solar still. Al-Hayek and Badran [42] made asymmetric greenhouse type solar still (ASGHT) with mirrors on inside walls and symmetric greenhouse type solar still (SGHT) to compare them. It was found that the ASGHT has higher production than SGHT due to the increase in the net solar radiation received by water in basin by high rate of reflections from mirrors, which minimized the heat energy loss. It is reported that the difference in production rate is about 20% and also that water depth affects the thermal capacity of the stills. Dev et al. [7] gave an account that curved reflectors are able to increase daily output as much as five times the conventional basin solar still. The experiment includes a curved reflector under the basin of the solar still with cover angle of 23° at 23.37°N latitude. Results produced for using curved reflectors were 6.3, 5.6 and 4.3 kg/m^2/d at water depths of 0.01, 0.02 and 0.03m respectively. While under same respective water depths, without using curved reflectors produced 2.1, 1.9 and 0.8 $kg/m^2/d$ respectively. This shows the amplifying effect of focusing energy especially when strong amounts of sunlight is not readily available or when ambient temperature is low. Omara et al. [35] studied on enhancing stepped solar still using internal reflectors. Using a conventional solar still basin, ascending steps were added into the basin while installing mirrors on the vertical sides of the steps. Results showed an increased productivity of approximately 75% with 6.35 $kg/m^2/d$ compared to a solar still without the enhancements which produced 3.63 $kg/m^2/d$.

Another design involves using solar collectors, which makes use of compound parabolic concentration (CPC) or flat plate collectors to draw extra solar radiation into the solar still. This method aims to increase the heat generated in the still for evaporation to take place. Badran et al. [8] made use of a design coupled with a conventional fin-tube flat-plate solar collector which was placed in a loop with a double-slope glass roof, a feed tank and a constant head tank. It produced ~2.3 $kg/m^2/d$ with a solar collector and ~1.5 $kg/m^2/d$ without a solar collector. The efficiency for both trials is 22.26% and 28.56% respectively. Prasad and Tiwari [9] proposed a double effect active solar still coupled with a CPC collector. Water was heated and evaporated in the still with the aid of solar collector heating the water as it entered the still. The still consisted of two glass covers - the lower glass cover with flowing water on the upper side, and another above the lower glass cover and exposed directly to the sun. Vapor condensed on the inner side of the lower glass cover where the latent heat was transferred to flowing water, whereas the secondary vapor condensed on the inner side of the upper glass cover. Nevertheless, even when coupled with solar collectors, a solar still would require more electricity for circulation of water so may not be appropriate in terms of cost efficiency and portability. Arunkumar et al. [45] worked on designing a concentric tubular solar still whereby CPCs are used to reflect concentrated beam radiation to the focal line of the tube. The inner and outer circle tubers are positioned with a 5mm gap for flowing water and air to cool the outer surface of the inner tube. Water was flowed at 10 ml/min while air was blew at a constant rate of 4.5 m/s. Under average solar radiation of ~905 W/m^2 and average ambient temperature of 30°C, productivity with air flow was 3.95 $kg/m^2/d$ while with water cooling was up to 5 $kg/m^2/d$, without any cooling aids the production was 2.05 $kg/m^2/d$. It is mentioned that the current tubular solar desalination system has a low warm up time compared to basin type. However, it is able to operate at high temperatures due to the focusing of the CPC. Riahi et al. [49] experimented on two systems which are 50 Watt solar photovoltaic panel with 40 Watt DC heater and 12V battery to power 40 Watt DC heater, to heat water in solar still basin. His findings showed productivity can increase by 150% and 480% using the two systems. Solar photovoltaic panel amplified the solar effect to further channel into heat energy and increase temperature at a faster rate. However, it is still dependant on the solar energy availability as power drops when solar radiation drops. Battery powered DC heater solar still was able to produce more water due to the constant rate of heating which gives a constant environment of heating in the solar still.

Furthermore, making use of enhancing condensation becomes an alternative route for still designs. As the evaporation is also affected by the rate of condensation, it is also a concern to increase productivity. Madhlopa and Johnstone [10] studied on a passive solar still with a separate condenser. It consisted of a horizontal basin with an evaporator chamber (first effect), a basin 2 above condenser chamber (second effect), a basin 3 over basin 2(third effect), a condensing cover and an opaque insulation shield to protect the condensing cover from sunlight. The theoretical productivity was reported to be 62% higher than that of a conventional unit. Efficiency was reported to be 32% for conventional solar still and 52% for the present solar still at the point of test. Distillate contributions were recorded to be 60, 22 and 18% for first, second and third effects respectively. Studies on covers report that a thinner glass cover of 3mm gives 16.5% higher productivity than thickness of 6mm [11] as well condenser material with high conductivity [12] could lead to increase in productivity. Glass is the preferred material due to its high solar transmittance for various angles of incidence as well as longer lifespan compared to plastics. Xiao et al. [3] suggests that a separate condenser can improve a still's productivity, while the vapor channel should be carefully designed to reduce increase in vapor diffusing resistance. Two recommendations are proposed. One is to enhance convection between the evaporator and condenser, which can be done by cooling condensation surface. Another is to decrease the vapor diffusing distance. If a lot of vapor remains in the evaporator, the solar radiation reaching the basin plate would be hindered and the partial pressure of vapor would increase, thereby slowing down the evaporation process. Arunkumar et al. [43] studied on a hemispherical solar still with flowing water over the cover with the use of devices for injecting and collecting flowing water. The average basin water and cover temperatures were 59°C and 40°C respectively while average solar radiation recorded was ~732 W/m^2. Under these conditions, productivity is about 4.2 $kg/m^2/d$ with water cooling and 3.6 $kg/m^2/d$ without. The flow rate of water was 10 ml/min for cooling the cover and this led to increased efficiency from 34% to 42%.

Besides, increasing free surface area would enlarge the free surface area of water and aid in increasing surface evaporation. Bassam et al. [13] made use of placing yellow and black sponge cubes, black coal and black steel in a basin to test for the increase of free surface area of water and evaporation rate. In the report, the distillate production increased up to 273% with black sponge cubes when compared to the still without sponge cubes under the same working condition. It is noted that the yellow colour of sponge cubes reflects some of the incident radiation onto the walls of the still and result in heat loss. Although initially the results reported that yellow sponge cubes produce slightly higher results than black sponge cubes. However, it was reasoned that theoretically black sponge should absorb more heat and may be due to covering of holes when spraying black paint on the sponge cubes. It was recommended to use naturally black sponge cubes for best effect. The report states that black sponge cubes with sponge-to-water volume ratio of 20% are recommended for a basin solar still, although the optimized size of a cube still differs with water depth in the basin. Velmurugan et al. [40] studied on performance of solar still installed with fins at the basin plate. Industrial effluent was used and underwent filtration process before entering the solar still. The still was tested using fin with various modifications such as sponges, pebbles, black rubber, sand and mixture of sand and sponges. Fin type with sponge displayed high productivity while the combination of fin type with sponge and sand showed highest with efficiency up to 69% and 75% in productivity. The average solar energy input, wind speed and ambient temperature recorded are 700 W/m^2, 1 m/s and 30°C respectively. Velmurugan et al. [41] also experimented with usage of solar pond to preheat industrial effluent before entering fin type single basin solar still and a stepped solar still separately. Water was sent to the solar pond in batch modes and then to the solar stills. It was recorded that stepped solar still with fin, pebble and sponge together with solar pond obtained productivity of up to 100%, that is ~1.8 $kg/m^2/d$ when compared to a solar still without any modification that produces ~0.9 $kg/m^2/d$. Janarthanan et al. [14] used a floating tilted-wick type solar still, whereby the water flowed slowly over an inclined plane filled with wicks in a thin layer. Because of its small heat capacity, the water evaporated easily. A flow rate of about ~1.5 m/s is recommended to flow over the glass cover to be optimum. The experiment was conducted under ambient temperatures of 28-36°C and solar radiation of approximately $710W/m^2$.

Other design influences include recovering latent heat. This applies to recovering vapor latent heat that otherwise would be lost and re-using in order to improve productivity and thermal efficiency. Tanaka et al. [15] studied a multiple-effect solar still with triangle cross-section, which involved a horizontal basin liner, a tilted double glass cover and vertical parallel partitions filled with saline-soaked wicks. The wicks are separated to have a small gap in between to increase efficiency of distillation. For a still with 11 partitions of 5-mm diffusion gaps, it managed to produce a distillation rate of 14.8-18.7 $kg/m^2/d$ when incident solar radiation on the glass cover ranged from 20.9 to 22.4 $MJ/m^2/d$ under ambient temperatures of 19-30°C. The results produced showed more productivity than 7-mm and 10-mm diffusion gaps. Another type of still Tanaka et al. [16,17] proposed is a vertical multiple-effect diffusion (VMED) solar still coupled with a heat-pipe solar collector. Theoretical analysis shows that a productivity of 21.8 $kg/m^2/d$ was obtained under a daily cumulative solar radiation of 22.4 $MJ/m^2/d$. Tanaka et al. [18] also studied on an outdoor VMED structure. The still productivity ranges from 6.1 to 13.4 $kg/m^2/d$ with 5-mm diffusion gap and six effects under global solar radiation on horizontal surface to be ranging from 13.4 to 15.7 $MJ/m^2/d$ and on glass cover to be from 20.2 to 22.9 $MJ/m^2/d$. Gang et al.[3] mentions that the VMED type of stills seem to have the highest productivity experimentally due to its high heat recovery ability when comparing to the other stills documented. It is also recommended to take distance of wicks into consideration as distance too close would contaminate the distilled water while too far would decrease efficiency. A distance of 5 mm to 20 mm would be in suitable range. Murugavel and Srithar [23] experimented on the effect of using spreader materials in the basin whereby a single basin with double slope passive type solar still is tested with a layer of water of approximately 2 mm depth under controlled input conditions. Different basin spreader materials like cotton cloth, jute cloth and sponge sheet, and porous materials such as washed natural rock and quartzite rock were tested. It was observed that light black cotton cloth was the most effective in production yield.

The sixth type of solar still design categorized is solar still coupled with heat storage. Since solar energy is never consistent in nature, its intensity depends on the surrounding geography, weather and time of day. In order to maintain solar energy on a continuous basis, it is possible to incorporate heat storage systems to an advantage. Tarbizi and Sharak [19] worked on studying a basin solar still integrated with sandy heat reservoir. During the 14-h test, the productivity obtained amounted to ~3 kg/m^2, which is an improvement compared to the conventional basin still which produced ~1.7 kg/m^2. El-Sebaii et al. [20] investigated a single basin still coupled with a phase change material (PCM) storage. This PCM is stearic acid and is placed under the basin water and acted as a heat source after storing heat under the sun for hours. Moreover, the temperature difference between basin water and glass cover became greater because the ambient temperature at night dropped from daytime temperature. The system's productivity increased from 5 kg/ m^2/d to ~9 kg/m^2/d on sunny summer days using 3.3cm of stearic acid. Murugavel et al. [21] accounted that a single basin slope solar still with energy storing materials such as red brick pieces, cement concrete pieces, quartzite rock, washed stones and iron scraps was able to store excess energy and increase production during the night. It was mentioned that 3/4 in. sized quartzite rock was the most effective one out of all the materials experimented. It obtained a productivity of ~3.6 kg/m^2/d with an increment of 6.2% when compared to a still having same water amount but without any energy storing material. Insulating materials are commonly used and painted black to increase absorption rate of heat. The storage of heat allows evaporation to continue despite lack of sunlight and would help in increasing production of distilled water per day. Sakthivel et al. [47] uses jute cloth which is kept in vertical position in the middle of the basin water and another row of jute cloth attached to the wall of the still. It is reported that the temperature difference between water surface and glass cover decreases instead of increasing due to the low thermal conductivity and low heat capacity of glass. To overcome this, the saline water is brought nearer to the air-vapour mixture between the water surface and glass cover to increase the rate of evaporation. Water is raised to the vertical jute cloth by capillary action. The yield is less during the early hours and afternoon compared to the conventional still but during evening hours, the yield with the jute cloth increases due to the utilization of heat accumulated in the air-vapour mixture and acts as a heat storage. The latent heat of condensation is absorbed by the jute cloth and the temperature of the bottom of glass cover is reduced. The daily yield amounts to 4 $kg/m^2/d$ using 30kg of saline water with jute cloth.

Apart from the design of solar stills, the changes in climate and operating condition also influence the productivity of distillation process. The climate condition mainly consists of solar intensity, ambient temperature and wind velocity, while the operating conditions are the cover angle, surface area and depth of water, temperature difference between water and glass cover as well as the insulation of solar still, the material coated or placed on the basin, etc.

It is mentioned that a transparent cover with an inclination angle of local latitude can fully receive solar radiation which leads to increased productivity [22]. Furthermore, the material used for coating the basin also influences the rate of absorbing solar radiation, as well as using materials which act as storage mediums of heat, are advantageous to increase output [21,24]. Ismail [44] designed a transportable hemispherical solar still made with transparent plastic cover. It is mentioned that the rate of increase and decrease in the cover temperature is faster than that of the water temperature without any cooling aids. This is likely due to the higher heat capacity of saline water in the still basin than that of the plastic cover. Productivity ranged approximately from 2.8 to 5.7 $kg/ m^2/d$. Wind speed was noted to be highest when obtaining maximum amount of distillate as well. There are some reports which contradict another. Voropoulos et al. [25] states that low ambient temperature aids in improving productivity, while Badran [26] published a contrary outcome. Badran [26] and El-Sebaii [27] claim that increased wind speeds aid in productivity, however Nafey et al. [28] and Velmurugan et al. [40,41] produced a higher distillation output with lower wind speeds. The reason for the controversy may be due to the greater temperature difference between the water and glass cover when a higher velocity wind or lower ambient temperature passes through the solar still, as well as a greater heat loss to the surroundings in the process. Increase in temperature difference has a positive effect but heat loss to surroundings does not.

A thin layer of water is effective in increasing rate of evaporation as well. This is due to the small heat capacity of a thin film of water and thus evaporates easily. Nafey et al. [28] reported that a daily productivity of 5.2 $kg/m^2/d$ was obtained when water depth was ~2 cm, whereas 4.5 $kg/m^2/d$ for a water depth of ~8 cm. The temperature of water in the still and of the glass cover, as well as their temperature difference, highly affects the productivity as well [29,30]. Rubioa E et al. [29] reports that for a temperature difference of 6.8°C, the productivity obtained was 0.18 $kg/m^2/h$ and when temperature of water is 54°C and temperature of glass is 43°C, which amounted to 11°C temperature difference, the productivity increased to 0.45 $kg/m^2/h$. For the same temperature difference of 10°C, a production rate of ~0.8 $kg/m^2/d$ was obtained when water temperature was 70°C, while it was only ~0.1 $kg/m^2/h$ when temperature of water was 30°C. Tiwari and Tiwari [46] studied on effect of water depths on mass and heat transfer in passive solar stills. In their findings, it is mentioned that the fluctuation in water temperature decreases with increase in water depths due to the storage effect. During morning hours, the glass encounters radiation first and its temperature rises faster compared to the rise in water temperature. At this point, the temperature difference becomes negative in terms of difference between water and glass. Their experiment showed temperature difference became positive at different times of the day depending on depth of water such as at depth of 0.04m and 0.18m, the temperature difference becomes positive at 12 noon and 3 PM, respectively, and this shows a 3 hour delay for the deeper water. It is concluded that temperature difference affects productivity and that the highest output and efficiency are at lower depths.

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CHAPTER 3

METHODOLOGY / PROJECT WORK

3. PROJECT ACTIVITIES

TABLE 3.1: Project activities for Final Year Project

Problem Statement and Objective	Identifying the purpose of this research project
Literature Review	Gathering as much information about solar still, design parameters, and influences on evaporation and condensation from various research papers and journals
Methodology	Identifying the project activities, key milestones, Gantt chart, tools and materials required, as well as the proposal flowchart
Result and Discussion	Performing and monitoring fabricated solar still, collecting the results, and analyzing the results
Conclusion and Documentation	Concluding the whole research with recommendation, and documenting it to be a report

The method of study opted for this research is to gather suitable data on designing a solar still. Preliminary research on the solar still was carried out through literature study and obtaining preliminary data. Through literature study, various solar stills designs have been studied along with their methodology, results, efficiency and productivity levels. With the information gathered, a solar still design was based upon their research results and improvements can be made to further optimize the design.

The preliminary data obtained and collection of data are based on secondary information sources. The design of a solar still derived from the basic basin solar still which consist of an inclined glass roof, basin, and a compartment to collect distilled water.

Materials required for a basic solar still is inexpensive but may increase if additional components are added, such as the use of pumps, cooling fans, durable components, collectors, etc. Several changing variables including solar radiation, ambient temperature and wind velocity were considered in this study. The solar radiation per square meter is measured using a compact digital pyranometer whereas the various temperatures are measured using a digital thermometer.

FIGURE 3.1: Digital Thermometer

FIGURE 3.2: Digital Pyranometer

Sample collections of water involved using tap water to measure the quantity of production. The assessment of performance of solar distillation system involved monitoring of the solar still daily as well as the ambient conditions; i.e. amount of solar radiation per square meter, checking the temperature of water in the solar still and temperature of inner and outer glass cover, ambient temperature efficiency of evaporation and condensation rate, and amount of distilled water collected daily. The position of the solar still is located in an open area within UTP grounds at 4.38°N latitude and 100.97°E longitude, near Block 13.

Results and discussions are obtained further as the project progresses after monitoring and testing of the fabricated solar still. The results obtained will be compared with previous works and will be discussed based on the findings. Conclusions are made after thorough checking and referencing of works and data to finalize the results.

3.1 Experimental procedure / Project feasibility

TABLE 3.2: Proposed duration of experimentation

No	Step	Duration
1	Fabrication of first solar still system	1 week
2	Setting up solar system	1 hour
3	Monitoring of climatic condition and condition of solar still	1 week
4	Analysis of water production	1 day
5	Fabrication of second solar still system	3 weeks
6	Setting up solar system	1 day
7	Monitoring of climatic condition and condition of solar still	2 weeks
8	Analysis of water production	1 day
	Total time	**7 weeks**

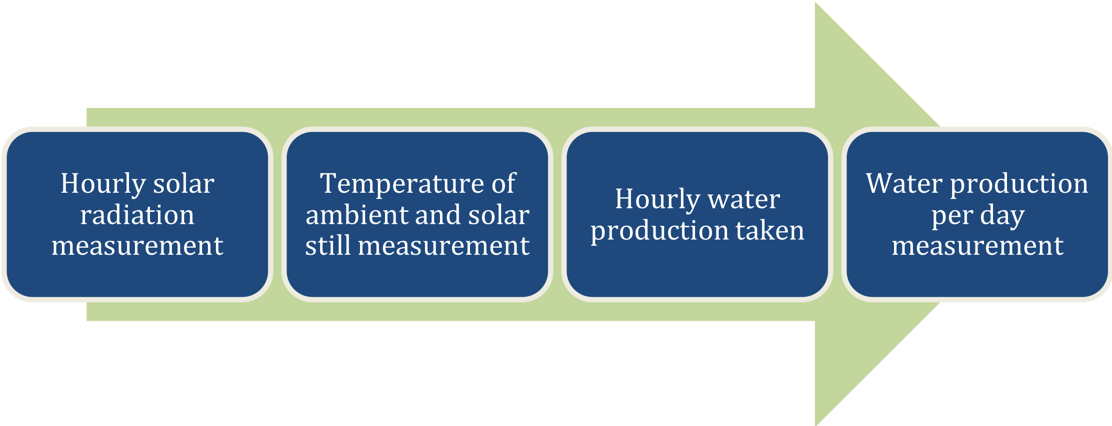


FIGURE 3.3: Procedure of conducting experimentation

The experiments carried out were based on the procedure in **FIGURE 3.3** to find for the solar radiation, temperature of ambient and in solar still system, and the hourly and daily water production.

3.2 Design Proposal

There are two design stages proposed for this project. Firstly, included designing of a basin which is to experiment on the type of suitable material to aid in absorption of heat. The second design is proposed for a solar capturing device to channel heat into flowing water of the system whereby it focused the heat onto the water. Hence, the making of a parabolic trough collector (PTC) to channel solar energy to further heat up the water as it enters the basin is proposed. The experiments were carried out in the month of July 2013. The design and methodology carried out in the experiments is based on Ali Riahi's method which used similar design and methodology as shown in a published paper [49].

3.2.1 Experiment Stage 1 - Basin Absorption Material

FIGURE 3.4: (L-R) Black paint basin, Sand layer basin, Conventional basin

Three models of triangular sloped solar still basins were fabricated with stainless steel basin of 50 cm length and 30 cm width with an area of 0.15 m^2, transparent plastic cover and PVC pipes as frames for the solar still. The plastic cover extended to the water collected situated at the bottom of the solar still.

The three models are to be used in experimenting with types of materials used in the basin to increase rate of absorption of heat which aids in increasing temperature of water. Materials tested for are flat black paint, sand layer, and conventional stainless steel surface.

The black paint stainless steel basin was made by spraying flat black paint with non-reflective surface to reduce lost of solar energy and increase absorption of heat. The sand layer in stainless steel basin is filled up to a depth of 2cm which is enough to cover the bottom part of the basin to reduce the reflectivity of the basin. The conventional steel basin is used to act as a control to compare the effectiveness of black paint and sand layer.

The experiment carried out lasted a duration of two days by exposing the triangular solar still models to direct solar radiation for investigating the sun radiation absorption, water evaporation and condensation rate under Malaysian climatic conditions.

3.2.2 Experiment Stage 2 - Parabolic Trough Collector (PTC)

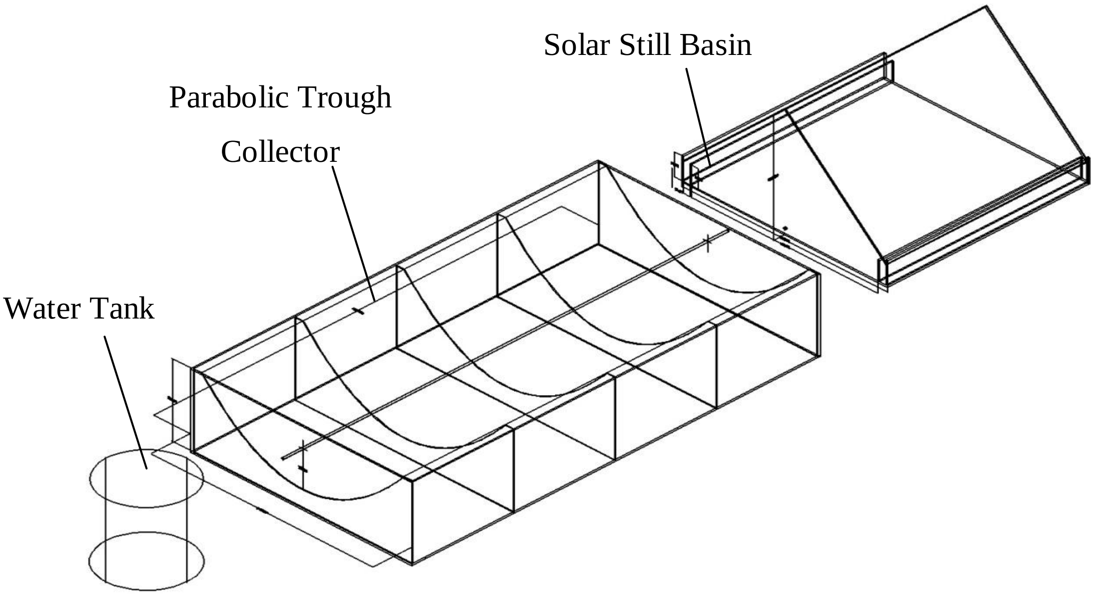


FIGURE 3.5: Proposed solar still design with PTC

FIGURE 3.6: Fabricated PTC system setup on the field

The proposed design is based on a solar still with a PTC. Cool water flowed from the water tank to the PTC and into the solar still basin. The system included a 10 mm diameter black steel pipe passing through the PTC of 1 m in length, using aluminum foil sheet as the collector material. The solar still is made from glass and steel while the collector is made using waterproof canvas. The level of water of the solar still is kept the same as the level of water within the water tank due to siphon and gravity effect. For the experiments, the level of water is maintained at 1 cm in the basin.

The water in the pipe is preheated before it entered the solar still due to the effects of the parabolic trough with aluminum foil sheet. The parabolic trough collector reflected solar radiation onto the focal point which is positioned with a steel pipe. The focus would amplify the heating effect of the water to near boiling point and aided in the process of evaporation. The PTC is fabricated to be freely rotational so that it can be directed to face the sun and capture solar radiation more effectively.

Upon water entering the basin solar still, the preheated water evaporated and vapour rise up to the bottom of the glass roof of the solar still. Condensation occurred with aid of ambient temperature and the condensed water flowed down along the double inclined roof into the water collector at the sides. From the water collector, the condensed water is collected into bottles and categorized as distilled water.

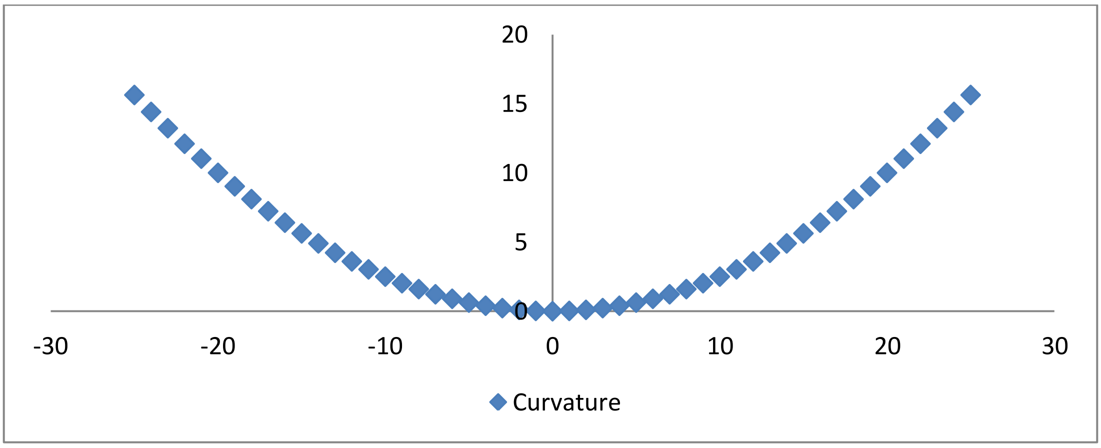


FIGURE 3.7: Curvature of the parabolic trough designed

The design of the PTC can be done using the formula to calculate focal point:

$$y = \frac{x^2}{4P}$$

Where y = height of parabola

x = width of parabola

P = distance of focal point from parabola

Here, x is taken to be 25 cm while P is 10 cm and y is calculated to obtain maximum height of 15.63 cm. Plotting the points using Microsoft Excel produces the graph as shown in **FIGURE 3.7**. Then the design of the solar still with PTC are drawn using AutoCAD and paper. The dimensions of the PTC is 1.0 m x 0.5 m while the solar still basin is 0.6 m x 1.0 m from end to end, with effective water basin area of 0.45 m x 0.9 m or an area of 0.405 m^2. The solar still system is fabricated using ironworks and steel welding as they have capabilities to withstand high temperatures. Glass is used as the basin cover.

3.3 Materials & Equipments Required

Materials

- Plastic sheet
- PVC pipes
- Steel sheet, frame
- Aluminium sheet
- Glass
- Coarse Sand
- Flat black paint
- Stainless steel pipe
- Rubber hose
- Connecting pipes

Equipment

- Thermometer - Ambient temperature, Glass cover, Water in basin
- Pyranometer - Daily solar radiation
- Water tank
- Water bottles - Water storage

3.4 Expected Results of a conventional solar still

- Mean daily dry bulb temp. = 27.2°C [48]
- Hourly global solar radiation [48]
- Data from year 2006-2008 averaged at Sitiawan Meteorological station:
  = 4.62 kWh/m²d
- 4.62 x 3600 = 16.632 MJ/m²d
- Latent heat of evaporation = 2260 kJ/kg [43]
- Assuming efficiency of 30%, for 1kg of water
- 16.632 / 2.26 x 0.30

  = 2.2 kg/m²d of treated water for a basic solar still

FIGURE 3.8 on the following page indicates the flow chart for procedures to follow to complete the project within the duration of Final Year Project 1 and Final Year Project 2.

TABLE 3.3-1 and **TABLE 3.3-2** on the following pages show the Gantt chart and suggested Key Milestones to follow for Final Year Project 1 and Final Year Project 2.

3.5 Proposal Flow Chart

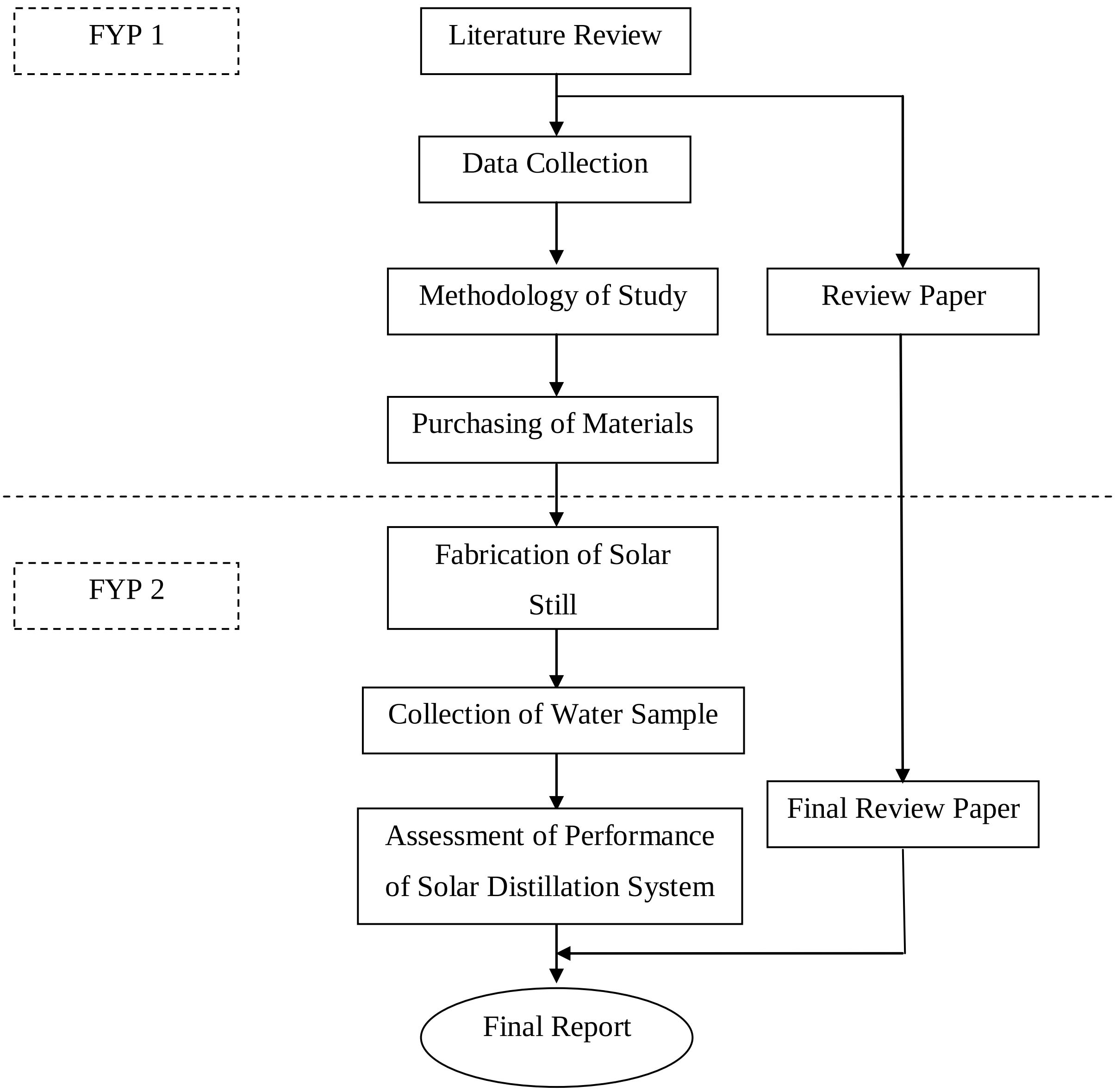


FIGURE 3.8: Process Flow Chart for FYP 1 & FYP 2

3.6 Gantt Chart

TABLE 3.3-1: Gantt Chart for Final Year Project 1

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic	■													
Supervisor Introduction		■												
Preliminary Research Work (Literature Study)			■	■	■									
Preliminary Data Obtained					●									
Submission of Extended Proposal Defence (Literature Review Submitted)						■ ●	■							
Proposal Defence								■	■					
Methodology familiarised (Expected Results and Calculations obtained)									●					
Design and modeling completed										●				
Planning for materials										■	■	■	■	
Literature Review Completed												●		
Ordering of materials													■	■
Submission of Interim Draft Report													■	
Submission of Interim Report														●

Legend: ■ Duration ● Milestone

TABLE 3.3-2: Gantt Chart for Final Year Project 2

Week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Finalizing of Stage 1 design	■														
Ordering Materials and Fabrication of Stage 1 Design		■	■												
Fabrication of Stage 1 Design finished			●												
Monitoring Performance of Stage 1 Design				■											
Results for Stage 1 Design obtained				●											
Finalizing of Stage 2 design					■										
Ordering materials and Fabrication of Stage 2 Design						■	■	■							
Fabrication of Stage 2 Design finished								●							
Progress Report submitted								●							
Monitoring Performance of Stage 2 Design									■	■					
Results for Stage 2 Design obtained										●					
Pre-SEDEX presentation prepared											●				
Analysed performance of Stage 2 Design											■				
Finalised Results for Stage 2 Design												●			
Draft Report submitted												●			
Dissertation (Soft bound) submitted													●		
Technical Paper submitted													●		
SEDEX presentation prepared														●	
Oral Presentation prepared														●	
Project Dissertation (Hard bound) submitted															●

Legend: ■ Duration ● Milestone

Key Milestones:

TABLE 3.4: Key milestones for FYP 1 & FYP 2

Milestones	Dates (Year 2013)
Preliminary Data obtained	15 February
Submission of Extended Proposal Defence	22 February
Methodology familiarised	15 March
Design and modeling completed	22 March
Literature Review completed	5 April
Submission of Interim Report	19 April
Fabrication of Stage 1 Design finished	7 June
Results for Stage 1 Design obtained	14 June
Fabrication of Stage 2 Design finished	12 July
Progress Report submitted	12 July
Results for Stage 2 Design obtained	26 July
Pre-SEDEX	31 July
Finalised results for Stage 2 Design	9 August
Draft Report submitted	9 August
Dissertation (Soft bound) submitted	16 August
Technical Paper submitted	16 August
SEDEX Presentation prepared	19 August
Oral Presentation prepared	23 August
Project Dissertation (Hard Bound) submitted	31 August

CHAPTER 4

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION FOR THE EXPERIMENTS

4.1 Results for Experiment Stage 1 - Basin Absorption Material

The results for the three basin experiment are obtained after a 2-day experiment duration during July 10th and 11th, 2013 and are presented as follows.

4.1.1 Results for Black Paint Basin

TABLE 4.1: Data for Black Paint Basin (July 10th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	W_{hexp} (ml/m^2)	W_{dexp} (ml/m^2)
9:00 AM	274	26	25	23	25	24	0	0
10:00 AM	269	28	26	22	27	22	0.00	0.00
11:00 AM	636	35	32	23	34	23	0.00	0.00
12:00 PM	885	45	36	25	42	27	62.67	62.67
1:00 PM	1118	51	40	26	46	29	325.87	388.53
2:00 PM	650	49	40	25	43	28	387.40	775.93
3:00 PM	596	47	39	25	42	29	284.13	1060.07
4:00 PM	362	44	37	25	40	26	266.07	1326.13
5:00 PM	286	43	36	24	39	25	286.60	1612.73

TABLE 4.2: Data for Black Paint Basin (July 11th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	W_{hexp} (ml/m^2)	W_{dexp} (ml/m^2)
9:00 AM	559	30	28	23	29	23	0	0
10:00 AM	447	36	32	24	35	25	0.00	0.00
11:00 AM	507	40	34	24	37	26	263.93	263.93
12:00 PM	627	49	39	30	43	29	281.80	545.73
1:00 PM	1110	52	41	31	45	30	495.33	1041.07
2:00 PM	678	50	38	24	43	27	299.67	1340.73
3:00 PM	901	51	40	29	44	29	380.00	1720.73
4:00 PM	307	48	37	26	41	27	331.00	2051.73
5:00 PM	276	45	37	25	41	25	307.47	2359.20

Where, Is = Hourly solar radiation

Tw = Temperature of water in basin of solar still

Tic = Temperature of inner cover of solar still

Ta = Ambient temperature

$T_{humidity}$ = Temperature of humidity in solar still

Toc = Temperature of outer cover of solar still

W_{hexp} = Hourly water production of solar still

W_{dexp} = Daily water production of solar still

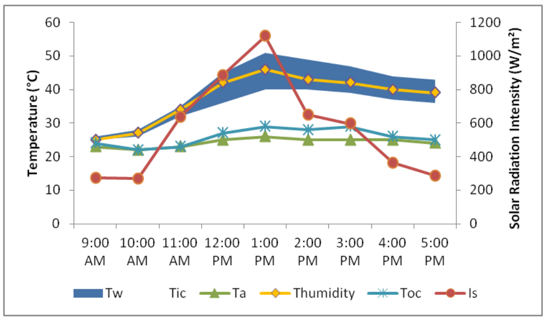


FIGURE 4.1: Temperature vs Solar radiation intensity with Time (Black Paint, 10/7/2013)

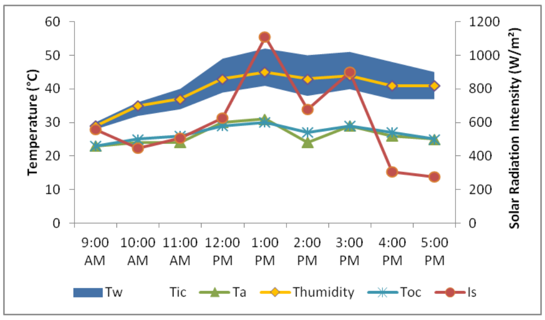


FIGURE 4.2: Temperature vs Solar radiation intensity with Time (Black Paint, 11/7/2013)

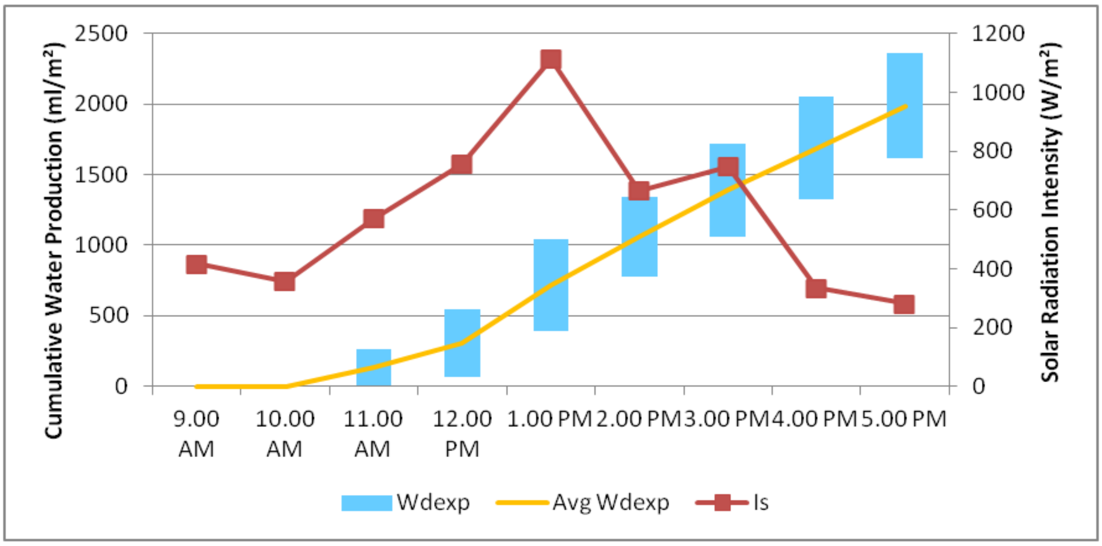


FIGURE 4.3: Range of Potable water production vs Average Solar radiation intensity with Time (Black Paint)

4.1.2 Results for Sand Layer Basin

TABLE 4.3: Data for Sand Layer Basin (July 10th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	W_{hexp} (ml/m^2)	W_{dexp} (ml/m^2)
9:00 AM	274	26	25	23	25	24	0	0
10:00 AM	269	27	26	22	27	23	0.00	0.00
11:00 AM	636	34	31	23	33	28	0.00	0.00
12:00 PM	885	43	36	25	39	31	0.00	0.00
1:00 PM	1118	48	40	26	43	30	148.87	148.87
2:00 PM	650	48	39	25	43	27	243.33	392.20
3:00 PM	596	47	38	25	41	26	238.87	631.07
4:00 PM	362	44	35	25	39	25	187.40	818.47
5:00 PM	286	43	34	25	38	25	288.33	1106.80

TABLE 4.4: Data for Sand Layer Basin (July 11th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	W_{hexp} (ml/m^2)	W_{dexp} (ml/m^2)
9:00 AM	559	29	28	23	29	24	0	0
10:00 AM	447	34	30	24	32	25	0.00	0.00
11:00 AM	507	38	33	25	36	28	141.33	141.33
12:00 PM	627	48	40	30	43	31	208.53	349.87
1:00 PM	1110	49	41	31	45	30	343.90	693.77
2:00 PM	678	48	37	24	43	26	210.57	904.33
3:00 PM	901	49	41	29	45	29	359.83	1264.17
4:00 PM	307	47	38	26	40	26	159.83	1424.00
5:00 PM	276	44	34	25	35	26	171.93	1595.93

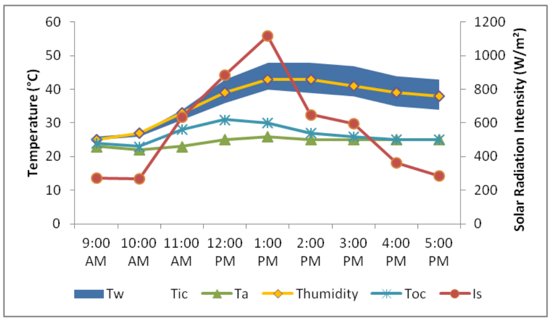


FIGURE 4.4: Temperature vs Solar radiation intensity with Time (Sand Layer, 10/7/2013)

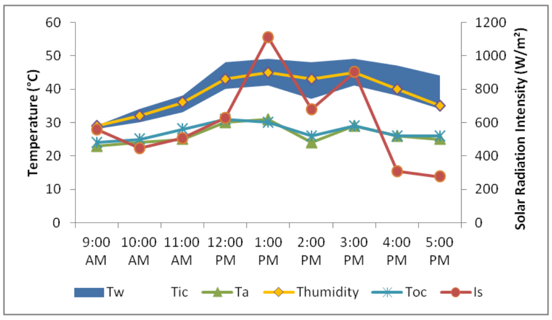


FIGURE 4.5: Temperature vs Solar radiation intensity with Time (Sand Layer, 11/7/2013)

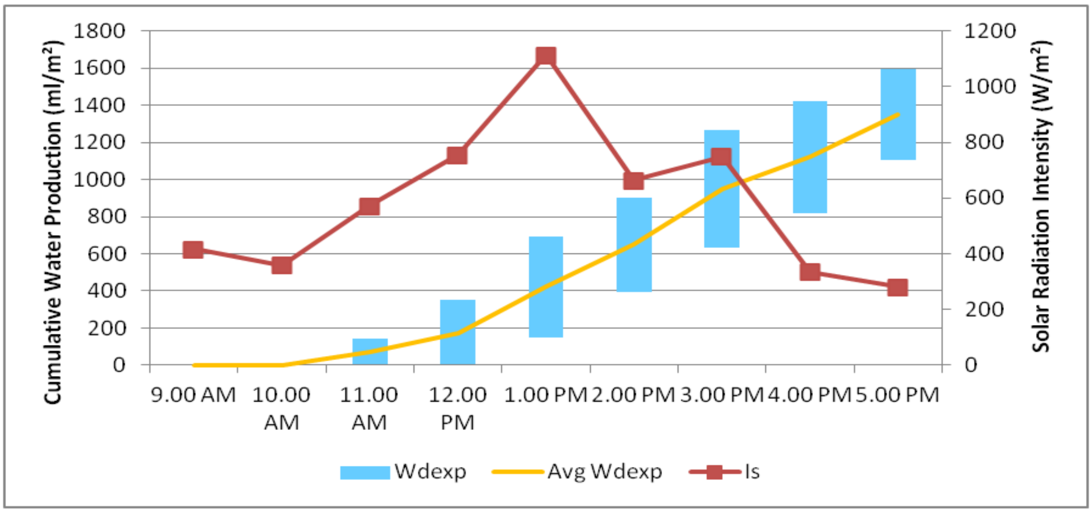


FIGURE 4.6: Range of Potable water production vs Average Solar radiation intensity with Time (Sand Layer)

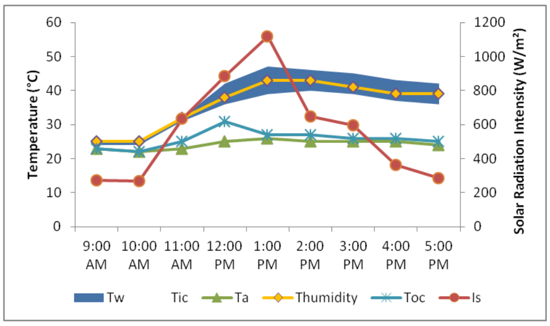
4.1.3 Results for Conventional Basin

TABLE 4.5: Data for Conventional Basin (July 10th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	W_{hexp} (ml/m^2)	W_{dexp} (ml/m^2)
9:00 AM	274	25	24	23	25	23	0	0
10:00 AM	269	25	24	22	25	22	0.00	0.00
11:00 AM	636	32	31	23	32	25	0.00	0.00
12:00 PM	885	42	36	25	38	31	0.00	0.00
1:00 PM	1118	47	39	26	43	27	195.13	195.13
2:00 PM	650	46	40	25	43	27	221.60	416.73
3:00 PM	596	45	39	25	41	26	209.87	626.60
4:00 PM	362	43	37	25	39	26	173.13	799.73
5:00 PM	286	42	36	24	39	25	148.67	948.40

TABLE 4.6: Data for Conventional Basin (July 11th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	W_{hexp} (ml/m^2)	W_{dexp} (ml/m^2)
9:00 AM	559	27	26	23	27	23	0	0
10:00 AM	447	32	29	24	30	25	0.00	0.00
11:00 AM	507	37	33	25	35	26	100.73	100.73
12:00 PM	627	45	37	30	39	29	203.20	303.93
1:00 PM	1110	47	40	31	43	30	206.67	510.60
2:00 PM	678	46	38	24	42	24	153.13	663.73
3:00 PM	901	47	39	29	43	29	340.00	1003.73
4:00 PM	307	47	38	26	41	28	204.00	1207.73
5:00 PM	276	44	37	25	39	28	176.73	1384.47



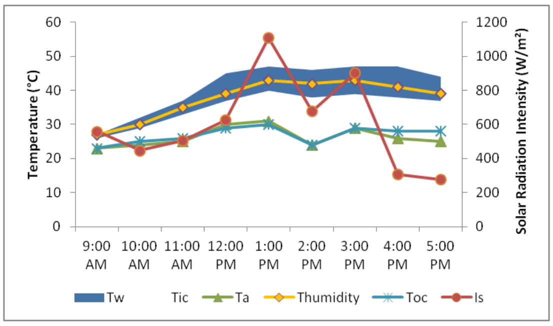


FIGURE 4.7: Temperature vs Solar radiation intensity with Time (Conventional, 10/7/2013)

FIGURE 4.8: Temperature vs Solar radiation intensity with Time (Conventional, 11/7/2013)

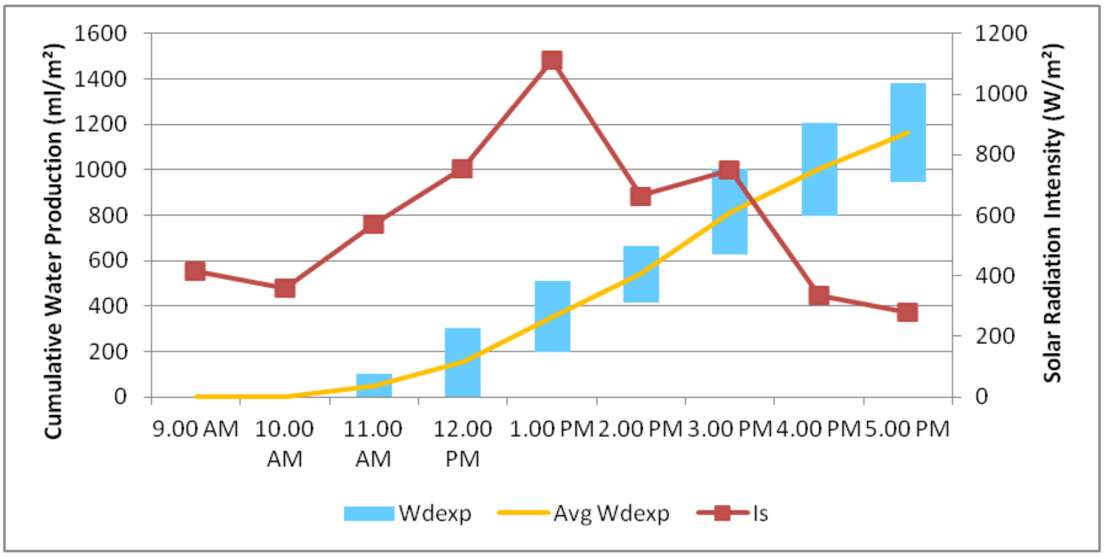


FIGURE 4.9: Range of Accumulative water production vs Solar radiation for Black Paint basin

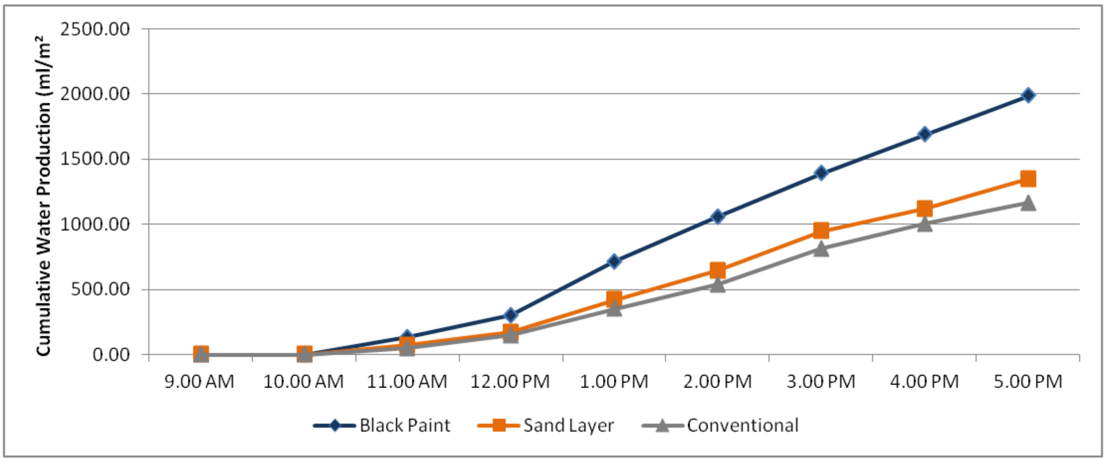


FIGURE 4.10: Average daily accumulative water production

4.2 Discussion for Basin Absorption Material

The two-day experiment tested for the effects of materials on the absorptivity of heat by solar energy. Flat black paint is tested for due to the natural effects of the colour being able to absorb and release heat fast. Sand layer is tested for its opaque and non reflective properties.

Weather effects were also noted during the experiment duration which ranged from and sunny to cloudy as well as a slight drizzle of rain. Weather effects have heavy impact on the productivity of the solar still, whereby cloudy conditions showed a drastic drop in temperature of the solar still and decreasing evaporation rate since heat cannot be kept constant or increased during that period.

The outer cover temperature is closely similar with the ambient temperature which showed a gradual increase from morning to afternoon and declined in the evening. The inner cover temperature is relative with the humidity temperature of the solar still which affects the rate of condensation by cooling the vapour back to liquid form. The inner cover temperature is usually lower than the humidity temperature. This shows that the cover is being cooled by the ambient temperature as well as implied by Ghoneyem and Ileri [11] that a thinner glass cover can help in faster heat exchange with the surroundings.

Solar radiation was relatively low during the first day of experiment due to cloudy and slight drizzle in the early morning. However, it eventually increased to its peak at 1.00 pm in the afternoon and then gradually decreased. The second day of experiment showed higher readings of solar radiation in the morning until reaching its peak at 1.00 pm again. The weather history for the month of July, 2013 can be seen in **APPENDIX 7**. A sudden drop in solar radiation at 2.00 pm was due to the cloudy conditions which cleared at 3.00 pm, and then decreased in the evening. Average solar radiation for July 10th, 2013 is 564 W/m^2 and 11th, 2013 is 601.3 W/m^2 during the 9-hours of experiment.

Average solar radiation = (564 + 601) /2 = 582 W/m^2

582 W/m^2 x 3600 x 9 = 18.8568 $MJ/m^2/d$

It is shown that black paint is able to produce a higher output of distilled water when compared to sand layer and the conventional stainless steel basin. Black paint basin was able to produce up to ~1.6 $kg/m^2/d$ on July 10th, 2013. It showed an increase in productivity over sand layer and conventional basins by 45% and 70% respectively. Black paint basin produced up to ~2.36 $kg/m^2/d$ the following day and managed a productivity increase of 47% over sand layer basin and 70% over conventional basin. Sand layer basin did not perform very well even under low solar radiation levels when compared to conventional basin and showed only a slight increase in temperature gain in sunny and hot conditions.

Average ambient temperature recorded for the two days are 24.2°C for first day and 26.3°C for second day. The peak temperature of water in basin captured by black paint, sand layer and conventional basin is 52°C, 49°C and 47°C respectively. On the hottest day, which is the second day of experiment with average of 601.3 W/m^2, the average temperature of water in basin is 44.6°C for black paint basin, 42.9°C for sand layer basin, and 41.3°C for conventional basin. This showed that the black paint is able to absorb and retain heat quite effectively than sand layer and conventional basins.

Efficiency of the basins has also been calculated to study their relationship between solar radiation and productivity. The daily efficiency can be calculated as follows:

Efficiency for the Black Paint Basin,

$$\eta_d = \frac{\sum Mew \times hfg}{\sum A \times I(t)} \qquad [35]$$

Where, M_{ew} = Mass of water production
h_{fg} = Latent heat of vapourisation
I (t) = Daily solar radiation
A = Whole area of collector

$$\eta_d = \frac{2.36\ kg/m^2 \times 2372000\ J/kg}{601.3\ W/m^2 \times 3600s \times 9}$$

η_d = 0.287 = 28.7% efficiency for Black Paint Basin solar still

TABLE 4.7: Hourly and Daily Efficiency for the 3 basins (July 10th, 2013)

10th July 2013		Black Paint		Sand Layer		Conventional	
Time	I_S	W_{hexp} (ml/m^2)	η (%)	W_{hexp} (ml/m^2)	η (%)	W_{hexp} (ml/m^2)	η (%)
9:00 AM	274	0.00	0.00%	0	0.00%	0	0.00%
10:00 AM	269	0.00	0.00%	0	0.00%	0	0.00%
11:00 AM	636	0.00	34.30%	0.00	18.37%	0.00	13.09%
12:00 PM	885	62.67	29.61%	0.00	21.91%	0.00	21.35%
1:00 PM	1118	325.87	29.40%	148.87	20.41%	195.13	12.27%
2:00 PM	650	387.40	29.12%	243.33	20.46%	221.60	14.88%
3:00 PM	596	284.13	27.79%	238.87	26.31%	209.87	24.86%
4:00 PM	362	266.07	71.04%	187.40	34.30%	173.13	43.78%
5:00 PM	286	286.60	73.40%	288.33	41.05%	148.67	42.19%
Daily Efficiency (%)			20.93%		14.37%		12.31%

TABLE 4.8: Hourly and Daily Efficiency for the 3 basins (July 11th, 2013)

11th July 2013		Black Paint		Sand Layer		Conventional	
Time	I_S	W_{hexp} (ml/m^2)	η (%)	W_{hexp} (ml/m^2)	η (%)	W_{hexp} (ml/m^2)	η (%)
9:00 AM	559	0.00	0.00%	0	0.00%	0	0.00%
10:00 AM	447	0.00	0.00%	0	0.00%	0	0.00%
11:00 AM	507	263.93	34.30%	141.33	18.37%	100.73	13.09%
12:00 PM	627	281.80	29.61%	208.53	21.91%	203.20	21.35%
1:00 PM	1110	495.33	29.40%	343.90	20.41%	206.67	12.27%
2:00 PM	678	299.67	29.12%	210.57	20.46%	153.13	14.88%
3:00 PM	901	380.00	27.79%	359.83	26.31%	340.00	24.86%
4:00 PM	307	331.00	71.04%	159.83	34.30%	204.00	43.78%
5:00 PM	276	307.47	73.40%	171.93	41.05%	176.73	42.19%
Daily Efficiency (%)			28.72%		19.43%		16.86%

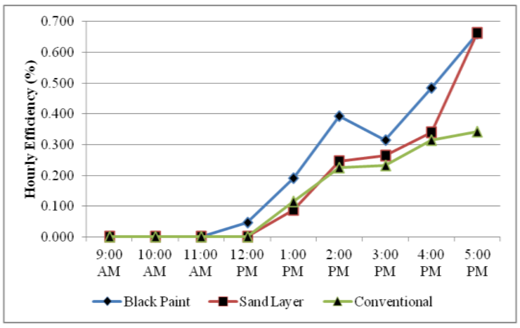


FIGURE 4.11: Hourly efficiency for the 3 basins (July 10th, 2013)

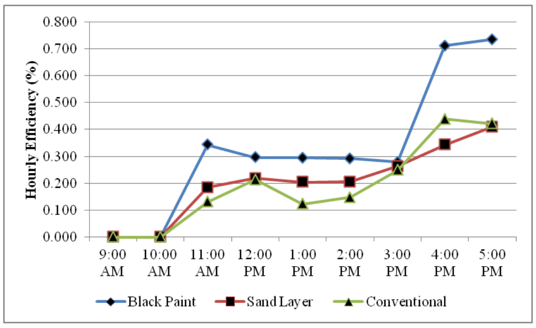


FIGURE 4.12: Hourly efficiency for the 3 basins (July 11th, 2013)

It can be seen that the daily efficiency is dependent on the amount of solar radiation per square meter. The daily efficiency would increase as the daily solar radiation increases. For 10th July, the total solar radiation accumulated in the 9-hour experiment amounted to 5076 W/m^2 whereas for 11th July, the accumulated total solar radiation is found to be 5412 W/m^2. Higher daily solar radiation would result in higher efficiency due to less fluctuation in increasing specific heat capacity of water and providing enough energy for latent heat of vapourisation of water. If solar radiation fluctuates, heat loss is certain and this would result in requiring more heat once again to raise the temperature up, and this would greatly affect the productivity at a given time. This could be a reason why black paint basin is able to produce a higher output as the reduce reflectivity and increased absorptivity is able to retain heat for longer periods.

Productivity is also found to be high when temperature difference between inner cover and water in basin is high. High production rate is observed whenever temperature difference is 9°C and above.

4.3 Results for Parabolic Trough Collector (PTC)

TABLE 4.9: Data for PTC System (July 27th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	$T_{parabola}$	W_{hexp} (ml/m²)	W_{dexp} (ml/m²)
11:00 AM	649	39	35	25	37	31	45	0	0
12:00 PM	906	46	38	26	43	35	56	0	0
1:00 PM	536	46	39	28	42	30	41	79.01	79.01
2:00 PM	1029	45	40	30	39	32	62	138.27	217.28
3:00 PM	783	49	42	31	45	32	59	46.91	264.20
4:00 PM	154	40	33	30	36	32	30	66.67	330.86
5.00 PM	Experiment halted due to bad weather								

Where, Is = Hourly solar radiation

Tw = Temperature of water in basin of solar still

Tic = Temperature of inner cover of solar still

Ta = Ambient temperature

$T_{humidity}$ = Temperature of humidity in solar still

Toc = Temperature of outer cover of solar still

$T_{parabola}$ = Temperature of steel pipe on PTC

W_{hexp} = Hourly water production of solar still

W_{dexp} = Daily water production of solar still

TABLE 4.10: Data for PTC System (July 28th, 2013)

Time	I_S (W/m^2)	Tw	Tic	Ta	$T_{humidity}$	Toc	$T_{parabola}$	W_{hexp} (ml/m²)	W_{dexp} (ml/m²)
11:00 AM	633	27	25	25	26	25	42	0	0
12:00 PM	721	45	40	33	43	39	64	69.14	69.14
1:00 PM	615	42	38	32	41	35	48	54.32	123.46
2:00 PM	500	42	39	32	43	38	62	51.85	175.31
3:00 PM	619	47	42	32	46	36	50	74.07	249.38
4:00 PM	620	46	41	29	44	31	49	61.73	311.11
5:00 PM	526	44	39	32	41	35	50	41.98	353.09
6.00 PM	317	42	39	28	41	33	50	86.42	439.51

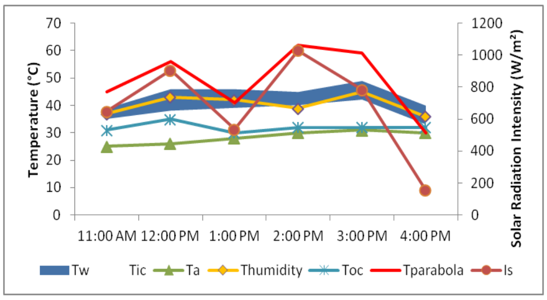


FIGURE 4.13: Temperature vs Solar radiation intensity with Time (27/7/2013)

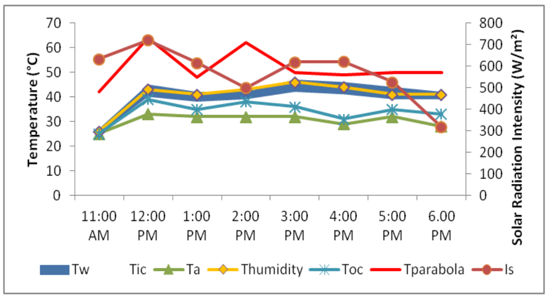


FIGURE 4.14: Temperature vs Solar radiation intensity with Time (28/7/2013)

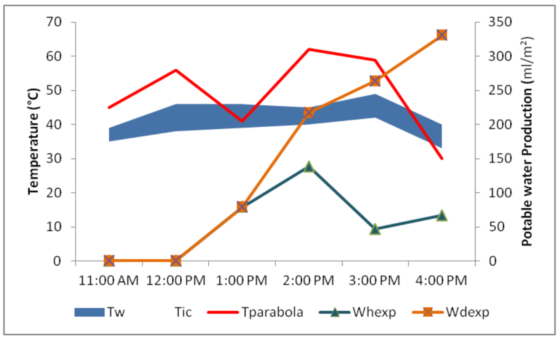


FIGURE 4.15: Temperature vs Potable Water Production with Time (27/7/2013)

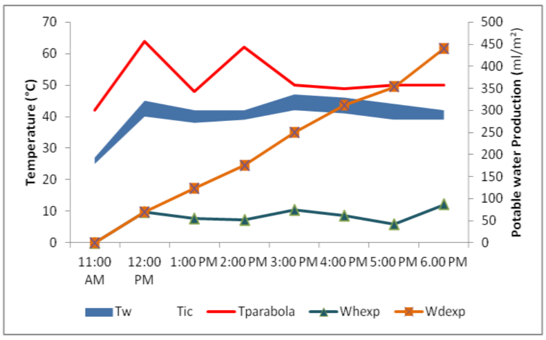


FIGURE 4.16: Temperature vs Potable Water Production with Time (28/7/2013)

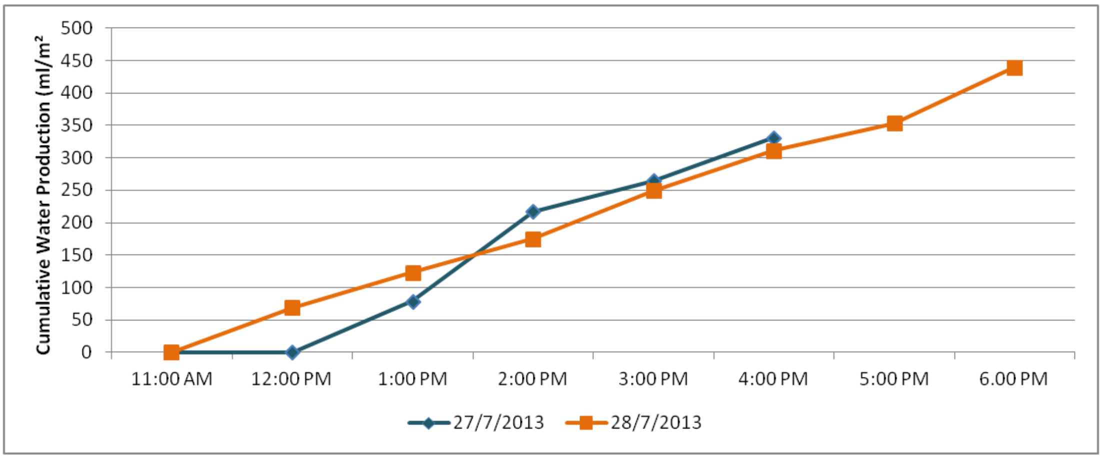


FIGURE 4.17: Accumulative water production for the PTC system

4.4 Discussion for Parabolic Trough Collector (PTC)

The two-day experiment was assessed on its functions as a solar still basin connected with a PTC. Cool tap water was supplied by a water tank attached to the PTC. However, the results obtained from the experiment were not very satisfactory due to various problems and unfavourable conditions during the conduction of the experiment.

The temperature difference for the first day was higher than the second day experiment. This is likely due to the low solar radiation intensity during the second day as cloudy effects lowered it. The temperature of the outer cover was always higher than the ambient temperature, which showed that the system is producing heat.

Weather effects for the two days were mostly cloudy. High solar radiation fluctuations were seen during the days of experiment in the month of July. The first day of experiment experienced cloudy weather in the morning, followed by a rise in sunlight during the afternoon, but was halted early at 4.00 pm due to dark skies and heavy rainfall. Day two of the experiment experienced cloudy conditions all day, whereby solar radiation in the morning was higher compared to afternoon.

Peak solar radtiation was found to be at 2.00 pm and 12.00 pm on July 27th and 28th respectively. Average solar radiation was 676 W/m^2 during the 6-hour experiment on July 27th and 568 W/m^2 for the 8-hour experiment on July 28th. Hence, average solar radiation of 622 W/m^2 for the two day experiment.

Average solar radiation = (568 + 676) /2 = 622 W/m^2

622 W/m^2 x 3600 x 6 = 13.9752 MJ/m^2/d

In addition, the solar radiation for the month of July is fairly low due to cloudy weather most of the time. It is one of the low radiation periods throughout the year when observed [48]. The graph which shows monthly solar radiation by the year in Subang can be seen in **APPENDIX 5**.

Temperature of the pipe on the PTC fluctuates with solar radiation. The temperature drops quickly when solar radiation becomes low. The effectiveness drops when solar radiation does not fall and be reflected completely on the focal point of the pipe. Proper angle rotation of the PTC collector to face the sun is required for maximum effect. Also, there is a lack of insulation materials and larger surface area of the 10mm diameter black steel pipe to capture and maintain heat may contribute to heat losses. Even though it is able to absorb heat fast due to the black paint, as the pipe is left to the open environment, wind effects and ambient temperatures are able to cool it and lower the temperature as well.

The average ambient temperature recorded are 28.3°C and 30.3°C for July 27th and 28th respectively. Peak water temperature obtained was 49°C when temperature of pipe on parabola is 59°C. Average water temperature is 44.1°C for July 27th and 41.8°C for July 28th.

Productivity obtained for the two days are 330 ml/m^2/d and 439 ml/m^2/d which is distinctively lower when compared to the solar still basin with black paint in an earlier experiment.

Efficiency of the PTC system is calculated,

$$\eta_d = \frac{\sum Mew \times hfg}{\sum A \times I(t)} \qquad [35]$$

Where, M_{ew} = Mass of water production
h_{fg} = Latent heat of vapourisation
I (t) = Daily solar radiation
A = Whole area of collector

$$\eta_d = \frac{.439\ kg/m^2 \times 2372000\ J/kg}{568\ W/m^2 \times 3600s \times 9}$$

η_d = 0.637 = 6.37% efficiency achieved for the PTC System

The hourly and daily efficiencies for the system can be seen in **TABLE 4.11**:

TABLE 4.11: Hourly and Daily Efficiency for PTC System

27th July 2013			
Time	I_S	W_{hexp} (ml/m²)	η (%)
11:00 AM	559	0	0.00%
12:00 PM	447	0	0.00%
1:00 PM	507	79.01	10.27%
2:00 PM	627	138.27	14.53%
3:00 PM	1110	46.91	2.78%
4:00 PM	678	66.67	6.48%
Daily Efficiency (%)			5.37%

28th July 2013			
Time	I_S	W_{hexp} (ml/m²)	η (%)
11:00 AM	633	0	0.00%
12:00 PM	721	69.14	6.32%
1:00 PM	615	54.32	5.82%
2:00 PM	500	51.85	6.83%
3:00 PM	619	74.07	7.88%
4:00 PM	620	61.73	6.56%
5:00 PM	526	41.98	5.26%
6.00 PM	317	86.42	17.96%
Daily Efficiency (%)			6.37%

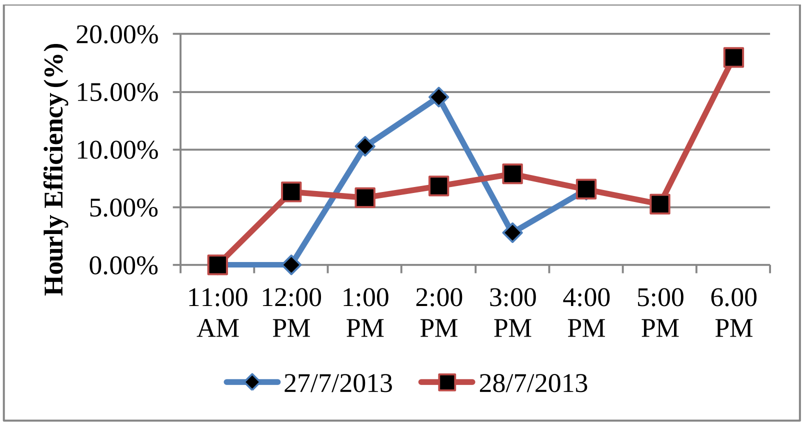


FIGURE 4.18: Hourly efficiency for PTC system

It can be seen that the daily efficiency is very low ranging from 5% to 6% only. The productivity is gotten to be low may be due to the solar radiation energy collected was not able to be effectively converted to be used in the evaporation-condensation process.

There were a few problems encountered with the system as well. One of them is the fabrication of the basin with glass cover. As the glass cover is not sealed entirely to the basin due to requirements to measure temperatures of the basin, it is possible for wind effects to enter into the basin trough the gaps and alter the evaporation-condensation process. It is observed in the morning periods that one side of the glass panel was experiencing condensation process while the other side was not. The side which condensation occured at a slower rate was where the wind was directed to.

Another problem encountered was the circulation of water in the system. The gravity flow system did not have much effect on circulating the water effectively. The water tank was left open to the environment and was left until water level was set to 1 cm in the basin. It was refilled each hour to suit the required water level in the basin. However, the temperature would drop drastically as cool water was poured into the system which was why the temperature of the pipe on the PTC fluctuates at the time of measurement. The lack of circulation meant most of the heat was left only in the pipe on the PTC and did not enter into the basin.

Temperature of the pipe on the PTC was extremely hot, peaking up to 64°C even on a cloudy day but decreased shortly after extending towards the solar still basin. This may be due to the heat loss experienced when transfering heat to the cool water. For this case, it can be said the system was not a closed system but open to the surroundings and resulted in many energy losses. The distance from pipe on PTC to the basin is also a factor.

Furthermore, it is identified of importance for the distilled water collector to be properly designed. Initially the design lacked proper gradient of slope which resulted in most of the distilled water remaining stagnant and unable to flow smoothly into the water collector. This resulted in low productivity as the water did not enter the collector and remained in the system which lead to the whole cycle of evaporation-condensation process being repeated.

Unexpected change of weather was encountered during this time of the year as dangerous levels of haze outbreak occurred in the middle of July and caused further delay of carrying out the experiment for the TPC system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

It is concluded that Black Paint basin has much capabilities in capturing and retaining heat from solar energy. Sand layer did not perform well despite having low light reflectivity. The conventional basin used stainless steel as basin which obtained the least amount of productivity.

The solar radiation per square meter in a day was found to be averaging 18.86 $MJ/m^2/d$ during the two-day solar still basin experiment. From the experiment, it is found that the Black Paint basin performs at 28.7% efficiency which is close to the expected results and is able to produce up to 2.36 $kg/m^2/d$. Highest water temperature reached in basin is by the Black Paint basin which achieved 52°C under a solar radiation of 1110 W/m^2.

For the PTC system, it did not perform according to expectations as there were problems encountered with the fabrication of the system and low solar radiation levels. The solar radiation per square meter in a day was found to be 13.9572 $MJ/m^2/d$ for the two-day PTC experiment. Maximum efficiency found for the system was 6.3%. Highest water temperature in basin recorded was 49°C under solar radiation of 783 W/m^2. The PTC system produced up to 439 $ml/m^2/d$ which is lower than expected. Unfortunately, the time duration allocated for the project is insufficient to further continue the study.

However, various recommendations can be put forward for future research and development of the PTC system. Firstly, the circulation of water in the system is recommended to ensure dispersion of heat in the water. Secondly, the system should be kept closed and sealed from wind or external effects. Moreover, the system should be kept compact to minimize heat loss from the heated water during transportation of water from water tank to PTC to basin. Fourthly, insulation of the basin or pipes can help to reduce heat loss such as using compacted saw dust. In addition, the PTC should be facing the sun's angle at all times. It is therefore recommended to use a motor and a sensor to track the sun and rotate the PTC accordingly. Last but not least, it is recommended for the collector for the condensed water to be properly designed with gradient of more than 7% for smooth flow.

Overall, solar-still water production under Malaysian conditions has potential to grow and may become an energy harnessing asset in the near future. Thereby, it is with hope that the findings of this project can aid in future developments of solar stills.

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APPENDICES

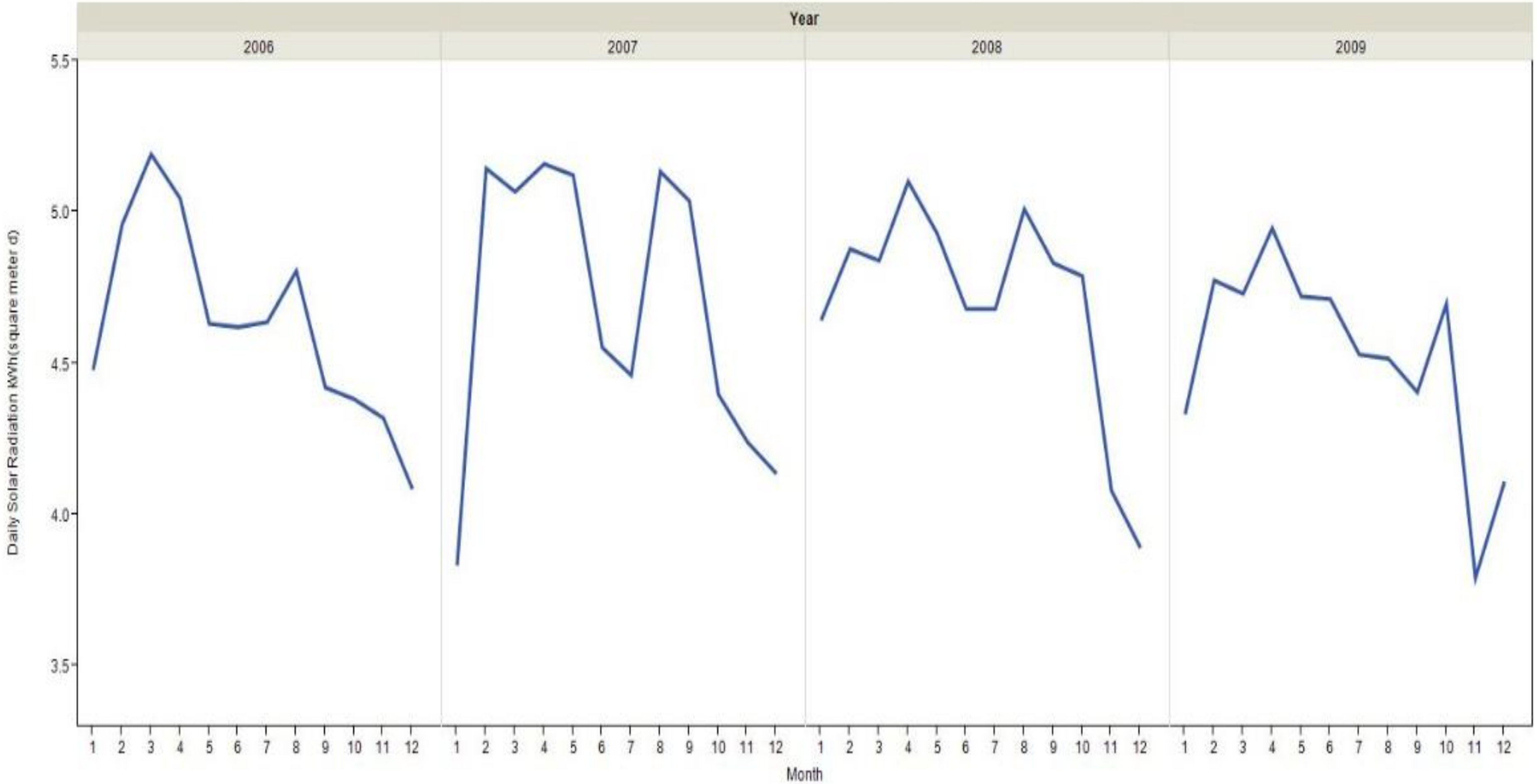
APPENDIX 1: Black paint basin water collector

A**PPENDIX 2: Painting black of basin for PTC system**

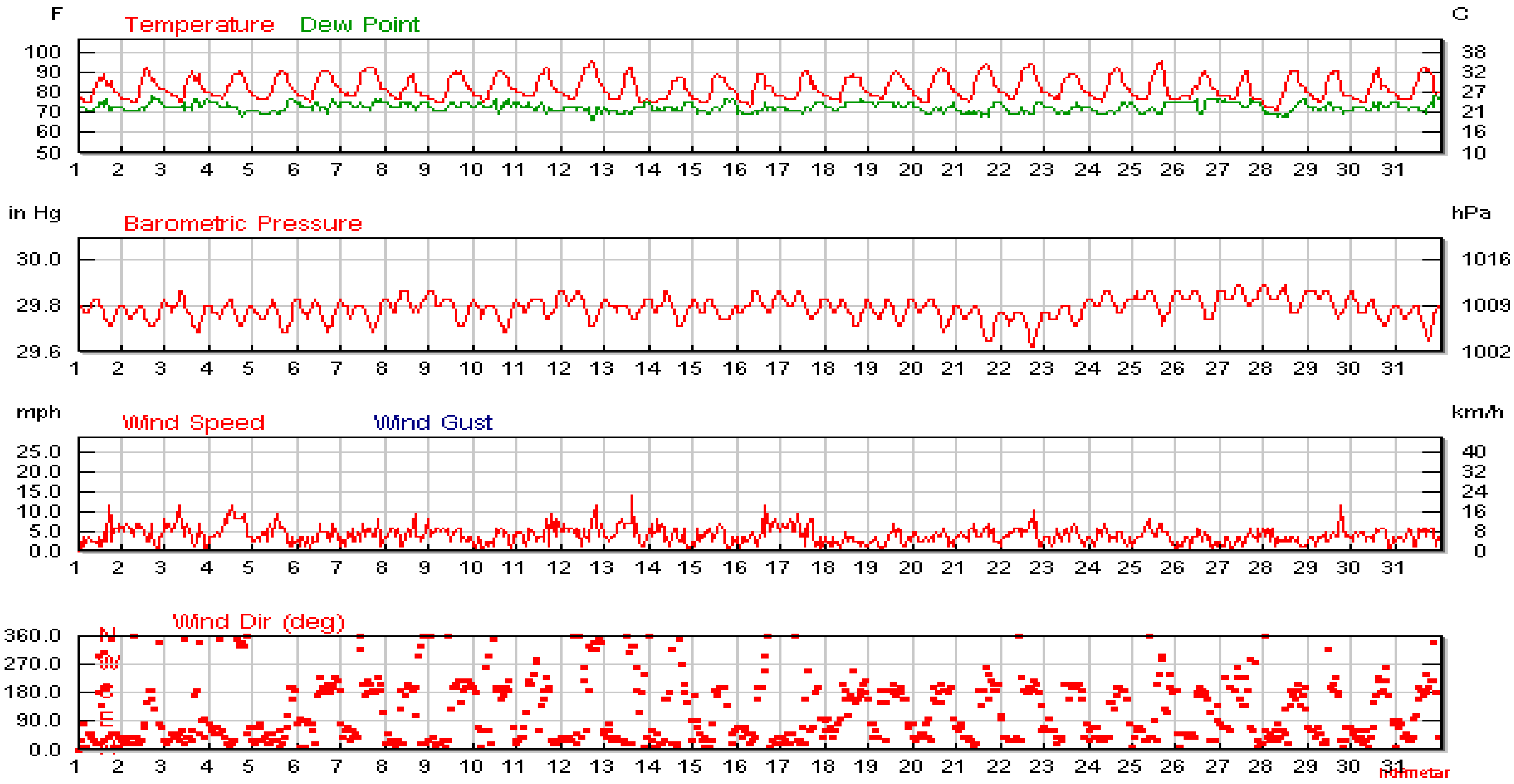
APPENDIX 3: Evaporation-condensation process in basin of TPC system

APPENDIX 4: TPC system under monitoring in the morning

APPENDIX 5: Monthly Mean Solar Radiation for Subang by Year [48]



APPENDIX 6: Temperature, Barometric pressure, Wind speed, Wind direction (deg) in Ipoh, Perak for month of July,2013 [50]



APPENDIX 7: Monthly Calendar Weather History Overview for July, 2013 [50]

« Previous Month « 2012 July 2013 2014 » Next Month »

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<tr><td></td><td>1
Actual: 32 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>2
Actual: 34 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>3
Actual: 33 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>4
Actual: 33 | 25
Precip: 0.00
Average: - | -
Precip: -</td><td>5
Actual: 33 | 25
Precip: 0.00
Average: - | -
Precip: -</td><td>6
Actual: 33 | 24
Precip: 0.00
Average: - | -
Precip: -</td></tr>
<tr><td>7
Actual: 34 | 26
Precip: 0.00
Average: - | -
Precip: -</td><td>8
Actual: 32 | 25
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Average: - | -
Precip: -</td><td>9
Actual: 33 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>10
Actual: 33 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>11
Actual: 34 | 26
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Precip: -</td><td>12
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Actual: 34 | 24
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Average: - | -
Precip: -</td><td>17
Actual: 33 | 25
Precip: 0.00
Average: - | -
Precip: -</td><td>18
Actual: 32 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>19
Actual: 33 | 25
Precip: 0.00
Average: - | -
Precip: -</td><td>20
Actual: 34 | 24
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Average: - | -
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Precip: -</td><td>22
Actual: 35 | 25
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Precip: -</td><td>23
Actual: 32 | 25
Precip: 0.00
Average: - | -
Precip: -</td><td>24
Actual: 34 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>25
Actual: 36 | 25
Precip: 0.00
Average: - | -
Precip: -</td><td>26
Actual: 33 | 25
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Actual: 33 | 24
Precip: 0.00
Average: - | -
Precip: -</td></tr>
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Average: - | -
Precip: -</td><td>29
Actual: 33 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>30
Actual: 34 | 24
Precip: 0.00
Average: - | -
Precip: -</td><td>31
Actual: 34 | 25
Precip: 0.00
Average: - | -
Precip: -</td><td></td><td></td><td></td></tr>
</table>

Calendar Legend

Sunny Clear
Mostly Cloudy Partly Sunny
Partly Cloudy Mostly Sunny
Cloudy
Rain
Snow
Hail Flurries
Thunderstorms
Hazy Fog
Sleet
"?" denotes "chance of"
Unknown

Actual: 90 | 58
Precip: 0.00
Average: 71 | 53
Precip: 0.03

Data Category
Condition
High Temp.
Lo Temp.
Precip. (in cm.)
Daily Avg. Temp.
Temps in °C
-50 -30 -10 0 10 30 50