University of Southern Queensland

Faculty of Health, Engineering and Sciences

Investigating productivity of double slope solar still with sponge cubes

A dissertation submitted by

Rimeta. Tabwere

in fulfilment of the requirement of

ENG 4111 and 4112 Research Project

towards the degree of

Bachelor of Engineering (Honours) (Mechanical)

Submitted October 2019

Abstract

One of the problems faced in arid third world countries is access to sufficient and safe drinking water. A possible solution to this problem is the use of solar desalination to convert seawater or brackish water to safe drinking water. This project investigates one type of solar desalination system which is a double slope solar still. Productivity of solar still with sponge is investigated. Effect of solar radiation and wind speed are discussed.

The use of sponge cubes in the basin of solar still increase surface area of water exposed to hot air and reduce heat loss from the basin to the surrounding. Using a 15.75% coverage of basin area reveals a 3.33 production ratio. Productivity of solar still with sponge cubes is 3 times more than productivity of solar still without sponge.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Limitations of Use

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

R. Tabwere

[redacted]

Acknowledgement

I would like to thank my respected supervisor Dr. Ahmad Sharifian for his guidance and patience throughout the progress of my project. I would also like to acknowledge the assistance of Mr Ahmed Alkaisi (PhD student at USQ) for his help on the technical side of solar still system as this project is using the double slope solar still device that was constructed for his PhD project. I would like to thank respected technical staff for their support regarding carrying out the experiment and provision of equipment used in the experiment:

1. Richard Landers – Electrical workshop technical staff whom taught me about using a data logger.
2. Mr. Mohan Trada – Mechanical technical staff for his help regarding understanding the measurement equipment used to measure output of the solar still (distilled water in Litres).
3. Brian Aston – Z4 technical staff for supervising access to the Z compound where the solar desalination system is situated.

I would also like to thank my family for their support throughout the initial stage and progress of the project. I would like to thank my father who suggested the field that I should look at which relates to the need of the people of my home Island. I would also like to thank my wife for the support and encouragement throughout the project.

Contents

List of figures

List of Tables

1. Introduction

1.1. Project Aim

The aim of this project is to develop sponge layout in double slope solar still and test it under the climatic conditions of Toowoomba. Sponge cubes increase exposure of water to internal heat and reduce heat loss from bottom of basin due to conduction heat transfer (Abu-Hijleh et al, 2003). This project make use of low cost and locally available materials to improve solar distillation system which is itself a system that does not require external source of electricity to purify contaminated water.

Solar distillation is an economical and environmental feasible system for purification of contaminated water. The system can be used in arid area at a convenient cost and does not require special skills for operation and maintenance (Kalogirou, 2005). This project aims to maintain low-cost for solar distillation with additional improvement method which is the use of locally available and low-cost regular sponge.

1.2. Project Objectives

The objective of this project is to develop a layout of sponge on the basin of a solar distillation system and test its production using experimental method. However, as initial parts of this project, literature review is used to investigate the solar distillation background such as history, types and importantly factors that impact productivity and methods to improve productivity. The outline of the objectives are as follow:

1. Review background information on desalination, solar still and methods to improve solar still.

2. Develop suitable layout of sponge on the basin which should be less cost and using local available sponge cubes.

3. Perform experiment test to investigate the modified double slope solar still and compare with simple double slope solar still in terms of productivity, water temperature and temperature difference.

4. Analyse the results of experiment and discuss improvement and deficiencies of the modified double slope solar still. This will include statements of further work that can be done.

5. Communicate project findings in the form of presentation and a written dissertation.

If time allows:

6. Investigate the quality of water produced from the solar still system.
7. Investigate the effect of inclination angle of glass cover.

1.3. Project Background

Freshwater supply is important for nation development and human survival. With the increase in population, the need for freshwater is inevitable and freshwater resources face stress and depletion. According to Kalogirou (2005) water covers 97% of the earth surface and from the overall water on earth only 1% or less is readily available for human use such as drinking and irrigation purposes. Desalination is a promising solution to address water problem in terms of that it can convert impure and unsafe water to freshwater. This process has been developed since the fourth century when Aristotle first described the method of evaporating impure water to obtain potable water (Kalogirou, 2005).

Desalination has now developed and used in many parts of the world to provide freshwater and address water shortage problems. Kalogirou (2005) states that solar distillation is one of the first method to be used for desalination process and the first large scale solar distillation system was constructed and used in Las Salinas in Chile in 1872 to provide freshwater for drinking.

At a large scale, solar distillation is space consuming since the productivity is proportional to the area of the solar still basin. However, small scale solar distillation system has also been developed and used for provision of freshwater for small communities. Kalogirou (2005) state that during World War II, patent were granted for plastic solar distillation apparatus and used in lifeboats and rafts.

Current large scale desalination system uses conventional source of energy which is fuel and produce high amount of freshwater. According to Aqua Tech (2019), Ras Al Khair desalination plant in Saudi Arabia is one of the top desalination plant in the world in terms of freshwater production, the system can produce up to 1,036,000 $m3d$ volume of freshwater. Although this type of desalination system is the required type in terms of

productivity, some developing countries may not have the funds to construct such large-scale plants. In addition, the use of fuel has the impact on environment sustainability.

Therefore, for developing countries where freshwater supply is a problem and land mass plus economic does not support for large scale desalination plant, the suitable solution will be the use of solar distillation systems for alternative provision of freshwater. The problem with solar distillation method is that its productivity is low compared to other types of desalination systems. That is why method of improving such desalination systems is viable in terms of providing adequate freshwater supply using solar energy and low-cost solar distillation plant.

1.4. Project Justification

This project has been derived from the need of freshwater supply in the country of Kiribati which is a nation made up of 33 low-lying coral atolls and where underground water is experiencing high salinity due to the intrusion of seawater during high tides (The World Bank, 2017). The possible solution for water salinity problem is solar distillation because it is low cost and provides freshwater from already available salinity water with use of free of charge source of energy – solar energy.

It is known that solar distillation can be a method to provide freshwater for small communities in arid areas where solar energy is abundant and provision of freshwater is a problem faced (Kalogirou, 2005). Solar distillation is simple to construct and can be made from locally available material which means that the use of solar distillation can provide freshwater with minimum cost for construction and maintenance (Ahsan et al, 2014). However, productivity of solar distillation is a question that needs be answered. According to Ranjan & Kaushik (2016), conventional solar distillation system cannot produce more than 4 to 5 $\frac{\frac{L}{m^2}}{day}$.

Low productivity of solar distillation has triggered research and development into the finding of new methods that can increase productivity (Vishwanath et al, 2015). There are three main parameters that are consistent throughout every research related to solar distillation and these are Operational, Design and Ambient parameters (these parameter controls the productivity of solar distillation).

Ambient condition cannot be controlled since it depends on the climatic condition of the local area. However, operational and design conditions can be controlled to provide increase in production of solar distillation (Vishwanath et al, 2015).

One method to improve productivity by manipulating the design condition is through the use of sponge at the basin of a solar distillation to assist in increasing temperature of water surface and to reduce the heat loss at the bottom of the basin (Abu-Hijleh, 2003).

Area of sponge should be relatively low compared to area of basin when using sponge cubes to improve productivity (Abu-Hijleh, 2003). This project will use a total number of 12 sponge cubes which are 9 cm x 7 cm in area each. The sponges are locally available and low cost. The purpose in the use of sponge is that there is more evaporation at the top of the sponge cubes. In this project, the layout of the sponge will be made so that more evaporation occurs close to the trough so that there is shorter distance for condensed water to travel down to the cutter (collection tube).

1.5. Scope

The purpose of this project is to investigate productivity of solar still with sponge. Therefore, the scope of this research project will be to conduct an experiment for solar still without sponge (reference still) and solar still with sponge and determine the production ratio.

An experiment using the available solar distillation system in the University of Southern Queensland Toowoomba campus will be carried out to test the method to improve productivity which is the use of sponge cubes at 15.75% area coverage of the basin. Analysis on the experiment will be made and discussion with conclusion will be required for this research.

Since there is only one solar still available, the experiment will be conducted at different days. This will require additional work than just comparing productivity. Effect of solar radiation will be compared. Productivity of solar still with sponge at different solar radiation will be compared. If the difference in productivity is less than difference in productivity between solar still with and without sponge, it can be concluded that the effect of sponge is significant to the increase in productivity compared to solar radiation.

1.6. Deliverables

In completion of this project the following things shall be produced:

- Literature review on solar distillation system, an introduction to the history of solar distillation, different types of solar distillation, and methods of improving the productivity of solar distillation.
- Methodology which will encompass experimental procedure and equipment used for the project.
- Analysis and discussion of the results obtained from experiment which will include charts and tables developed from data obtained using data logger.
- Recommendation on suitable and practical method for improving solar distillation productivity that will also allow for economic and environmental sustainability.
- All of the above deliverables will be presented in both presentation and Dissertation write – up.

1.7. Dissertation Overview

This subsection will show the outline of the dissertation including major headings and description. This dissertation will include the following chapters:

Chapter 2 is the literature review based on developing the understanding on solar distillation including previous and current development of the system. This chapter will also include improvement method previously investigated and methodology on how to conduct experiment.

Chapter 3 will define the methodology that will be used to carry out the investigation. The methodology will be developed based on the findings in the literature review.

Chapter 4 will illustrate the analysis and discussion of the findings from experiment with the support of charts and tables.

Chapter 5 will conclude the project and discuss both strong and negative aspects of the project.

Chapter 6 This chapter will discuss recommendation on further work that will be required for solar distillation productivity.

2. Literature Review

2.1. Chapter Overview

This chapter will include explanation of solar distillation according to published literature, include the advantages and disadvantages of solar distillation, the different type of passive solar distillation, factors that affect the productivity of solar distillation and methods to improve solar distillation productivity based on previous research. The purpose of this literature review is to develop the knowledge gap which will become the question that is to be answered with this project and also discover experimental methods used to investigate productivity from previous work to develop suitable methodology of the project.

2.2. Solar distillation

Solar distillation is a system that is used for seawater and brackish water desalination. The main function of a solar distillation is to produce freshwater from contaminated or salty water source. According to Kalogirou (2005), nature uses solar desalination to produce freshwater in the form of rain. The process starts by solar radiation emitted to the water surface of ocean and other open water sources which initiate the heating and evaporation of water. The evaporated water vapor is carried by the wind, and as it cools down to its dew point (condensation) water vapor will convert back to liquid and form rain (freshwater). Solar distillation is a man-made system that is the duplication of the principle found in natural solar desalination (this is also known as the hydrological cycle).

The component of a simple solar distillation system includes the following (Basin type):

- Transparent cover (glass or plastic)
- Solar still basin (can be any shape – usually rectangular or square)
- Trough – to capture condensed water vapor
- Filter – to filter any large particles before feedwater enters the system
- Tubing – for inlet water and outlet water to storage
- Storage tank – store distilled water (output)

The design of basic double slope solar distillation is as shown below:

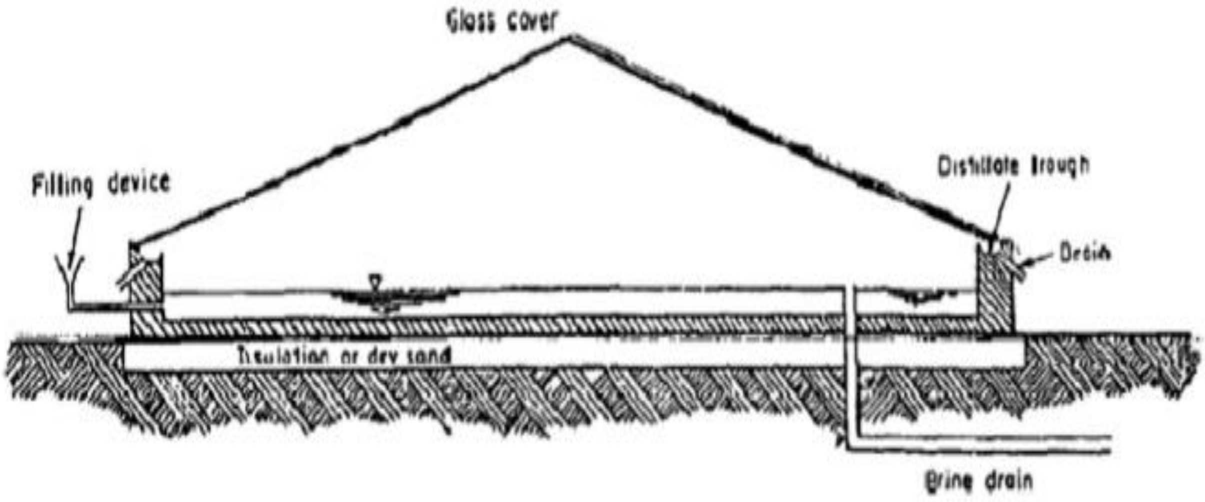

Figure 1:conventional Double slope solar still (Kalogirou, 2005)

The operation is similar to that of natural solar desalination however, in a solar distillation water movement is controlled within the confined space between the basin and the transparent cover. In solar distillation, the pathway of condensed water is controlled by the inclined structure of the transparent cover and gravitational force. Condensed water travels down the inclined cover and is captured by the trough which directs it to storage through tubing. The feedwater for solar distillation is seawater or brackish water that is unsafe to drink. Before going to the distillation system, feedwater must be filtered from any debris and other larger particles that can influence the quality of the produced water and affect the efficiency of the system.

2.2.1. History of Solar distillation

Solar distillation has been used since the fourth century using the idea developed by Aristotle which is boiling and evaporating impure water to obtain potable water (Kalogirou, 2005). It has been used since then to produce freshwater from impure water. According to Arjunan et al (2009), the earliest use of solar distillation recorded was by the Arabian alchemists in the sixteenth century. Solar distillation has proved to be one of the most effective way to provide freshwater from impure water and further investigations and research were made to develop its application. Las Salinas was the first build large-scale solar distillation plant and is also the first desalination process to be made. The plant was designed and built by a Swedish engineer Carlos Wilson in the 1872 (Kalogirou, 2005).

As time pass, new technologies and innovative ideas emerge and instead of solar distillation, the principle is used with the help of conventional means of energy such as fuel to speed up the process and produce more freshwater. In addition, other method of desalination was developed which is reverse osmosis desalination. The new systems of desalination were massive plants such that the largest productivity of conventional desalination plant produces up to 1,036,000 $\frac{m^3}{d}$ volume of freshwater. Solar distillation is incapable of competing with conventional type desalination systems in terms of productivity but on the other hand, solar distillation system outstands conventional desalination systems in terms of lowest environmental impact due to emission of greenhouse gas.

The applicability of solar distillation is feasible in arid areas due to its low cost and that freshwater is a required necessity in such places. Kiribati is one of the places where solar distillation can be used since it is surrounded by ocean, low lying coral atoll and solar radiation is abundant. Other countries like Africa rural areas where freshwater supply is needed can make use of solar distillation as well due to its easy to construct and operation for producing small-scale freshwater for small communities. According to Arjunan et al (2009), solar distillation is still manufactured by McCraken Solar Company in California but for residential use only (not a large plant).

2.2.1. Advantage of solar distillation

The main advantage of solar distillation is that it can produce freshwater from ocean seawater and other contaminated water sources. Solar distillation uses solar energy to operate which is an abundant source of energy and is environmentally friendly. Solar distillation can be designed and constructed at low cost and does not require special skills to operate and maintain the system. An experiment by Ahsan et al (2014) state that a solar distillation system can be constructed at a low cost of 112.1 RMI which is equivalent to $38.69 AUD (current exchange rate). Bhattacharyya (2013) states that solar distillation is one of the best practical and most economical desalination processes since it does not require high intense energy (for small scale production) compared to other type of distillation methods which will have high cost for energy to run the operation. In addition, solar distillation is a possible solution for seawater conversion to pure water and uses free energy source which is the sun.

Ocean water covers more percent of available water in the Earth and is of high salinity, but it is high salinity and cannot be used for drinking or irrigation purposes. If other source of resources is facing stress and depletion, the one solution is to convert ocean water to freshwater to address water shortage problem. According to Kalogirou (2005), desalination is an ideal solution for water problem since the ocean water is abundant but is of high salinity. Salinity of seawater is 35,000 to 45,000 ppm and the permissible limit of salinity in water according to World Health Organization is 500 ppm.

Therefore, solar distillation is of advantage for conversion of seawater to freshwater using the freely available solar energy at no cost, easy to construct and operate, and can be easily available for arid areas in developing countries where freshwater and economic are a problem.

2.2.2. Disadvantage of solar distillation

Solar distillation is an environmentally friendly solution to seawater conversion and freshwater supply. However, there are drawbacks of this system that require attention before construction. First of all, the system productivity is proportional to the area of the basin which will mean that the more productivity you will require, the more space (landmass) the system will need to take. Secondly, solar distillation is of low productivity compared to other desalination method. Thirdly, solar distillation relies totally on solar radiation which will mean that when there is no solar radiation (night time), the system cannot operate (little production can still be produced from the heat stored in the system). These are the major draw backs for solar distillation and can be improved by manipulation of the design. For example, addition of heat absorbing materials can sustain the heat obtained by solar radiation in the day time to run nocturnal distillation process.

2.3. Type of solar distillation

Different types of solar distillation have been developed for use in seawater desalination. Vishwanath et al (2015) compiled the different researched conducted on solar distillation and the following types of solar distillation (or solar stills) were discussed.

2.3.1. Basin type

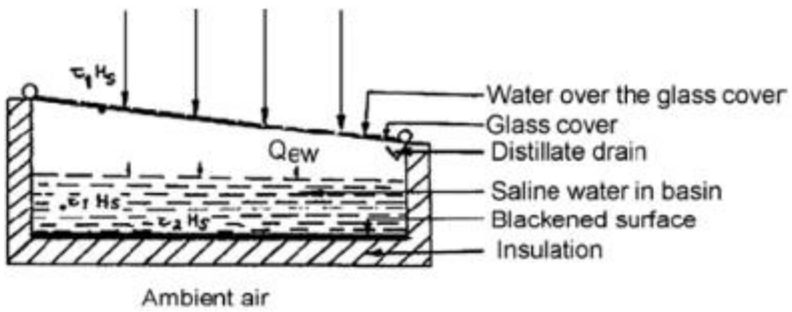

Figure 2: Basin type solar still (Vishwanath et al, 2015)

Basin type solar still is one of the most commonly used solar still and the process is a duplication of natural hydrological cycle (production of rain). This system is can be made from locally available materials and does not require special skills for operation and maintenance (Vishwanath et al, 2015).

2.3.2. Diffusion type

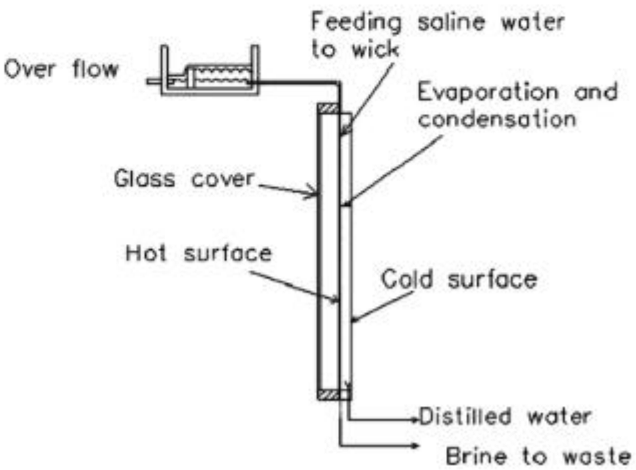

Figure 3: Diffusion type solar still (Vishwanath et al, 2015)

In a diffusion solar still, a hot and cold surface are placed parallel to each other and separated by a small cap. Gas (like air) fills the gap between the surfaces. Solar radiation enters through the glass cover and is absorbed by the front surface of the partition. Water is allowed to flow over the hot surface where it is evaporated across the gap and condenses on the cold surface (Vishwanath et al, 2015). Figure is as shown to the left.

2.3.3. Wick type

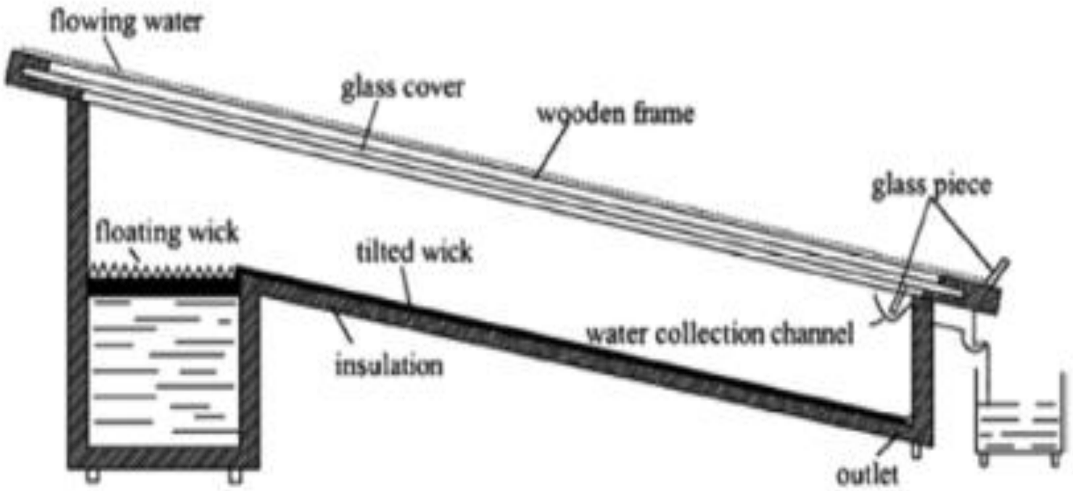

Figure 4: Wick type solar still (Vishwanath et al, 2015)

In a wick type solar still, water is allowed to flow slowly through a porous, radiation-absorbing material (the wick). Wick type solar still can be tilted to allow for better angle to the sun (increase in evaporation rate). Reflection of solar radiation is reduced in wick type solar stills due to the use of radiation-absorbing material (the wick). Less feedwater in wick type solar still makes it easier for evaporation process. However, Wick solar still will only operate during sunny times, and after the sun passes there is no production (This is not the case for a basin solar still – still produce after sun has passed due to heat stored in the basin water). The figure of the Wick type solar still is as shown above (extracted from Vishwanath et al, 2015).

2.3.4. Solar still with greenhouse combined

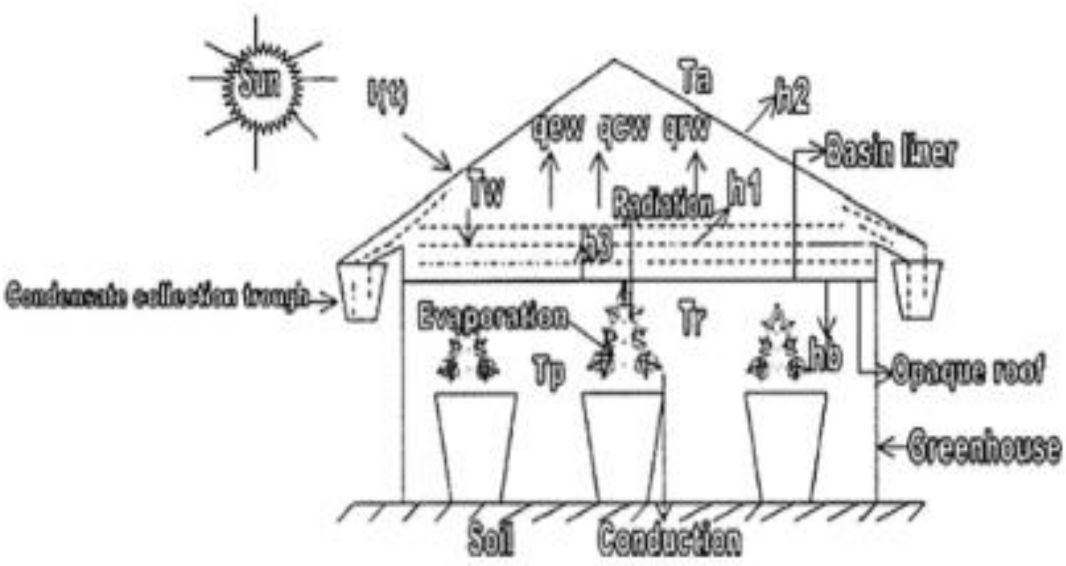

Figure 5: Solar still & greenhouse combination (Vishwanath et al, 2015)

In a solar still combined with greenhouse, the basic principle in the basin type solar still is used to desalinate saline water. However, in solar still combined with greenhouse the system is aligned sol that the basin liner is above plants to be watered and irrigated (this type of system is mostly to desalinate saline water for irrigation purpose). Heat loss from the basin liner is passed through convection, radiation and conduction to the plants beneath the basin liner. Radiation is absorbed by the plants below and the floor. Heat loss is transmitted to the soil through conduction (from the floor) leading to high crop yields with low water consumption (Vishwanath et al, 2015)

2.3.5. Weir type

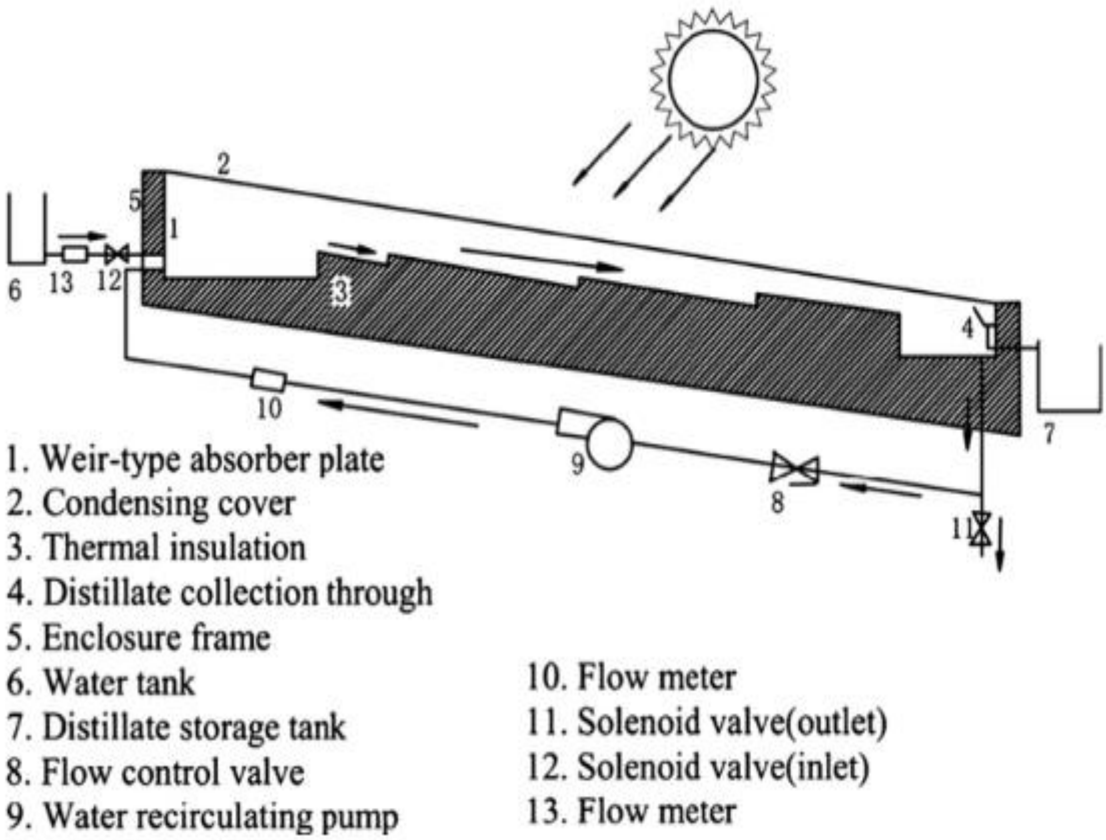

Figure 6: Weir Type solar still (Vishwanath et al, 2015)

The Weir type solar still (figure above) uses a weir-shaped absorber plate and is usually constructed in an inclined angle. Weir absorber plate can be made in a cascade profile (like stair-case) or normal weir shape as shown in the figure above. A Weir type solar still constructed by Tabirizi et al has a circulation system where the brine water is introduced to the inlet to increase the temperature of feedwater and therefore increase evaporation rate (Vishwanath et al, 2015).

2.3.6. Spherical solar still

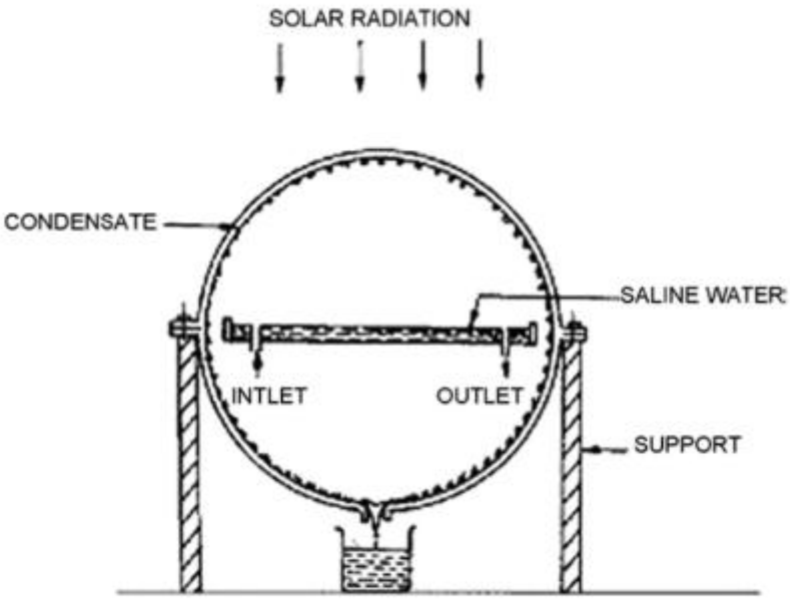

Figure 7: Spherical solar still (Vishwanath et al, 2015)

A spherical solar still has a spherical glass cover with a horizontally fitted black plate at the centre (basin liner). The black plate is here feedwater is introduced for evaporation process. Condensation takes place at the inner surface of the spherical glass cover. Purified water is collected at the bottom of the still (Vishwanath et al, 2015).

2.3.7. Tubular solar still

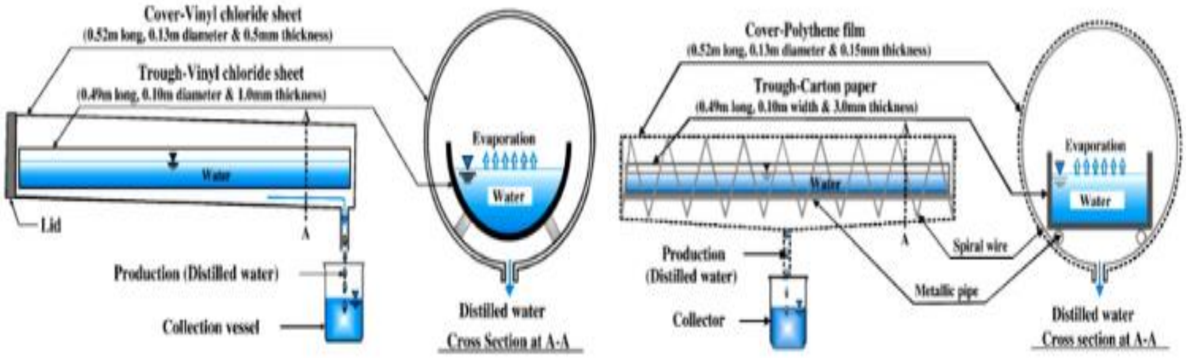

Figure 8: Tubular solar still (Ahsan et al, 2017)

Tubular type solar still is the later version solar still based on the concept of basin type solar still. The basin is surrounded by a tubular glass cover that is designed so that purified water can travel along the inner surface of the tubular glass cover and directed into a single outlet to storage (Ahsan et al, 2012)

2.3.8. Pyramid & Rectangular

Figure 9: Triangular pyramid and Rectangular cover still (Vishwanath et al, 2015)

Pyramid solar still has a glass cover in the shape of either a triangular pyramid or square shaped pyramid. The rectangular type still has a rectangular shaped glass or plastic cover. The advantage of pyramid solar still is that it does not require to moving of the system to follow the movement of the sun for greater solar radiation absorption. In addition, pyramid solar type solar stills reduce shade of side walls that reduce heat in basin type solar still (Vishwanath et al, 2015).

2.4. Factors affecting productivity of solar still.

In basin type solar still (also for most solar still types), productivity is controlled by operation, design and ambient condition (Muftah et al, 2014). Research have been made to investigate the effect of operational condition such as water depth, temperature difference, etc. on the productivity of solar still. Design conditions relate to the construct and design of the solar still including addition of external components such as reflectors to enhance and concentrate solar radiation (Vishwanath et al, 2015). Example of design condition include incline angle of glass cover, material selection of basin and glass cover material, etc. Ambient condition refers to the climatic condition of the area where the solar still is situated, for example, solar radiation, ambient temperature and wind speed. Ambient condition cannot be controlled but is used as the independent variable for theoretical calculations of solar still productivity. In this section, some investigations made by previous research on the different conditions (operational and design) will be discussed. It is noted that ambient condition is always included in the investigation either operation or design conditions.

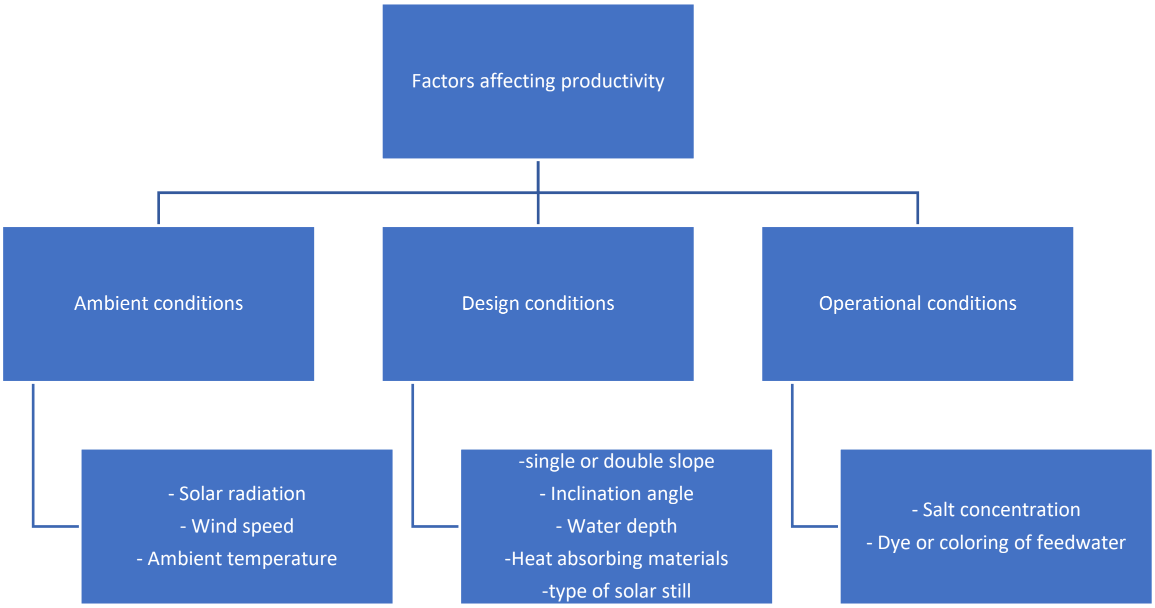

Figure 10: Factors affecting solar still productivity

2.4.1. Operational condition

2.4.1.1. Water depth

Water depth is an important parameter to consider in solar distillation productivity since it has a significant contribution to the productivity if well understood and maintained accordingly. Based on previous research on solar distillation, water depth at minimum level yields more productivity for the reason of that it is easy to heat and start evaporation process where as in high level water depth will take longer to heat and to start evaporation. These research works have been conducted with the study of other parameters including water depth and its effect.

Phadatare & Verma (2007) conducted a theoretical and experimental investigation on a single slope solar still performance. Theoretical part shows three heat transfer equations that explains the process occurring within the solar still. The three relations are convection, radiation and evaporation. Convection heat transfer is free convection since the variations in density and humidity caused by temperature difference drives the buoyancy force within the still. Radiation is considered within the still and assumed that the inclined angle of the glass cover is relatively small therefore considered parallel to the surface of the water. For experimental investigation, an hourly measure of ambient temperature, basin water temperature and cover temperature from 7 a.m. to 7 p.m. These temperatures were measured with the aid of copper-constant thermocouples and recorded by Data Logger. Water depth varies from 2, 4, 6, 8, 10 and 12 cm respectively. For each measure of water depth, solar radiation, glass cover, water surface and basin liner temperature were measured. The productivity and efficiency of the still were recorded according to different water depth. The result shows that the increase in productivity is observed when water depth decreases. On the other hand, efficiency of the still increases with the increase in water depth and furthermore, the temperature of the water surface increase with the increase in water depth. Maximum distillate was 2.1 L/m^2/day.

One of the most important research regarding solar distillation is that of Ahsan et al (2014). In the research, Ahsan et al (2014) developed a solar distillation system that cost a total of 112.2 RMI which is equivalent to approximately 40 AUD (current exchange rate). This is the sole purpose of solar distillation, if it cannot compete with other method of desalination in terms of productivity, it can certainly compete in terms of cost. Maintaining a low-cost solar distillation is a key factor to promote this idea of competition.

Ahsan et al (2014) tested the productivity of the newly designed and constructed low – cost solar distillation. The parameters that were measured include; solar radiation intensity, ambient air temperature and the initial water depth on the daily water production. The arrangement of the solar distillation system is as shown below.

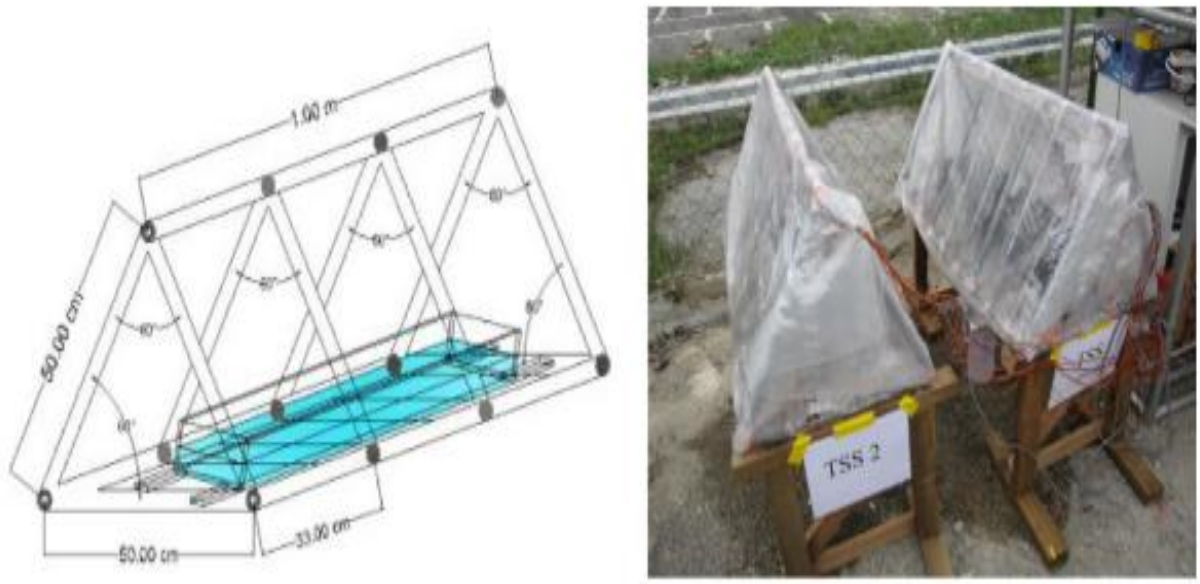

Figure 11: Low-cost double slope solar still (Ahsan et al, 2014)

Furthermore, the experiment evaluated the impact of solar radiation, ambient temperature and initial water depth on the productivity of the still. The result shows that the distillate output increase when the water depth is lowest value. On the other hand, ambient temperature and solar radiation have the same effect which is that at maximum peak of ambient temperature and solar radiation, solar still productivity increase. Water quality was tested for safe drinking against the World Health Organisation standards for safe drinking water.

Abhay et al (2017) studied the performance of a single slope (SS) solar still with the focus on basin water temperature, glass cover temperature, distillate output, evaporative, convective and radiative heat transfer coefficients. The investigation was conducted to investigate the effect of different climatic and operational parameters for the climatic conditions of Rewa, India. The solar still basin was fabricated using a galvanised iron sheet and is contained within a plywood box for insulation purpose. The top cover of the still is an ordinary glass with 4mm thick and is inclined at angle of 23 degrees. The experiment was carried out for five consecutive days for different water level 2,4,6,8,10 cm respectively. Required reading for the still were collected every hour from 7 a.m to 7 a.m in the next day and various parameters from readings were recorded against time (every hour). Basin, water, ambient and glass cover temperature were measured during experiment and the same measurement were used for theoretical calculations. The experimental finding shows that the maximum water temperature value decreases with the increase in water depth. Evaporative heat transfer increase with time until it reaches maximum and then decrease for the remaining time of operation, this is observed for all water depth. Lowest value of evaporation heat transfer coefficient is observed for maximum water depth because of the increase in thermal inertia which decrease the evaporation rate. Radiative and convective heat transfer coefficient have lower values than evaporation heat transfer. Radiative being higher than convective heat transfer coefficient. The distillate output of the still was observed and found that the maximum yield is obtained for the lowest water depth value and the minimum yield for high water depth. It can be said that water depth is inversely proportional to distillate yield, and evaporation rate. Maximum yield of the still is 830 gm/m^2 which is equivalent to 0.8 $\frac{l}{m^2}$.

2.4.1.1. Temperature difference

Temperature difference between the glass cover and feedwater surface act as the driving force for the desalination process in solar stills. Therefore, the impact of this parameter is significant to the productivity of solar stills. The main idea in solar still is to increase the temperature of the feedwater and to reduce temperature at the inside surface of the glass cover. There have been studies on different method on how to improve water – glass temperature difference.

Abdenacer & Nalifa (2007) investigated on the importance of temperature difference between the glass cover and the water surface of a solar distillation. The investigation includes a theoretical and experimental study where in the theoretical study, thermal balance and simple hypothesis were used. In the experimental study, a computational method was used to study the performance of the solar still using iteration method given the initial time ‘t’ and the initial temperature $'T_e'$. The investigation shows the importance of temperature difference between the cover of the still and the water surface which have a significant effect on the productivity of solar distillation. In general, Abdenacer & Nalifa (2007) suggested that a cool cover surface and a hot water surface is a required combination for a basin type solar distillation system. The study analyses the importance of temperature difference. Therefore, using this idea, a solar distillation system can be improved by finding methods of increasing the temperature of water in the basin and finding methods to reduce temperature in the surface of the cover.

Velmurugan & Srithar (2011) used a regenerative solar still to investigate the effect of temperature difference between the glass cover and the feedwater surface. The physical layout of the regenerative solar still is as shown below.

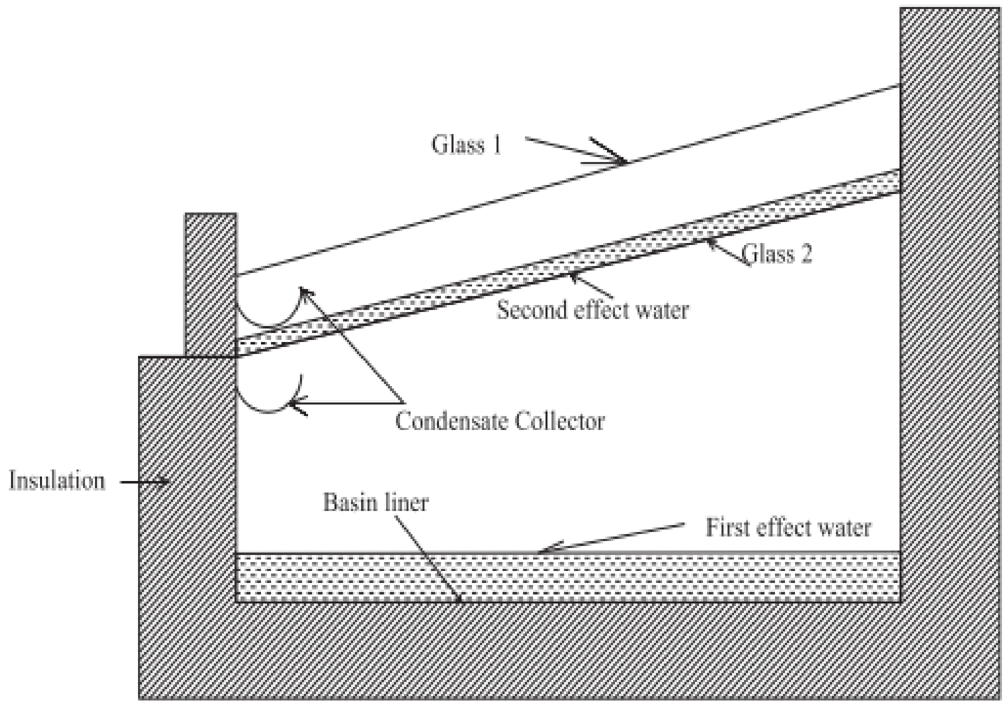

Figure 12: Regenerative type solar still (Vishwanath et al, 2015)

Regenerative solar still increases temperature difference between water and glass cover in the first effect (the desalination process that occurs between the water depth and the inside glass) and uses latent heat of vapor condensation on the glass of the first effect to produce more freshwater in the second effect (the desalination process that occurs between outer surface of inside glass, and inside surface of outside glass, where latent heat of vaporization is the feedwater). Result shows an increase in productivity due to increase in temperature difference.

Arunkumar et al (2012) investigated the effect of water cooling using a hemispherical cover solar still. The investigation used identical design which is hemispherical solar still throughout the experiment, but the changes was with or without cooling effect. Cooling effect was performed from water flow on the cover of the solar still. Results shows that without cooling, an efficiency of 30% was obtained but with water cooling effects the efficiency increased to 42%. Important parameters measured during the experiment include: water and cover temperature, air temperature, ambient temperature, and distillate output.

2.4.2. Design condition

Different productivity and different performance of solar still depend significantly on the design and construct of the still. The normal conventional type has the same principle and therefore will experience same performance and production with the change only on the area of the basin (more production if the effective area is increased) and the inclination of the glass cover. In previous research some of the most investigated design conditions include incline angle of cover, material selection and introduction of internal or external reflectors (Muftah et al, 2014).

Inclined angle of solar still cover is one of the design conditions that can be controlled to obtain increase in productivity for solar still. Singh & Tiwari (2004) used a numerical analysis to evaluate the performance of passive and active solar still under the climatic condition of New Delhi, India. The investigation includes the evaluation of different parameters and among them was the inclined angle of glass cover. It is stated that the annual yield of solar still is maximum at 28.58° which is equal to the latitude of New Delhi. Another experiment on the different design of cover was by Malaeb et al (2014) where different geometry of cover was used with an additional drum in the basin of the solar still to improve productivity. Results from the investigation by Malaeb et al (2014) shows that the maximum yield was approximately 2.5 litres which is the result of a single slope solar still at an inclined angle of 23° which is equal to the latitude of the location of experiment. According to research it is stated that the inclined angle of the cover for solar still should be equal to the latitude of location to allow for better solar radiation absorption and therefore more yield.

Material selection is another important aspect that is required in the design condition in terms of improving productivity, performance and sustainability of solar still system. According to Muftah et al (2014) the material for the cover of the should be between a glass or plastic that is transparent and absorbs solar radiation. Glass cover is preferred in terms of more solar radiation absorption while plastic can be an alternative in terms of low-cost. Furthermore, Badran (2007) states that the material of the basin liner should be resistant to heat, corrosion and sudden puncture from damage (possibly from broken glass). The liner is attached to the basin and its purpose is to absorb solar radiation. Badran (2007) investigated two type of basin liner which are asphalt and black paint. It is found that productivity increase when asphalt is used compared to when black paint is used as basin liner. It all comes down again to what is required, in terms of productivity asphalt is preferred where as in terms of reduced cost, black paint will be the alternative.

Addition of internal and external reflector is another design condition that can improve the productivity of solar still desalination. It is known that solar radiation is not fully absorbed by the basin and the water surface, instead partial of solar radiation exit the system through convection, radiation and conduction effect. The importance of internal and external reflector is to reflect solar heat that exits the system through radiation back into the system. This will not be covered in the project but in terms of productivity, addition of internal and external reflector will increase production, however, in terms of maintaining low-cost of solar still, this system might be an alternative in a later phase if the solar still production is consistent and cost of adding extra component will not affect the cost of water produced.

2.5. Methods to improve solar distillation productivity

Solar distillation faces a problem which is low production. This can be addressed by several approaches both design or operation enhancement. Many researches have been conducted to study the performance of solar distillation and to find methods to improve productivity. According to previous research, solar distillation relies on the design, operation and climatic condition. In any solar distillation system, the temperature difference between the glass cover and the water surface should be increased, and the water should be easily evaporated. Main methods to improve productivity therefore relates to the following ideas. To increase temperature difference, cover temperature should be reduced, and water surface temperature should be increased. To make sure that water is easily evaporated, pre heat of feedwater is performed or water level is maintained at a minimum level.

One of the low costs and easy method to use to improve solar distillation is the use of heat absorbing materials at the basin of the still (this depends on the material cost of the heat absorbing material). Many researches have been carried out using different type of heat absorbing materials for the improved productivity of solar stills.

A study on use of sponge by Lalitha et al (2019) investigate the shape of the sponge using tetrahedral shaped sponge. An experiment was conducted in India to investigate the effect of using tetrahedral shaped sponge as the heat absorbing material for passive type solar still system. The layout of the system is shown in figure below.

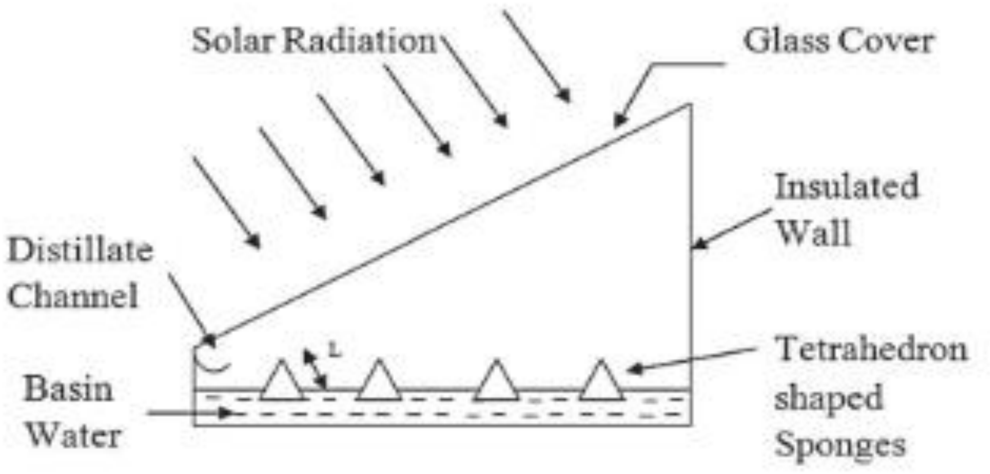

Figure 13: Solar still with tetrahedral sponge (Lalitha et al, 2019)

The experiment by Lalitha et al (2019) uses different water level for the solar still with sponge and without sponge. In the result, it is shown that the highest productivity can be found for water level of 4 cm in a solar still without sponge and a high productivity is observed at water level 5cm for solar still with the sponge. This agrees with the finding from Abu-Hijreh et al (2003) where the increase of water level in a solar still with sponge will increase productivity. Furthermore, after water level reaches the height of sponge, there is no effect of further increasing water level above. Therefore, maintaining water level close to the height of the sponge is more preferable in solar still with sponge. The use of tetrahedron shaped sponges shows an increase in efficiency compared to that of sponge cubes. This is shown in the graph below

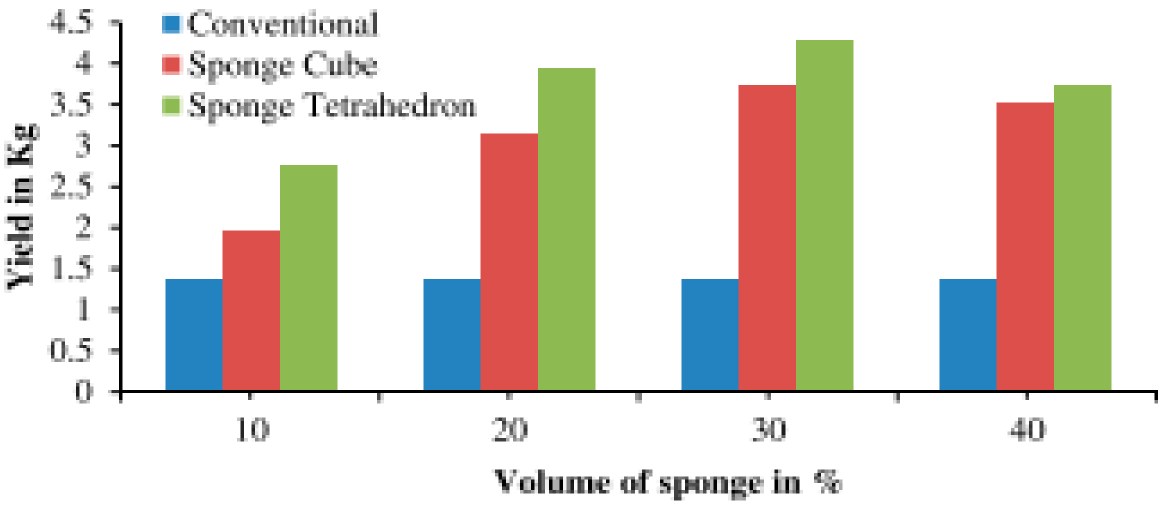

Figure 14: Comparison of productivity (Lalitha et al, 2019)

The figure above states that productivity of solar still increase when using sponge Tetrahedron compared to using sponge cube. Maximum yield is approximately 4.5 kg which can be observed at the 30% volume of sponge.

Abu-Hijleh & Rababa'h (2003) conducted an experiment to increase surface area of a single slope solar still with the use of sponge cubes. The experiment was conducted at Jordan University of Science and Technology, Irbid Jordan. The still base was measured 50 X 50 cm and the inclined angle of the cover is 23 degrees. Figure below shows the layout of the sponge cubes in the single slope solar still.

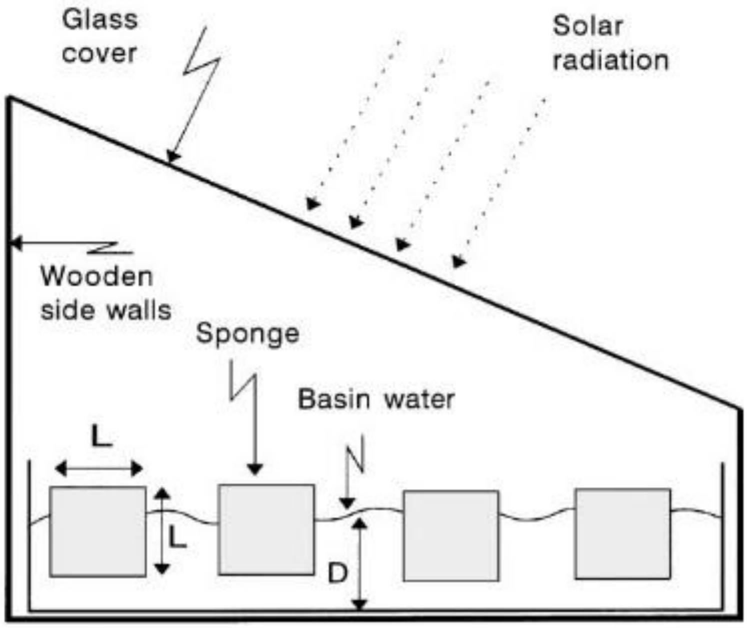

Figure 15: Solar still with sponge cubes (Abu-Hijleh et al, 2003)

Based on the result from Abu-Hijleh & Rababa'h (2003), the smaller the height of sponge above water surface level will increase the productivity. With the different dimension of the sponge the production ratio was that the 6cm cube has the highest production ration. In terms of water depth, 7cm water depth shows the highest production ratio. In addition, increasing the volume of sponge cubes in the basin can be achieved by including more sponge cubes and this reason for this that the more exposure of wetted surface area of sponge cube where evaporation can occur will increase evaporation and productivity. This idea can be contradicted by the fact that the amount of salt residue after evaporation can clog the sponges making it difficult to absorb feedwater to the top surface. There is another option which is to select a layout that will be sufficient to allow for space between the sponge cubes so that it will be easier to cleanse the system from salt residue.

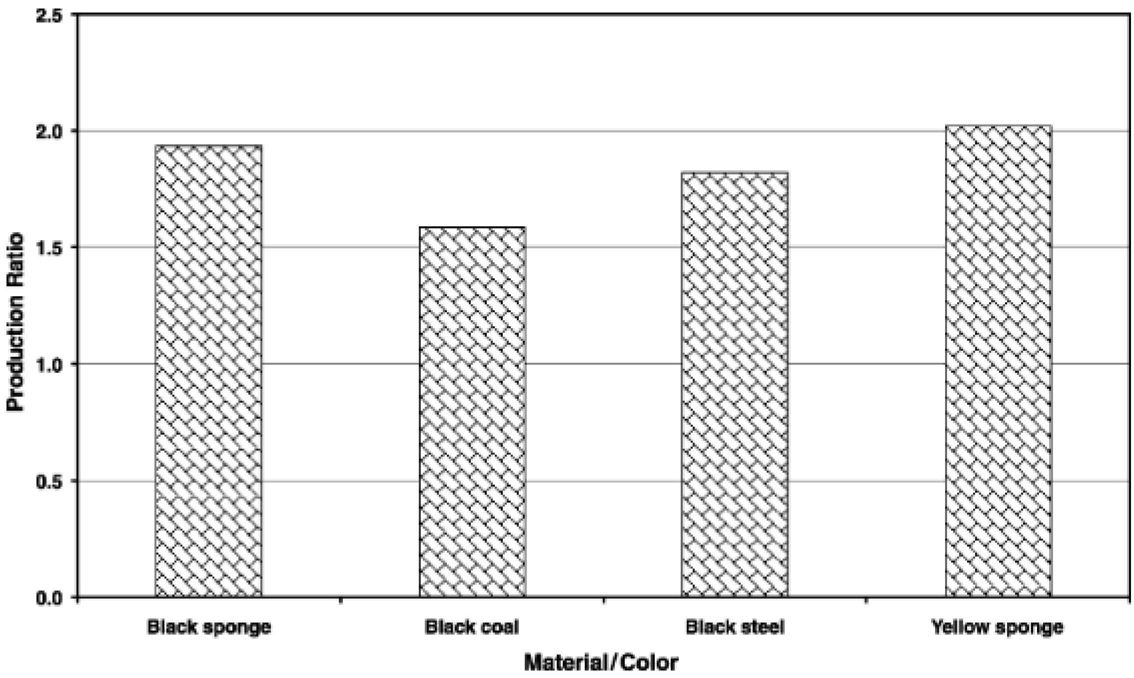

Figure 16: Different sponge material colour (Abu-Hijleh et al, 2003)

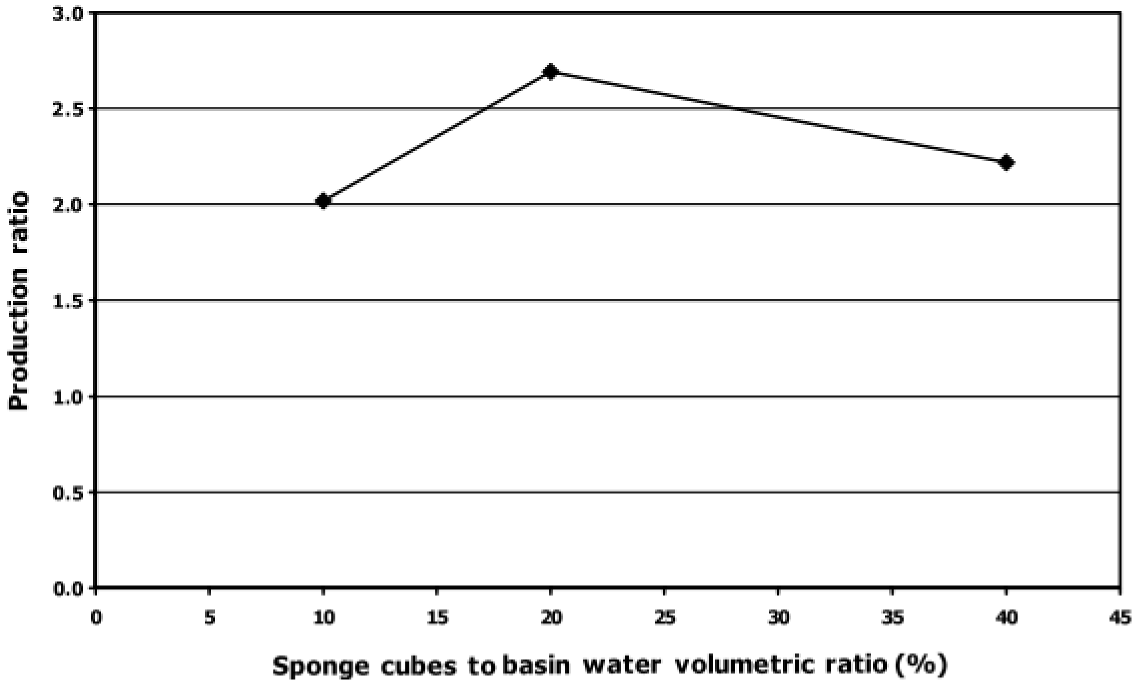

Figure 17: Sponge cubes volume production ratio (Abu-Hijleh et al, 2003)

From the results of Abu-Hijleh et al (2003), the yellow coloured sponge result in increased production ratio as shown in figure 16. In terms of volumetric ratio, 20% volumetric ratio results in increased production ratio.

Kalidasa Murugavel et al (2008) investigated the productivity of a single basin double slope passive still with different absorption methods used. The double slope was fabricated using mild steel plate for the basin and a 4mm thick glass was used for a 30° angle inclined cover. The solar still fabrication included one hole at the wall of the basin to allow thermocouple to measure the water temperature and another hole to allow inlet of feedwater. The experiment used a light jute cloth, light cotton cloth, and sponge of 2mm thick as the basin material along with quartzite and natural washed rock as basin materials with a maintained layer of water which is 3.4 kg. During the experiment the following parameters were measured for different materials used:

- Temperature of the water
- Temperature of the glass cover
- Solar radiation

Productivity was compared between each material used for the basin. The result shows that the maximum production rate was higher when using a light cotton cloth as material for the basin. highest production rate was approximately 1000 g/h (equivalent to 1 litre/hour).

Kabeel & El-Agouz (2011) reviewed the different types of solar still configurations and different methods to modify the productivity of single effect solar still. Among the reviewed researches was the research on the use of sponge cubes to increase productivity. According to Kabeel & El-Agouz (2011), most solar still productivity and efficiency increased when using sponge cube (or other heat storing materials) compared to identical solar stills without sponge cubes.

Sellami et al (2017) conducted an experiment on four identical single slope solar stills. One of the solar still was a conventional (simple) single slope still used for reference while the other three include different dimension sponges blackened with matte black paint and glued using silicon to the base of the basin. The thickness of each sponge used for different solar stills were 0.5, 1.0 and 1.5 cm respectively. During the experiment, the maximum solar radiation measured was 905 $\frac{W}{m^2}$ which corresponds to a 39 $°C$ at 2:00 pm. The experiment shows that the increase in temperature is directly proportional to the increase in solar radiation. The result shows that the thickness of the sponge has a storage effect which takes time for it to start distillation. The thickness of the sponge of 1.5 cm has the lowest distilled output while the thickness of 0.5cm produces the highest distilled productivity of 4.809 $\frac{L}{m^2}$.

2.6. Chapter summary

Solar still productivity depends on Ambient, Operational and Design conditions. Operational and Design conditions can be manipulated to obtain satisfaction in productivity of double slope solar still. Water depth is one design condition that can be manipulated to obtain high productivity of solar still. A thin layer is more suitable rather than a thick layer of feed water. Another design condition is the use of heat energy absorbing material such as sponge, gravel and other materials. The use of sponge should be maintained minimum range because this will make easier for basin black body surface to absorb solar radiation and provided the required heat for the water. The purpose of sponge cubes is the capillary actions that increase surface area of water which increases evaporation rate. Another important purpose of the sponge cube is that it reduces the loss of heat from the bottom of the basin, this allows more heat in the water which is ideal for solar still.

3. Methodology

3.1. Chapter overview

The technique used in this research project to find the suitable solution for solar distillation is based on previous literature where an experiment is carried out for double slope solar still without sponge cube and with sponge cube and the productivity is compared along other important variables (i.e. water temperature).

Since temperature difference is the important factor in solar distillation, it is clear that a solution to improve the performance of solar distillation is to have heat absorbing materials at the basin of the system to allow for greater temperature difference or have the cover of the solar still cooled with water flow. To maintain the simplicity of solar distillation, sponge cubes can be investigated to determine increased production at low cost when using locally available and low-cost regular sponge cubes. Having heat absorbing materials at the base of the basin is simple and does not require any electrical system or any sort of power consumption (Abu-Hijleh, 2003).

Selection of heat absorption can be difficult in terms of finding the right material with heat absorbing properties and can also be costly for the solar distillation. This project will determine the applicability of regular sponge to use in solar distillation which is low-cost and locally available. In addition, this project will analyse a layout which is 15.75% of basin area coverage – this equal to a total number of 12 sponge cubes. The dimension of the sponge cube is a 9cm x 7cm area and the color is yellow. Other test of different colours of sponge has been conducted in previous research

Sponge cube layout can be controlled to obtain the best production out of the system. Previous research has used sponge cubes in solar distillation at a 10% of volume ratio between sponge and water volume, the productivity is found to increase in such configuration and therefore, it is the expected outcome of this project to observe an increase in productivity compared to a reference solar still (still without sponge).

3.2. Explanation of the sponge and layout chosen

The sponge that will be used in this project will be a regular sponge found in local shops to follow the aim of this project which is to use locally available materials. Quality of distilled water from using regular sponge cannot be proved in this project to be safe for drinking purpose. Testing of water quality of the distilled water is not the main focus of this project. The focus is to increase the productivity of the solar distillation. Further analysis on the material of the sponge and the quality of water produce will be needed as further work for investigating if the regular sponge is applicable for use in solar distillation process.

The layout of the sponge is 15.75% of the surface area of the basin and the reason for this is to have the effect of both the sponge and the basin of the still. It is noted from previous research that the basin is usually painted black to easily obtain solar radiation, in the analysed system for this project it will not be different. The black body of the basin surface has the ability to initiate evaporation process quickly. That is why the available 84.25% of the basin will generate heat instantly from solar radiation. The purpose of the sponge is to expose more water to heat and to reduce heat loss from the base of the basin. As mentioned earlier, this layout can be varied to obtain more productivity and increase efficiency of the system. The layout of the sponge is as shown in the figure below.

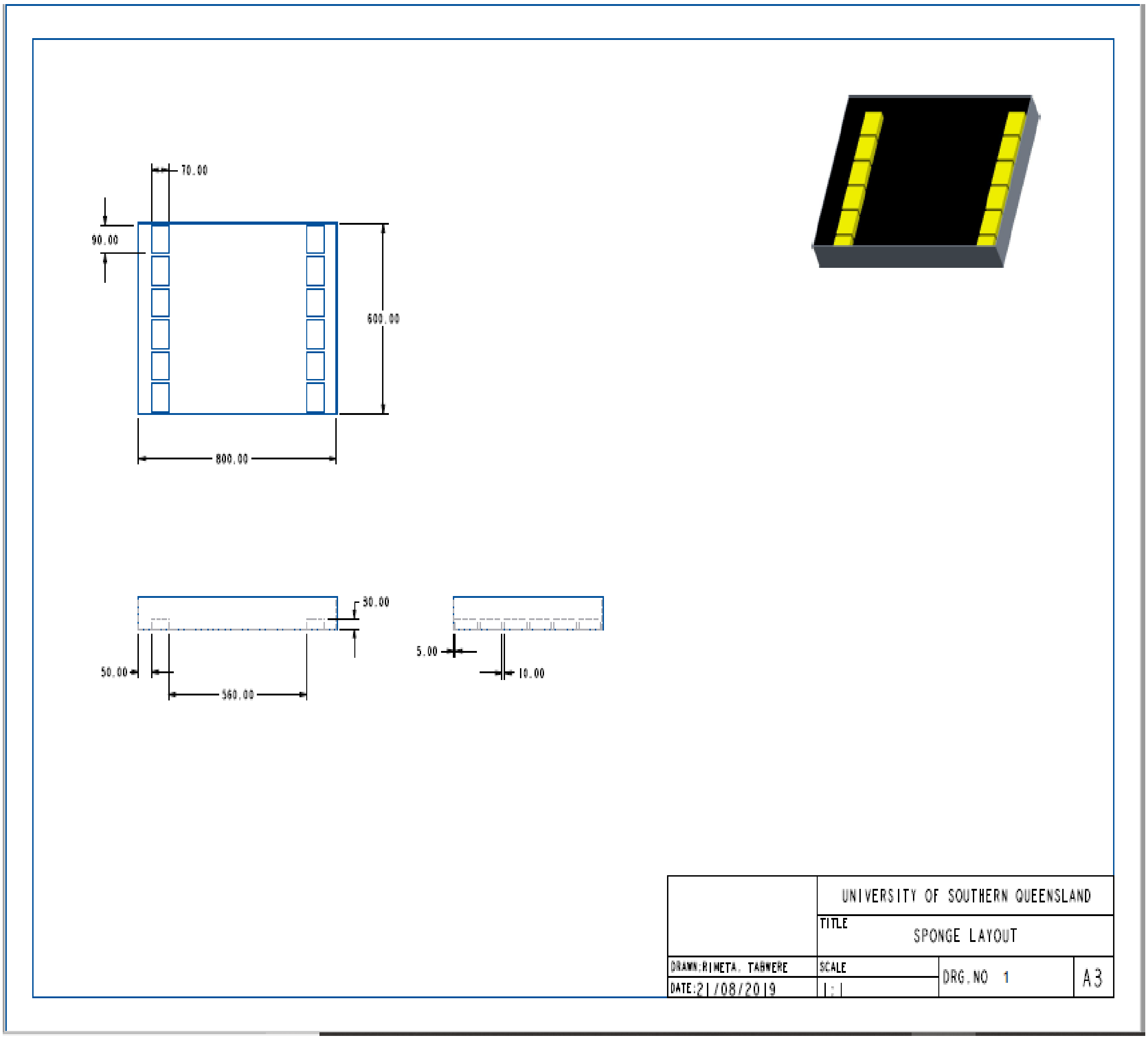

Figure 18: Sponge layout

The effective area of the double slope solar still basin is 600 x 800 mm. The sponge cube dimension (per unit) is measured 90 x 70 mm and therefore the percentage area of the basin that is covered can be calculated by:

$$\%\ of\ area\ covered = \frac{Area\ of\ sponge\ in\ total}{Area\ of\ basin}$$

$$\%\ of\ area\ covered = \frac{12(0.09 \times 0.07)}{0.8 \times 0.6} = \frac{0.0756\ m^2}{0.48\ m^2} = 0.1575\ \approx 15.75\%$$

Equation 1: Area of sponge percentage

Note that the dimensions of the schematic are in millimetres (mm)

3.3. Experimental setup

The experiment of this project will be carried out at the University of Southern Queensland Toowoomba campus at Z4 compound using the available solar distillation from previous student research. This experiment will only use the simple design and modify with use of regular sponge at the base of the basin.

3.3.1. Experiment location

The experiment will be carried out at Z4 TWB compound at the University of Southern Queensland Toowoomba, Australia. Toowoomba is situated $27.6°\ S\ and\ 151.96°\ E$ (location is as shown in figure below).

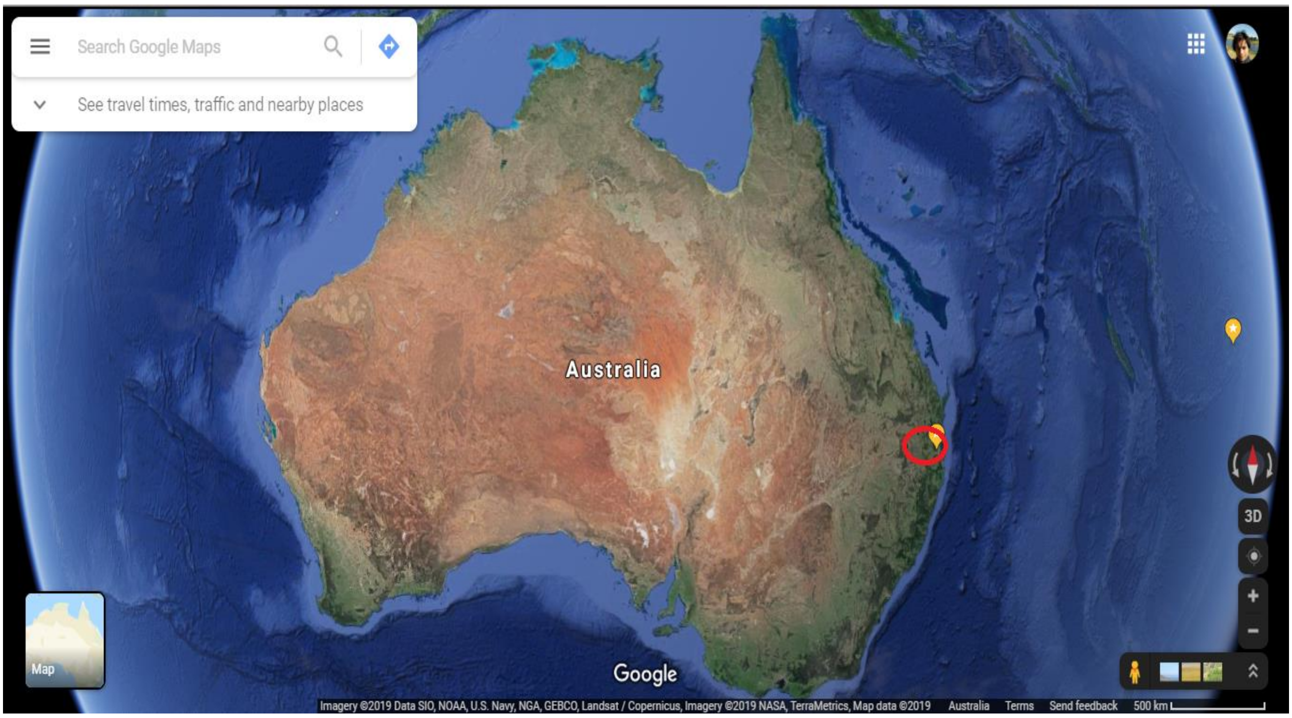

Figure 19: Location of Toowoomba in Australia

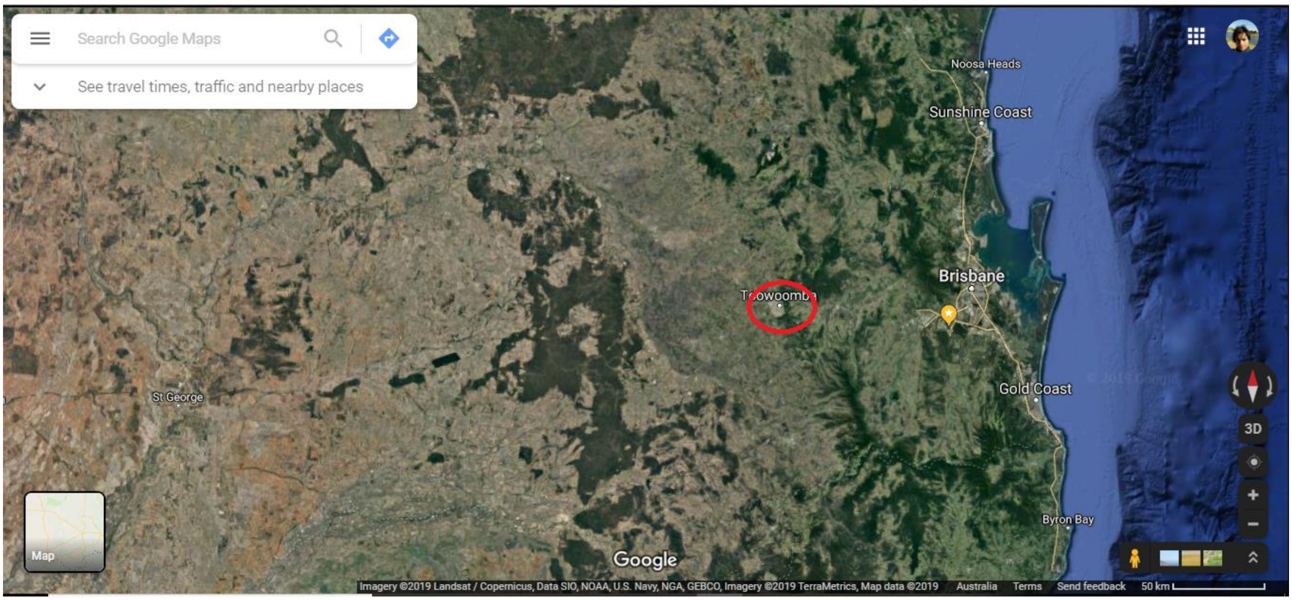

Figure 20: Location of Toowoomba from Brisbane

The location of experiment at the University of Southern Queensland is as shown in figure below. The location is outside Z4 TWB Workshop beside the Security office at Toowoomba campus.

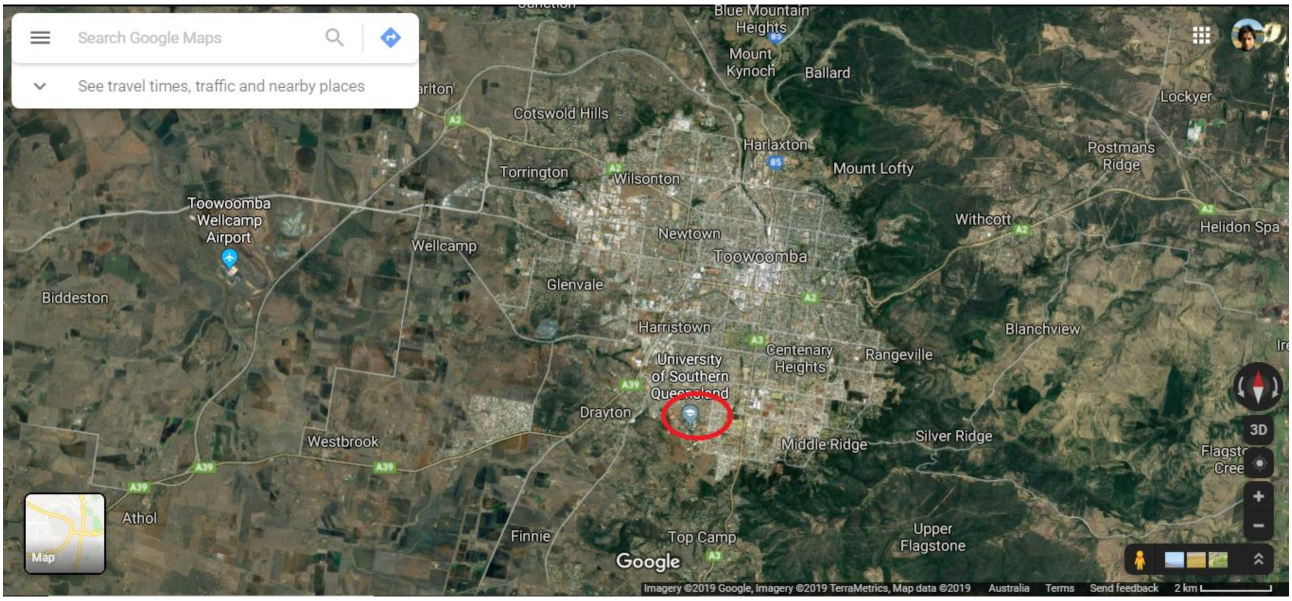

Figure 21: Location of University of Southern Queensland in Toowoomba

Figure 22: Location of Experiment within USQ

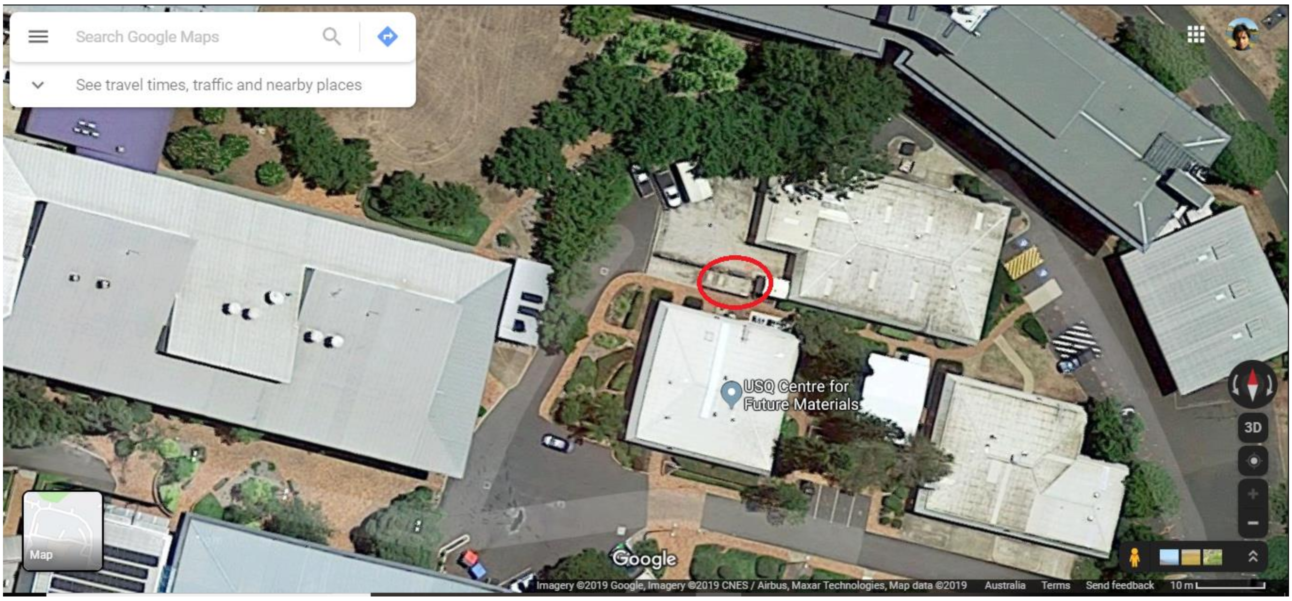

Figure 23: Location of Experiment in University of Southern Queensland

Solar radiation and wind speed measurement are obtained from a weather station also available in University of Southern Queensland (USQ) and is relatively close to the location of experiment. Figure below shows the location of weather station at USQ relative to location of experiment. Weather station circled in yellow and experiment location circled in red.

Figure 24: Weather station location relative to experiment location

3.3.2. Equipment for experiment

The experiment will be using the following equipment:

- Solar distillation system – 1 double slope solar still available in University of Southern Queensland Toowoomba campus
- 12 Sponge cubes – bought from local shop (Spar at Uniplaza court) at a total cost $6.18
- Thermocouples – 4 thermocouples will be used which is a K-type and connected to a Graphtec data logger to measure temperature of: Glass cover, Water surface, and Ambient temperature. (provided from USQ)
- Data logger – Graphtec data logger that support USB to record temperature measurement from thermocouples in .csv files that can be further analysed using excel. (provided from USQ)
- Storage tank and Measuring Jar – This will store produced water from the system which will be measured using a measuring jar at the end of each day. (provided from USQ)

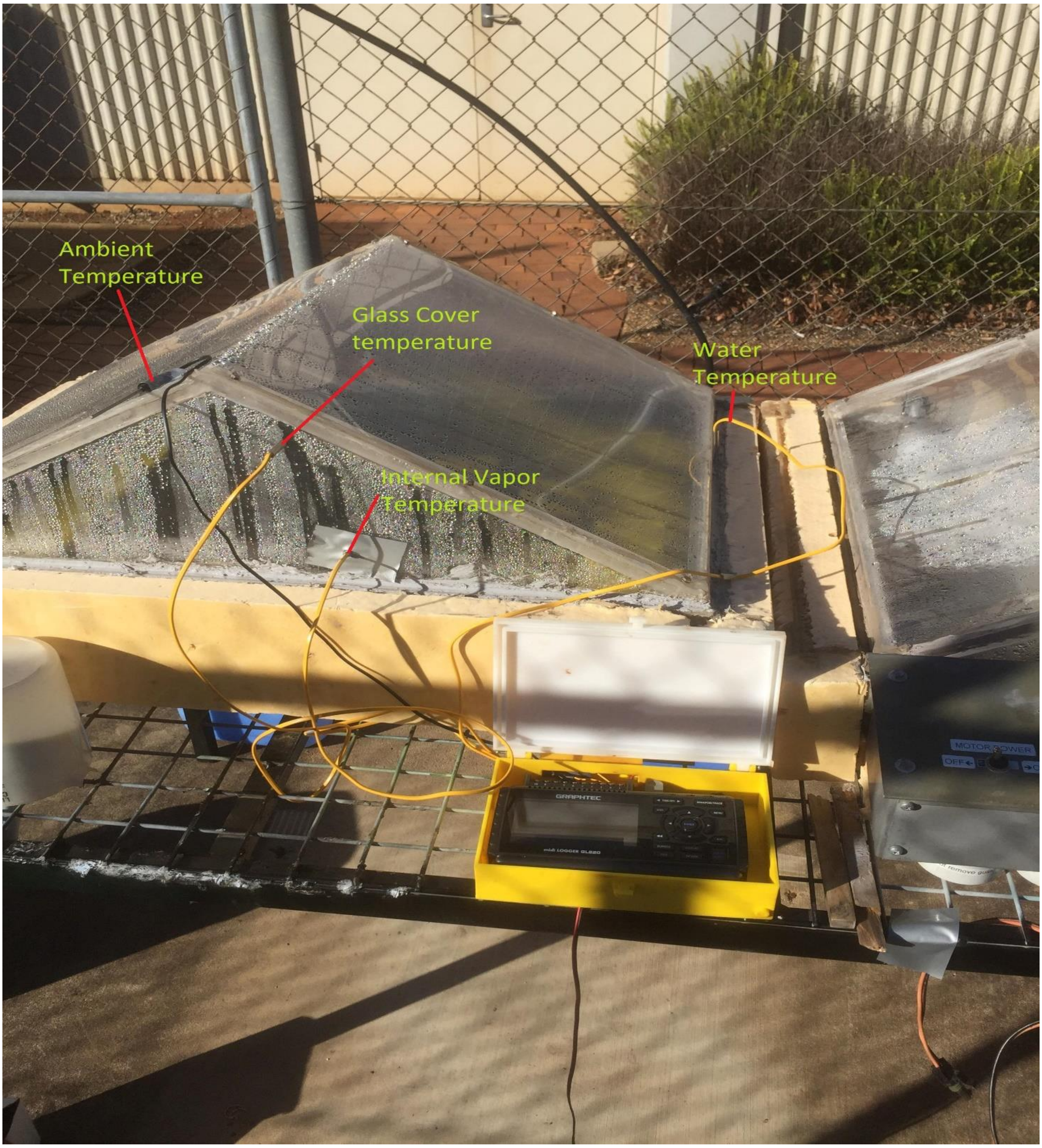

Figure 25: 4 thermocouples set up

The solar still can be described as follow:

- Double slope glass cover made from Plexiglas (3mm thick) and titled at an angle 27.5 degrees.
- Orientation is East – West for the slope of the glass cover.
- Basin is rectangular with 800 mm length, 600 mm width, and 100 mm height. Material for Basin is aluminium and 3mm thick.
- Metal shield – Grey (Delux) is used as a coating for the aluminium basin.
- Duramax Flat black (Delux) paint is used to paint inside the basin where water will be evaporated.
- Roof and Gutter silicone sealant (SikaSeal) is used to seal the glass cover and basin.

Temperature measurement were accomplished using 4 k-type thermocouples and a data logger where temperature is measured every 10 minutes and stored into a USB drive (see figure 25).

Figure 26: Calibration of K-type Thermocouple

Figure 26 shows the calibration process of the 4 k-type thermocouples. In the process, the thermocouples were put in a hot water and then after putting in an iced water. This is used to make sure that the readings from the data logger is appropriate (or according to expected).

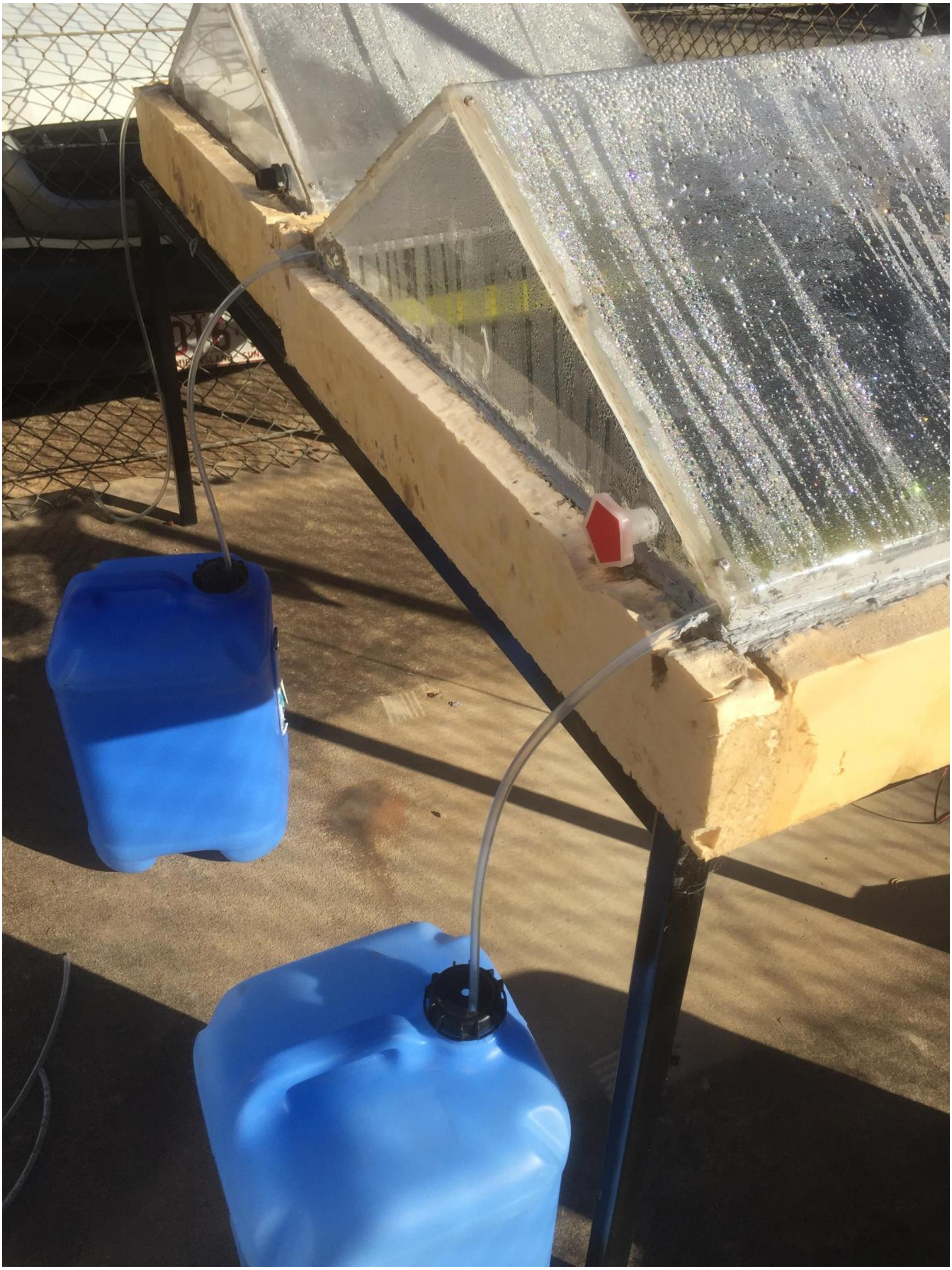

Figure 27: 2 storage tanks and tube connected to the trough

Figure 28: Measuring Jar

Figure 27 shows how the produced water from the solar still is channelled down the trough and into the collection tanks and figure 28 shows the measuring jar that is used to measure distilled water in millilitres (ml) for a one-day production.

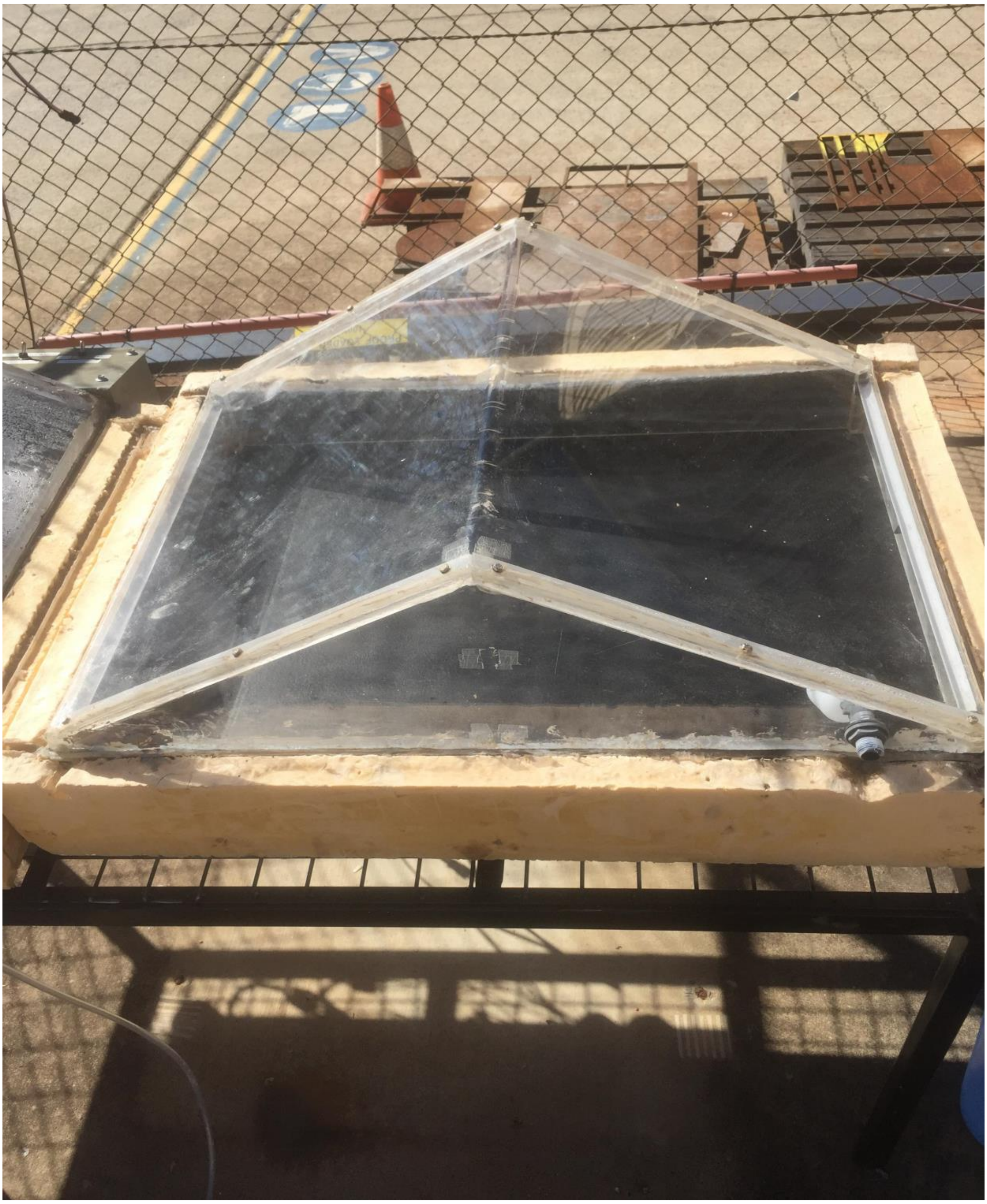

Figure 29: Solar still without sponge

Figure 29 shows the solar still without sponge which will be referred to in this experiment as the reference still and the comparison of the output from reference still and solar still with sponge will be the method to analyse productivity.

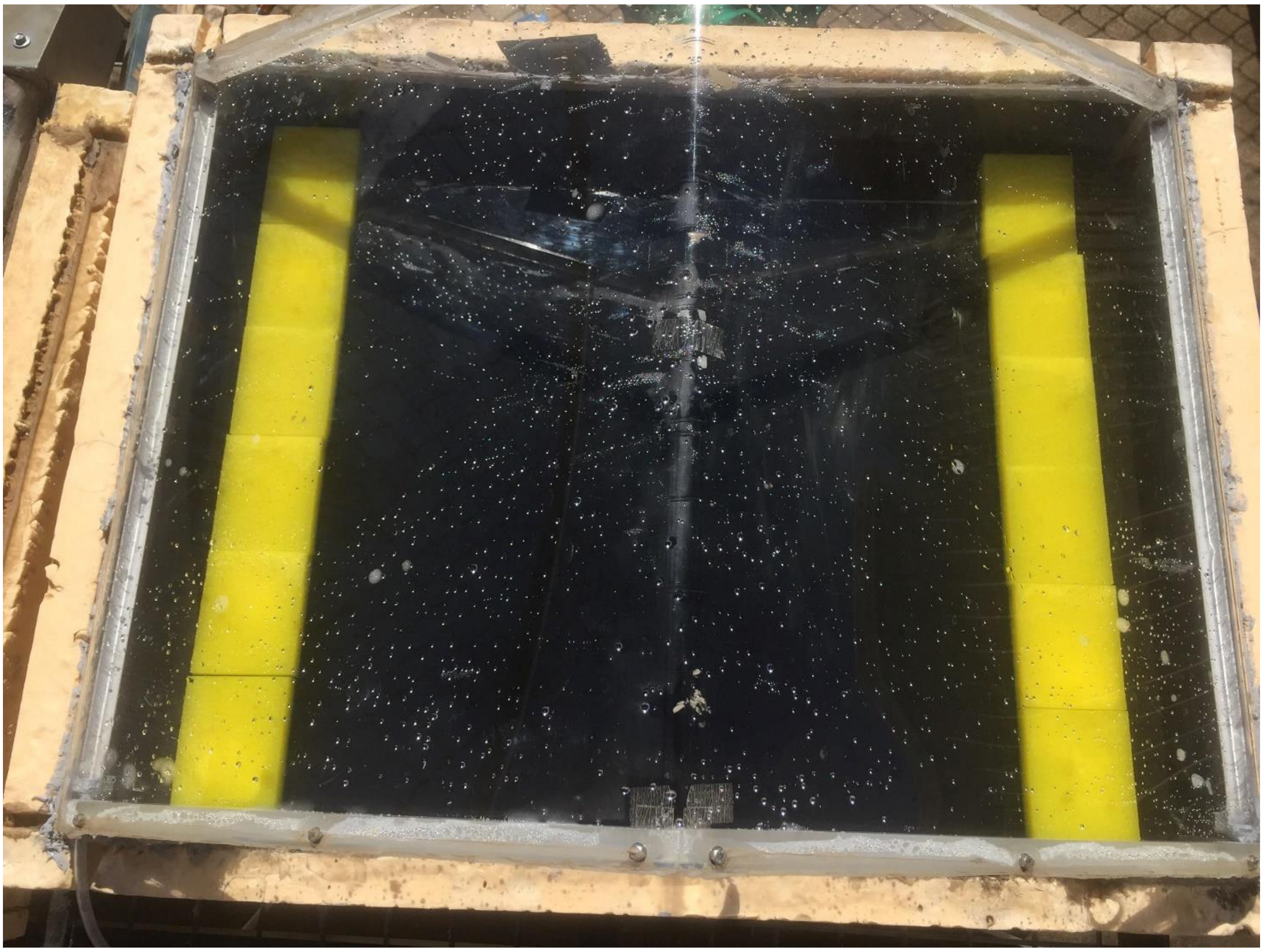

Figure 30: Solar still with sponge

Figure 30 shows the arrangement of sponge cubes in the basin of the double slope solar still. This is the modification that will be analysed in terms of temperature of water and output water (distilled water).

3.4. Experiment procedure

Step 1: Collecting instrument

Before carrying on any experiment testing, the equipment mentioned in subsection 3.3 were collected from allocated technical staff of the Faculty of Engineering and Surveying department. The instrument that were provided from the staff include: Data logger (Graphtec), 4 thermocouples, Battery to run Data logger, and measuring jar.

Step 2: Getting Access to the experiment location

The solar still system was located Z4 TWB compound and therefore, arrangement were made with Z4 workshop technical staff at University of Southern Queensland Toowoomba campus. The technical team required a risk assessment document to be filled so it was arranged and with the assistance of my supervisor the team finally gave me access to the experiment location.

Step 3: Preparing Experiment

Before the actual experiment was carried out, certain work were required. The first task was the removal of glass cover, cleaning and repainting the basin of the solar still black. Second task was calibrating the thermocouples. Third task was running initial testing to see productivity of system. After carrying out initial testing, it was found that water was not going into the storage tank. Further work was done which was adjustment of the connection from trough to storage tank. After this adjustment, there was productivity and actual experiment was ready to commence.

Step 4: Solar still with sponge

The initial experiment was solar still with sponge layout as shown in figure 26. This was carried out for a total of 8 days because the idea was to collect data for several days and do the same for solar still without sponge, and then compare the climatic condition where the most similar days are taken as the final results.

Step 5: Solar still without sponge

The last and final step for experiment was the solar still without sponge as shown in figure 25. Measurement of temperatures were done every 10 minutes and the system starts from 9:00 am – 4:00 pm (similar to that of solar still with sponge). Daily output was measured using measuring jar which will then be compared with productivity of solar still with sponge.

Task 6: House keeping

After the final experiment has been carried out, water will be removed from the solar still, experiment location will be cleaned and equipment that were used will be returned to the allocated office where it was collected.

Task 7: Analysis

This is not an experiment but after the experiment is complete, the analysis of experiment finding will be carried out which will be part of the result.

3.5. Risk Assessment

Some of the risks that can be found in this project include:

- Experimental hazards (low risk)
- Risk in typing and interacting with computer
- Damage of equipment can cause high cost

The main concern is the experimental risk which is a requirement to go through before accessing the compound. This is a part of the University procedure in accessing workshops and places where hazard will be present and is a good thing because it keeps the personnel alert of the dangers in the work he/she will be doing.

As mentioned before, the experiment was not high risk but nevertheless a risk assessment plan was conducted to allow myself and the staff to know what sort of risk that I will be exposed to when doing my experiment. The risk assessment plan is attached in Appendix B.

4. Result and discussion

4.1. Solar still without sponge Vs Solar still with sponge

4.1.1. Productivity

Different days are used to experiment solar still with and without sponge cubes. Solar radiation will be used to determine the validity of the result (i.e. whether productivity increase due to use of sponge or is it because of increased in solar radiation)

The days selected for the result comparison will be based on relatively similar ambient temperature. The figure below shows the graphical comparison of ambient temperature. These days are selected because of minimum difference in ambient temperature.

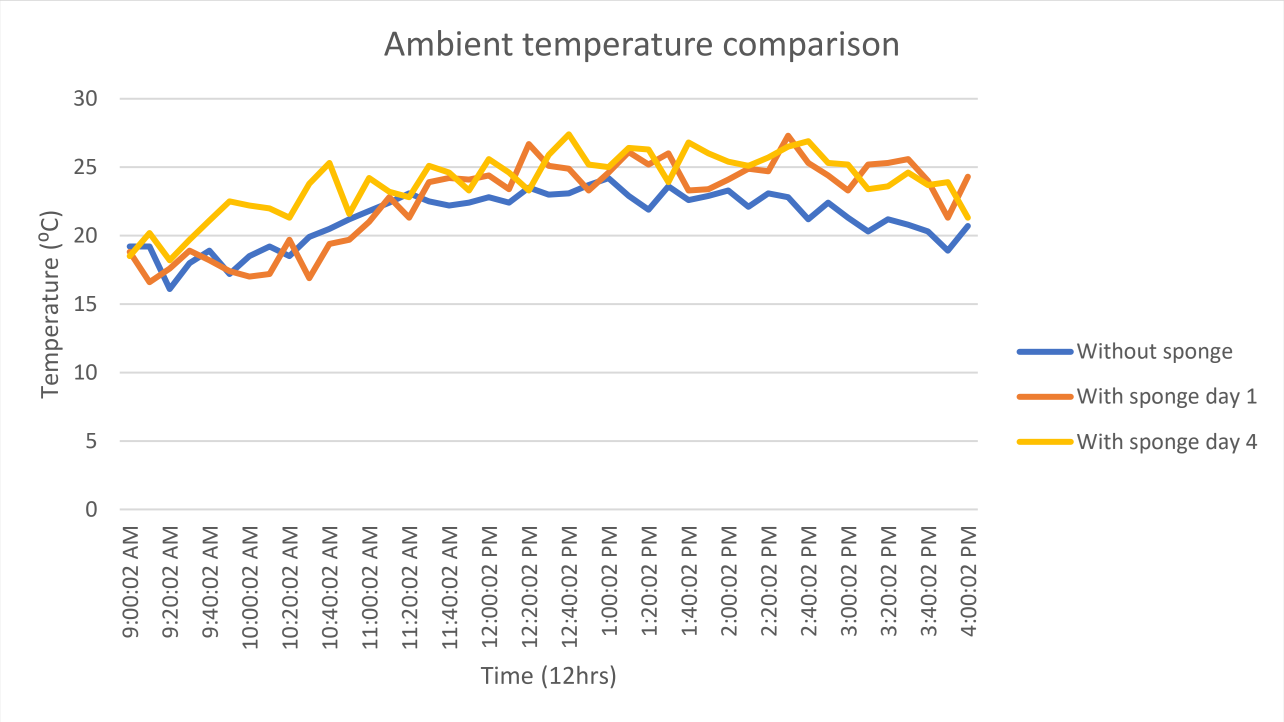

Figure 31: Ambient temperature comparison

Table 1: Ambient temperature comparison

		With sponge		Difference	
Time	Without sponge	Day 1	Day 4	difference for day 1	difference for day 4
9:00:02 AM	19.2	18.8	18.5	0.4	0.7
9:10:02 AM	19.2	16.6	20.2	2.6	-1
9:20:02 AM	16.1	17.6	18.2	-1.5	-2.1
9:30:02 AM	18	18.9	19.7	-0.9	-1.7
9:40:02 AM	18.9	18.2	21.1	0.7	-2.2
9:50:02 AM	17.2	17.4	22.5	-0.2	-5.3
10:00:02 AM	18.5	17	22.2	1.5	-3.7
10:10:02 AM	19.2	17.2	22	2	-2.8
10:20:02 AM	18.5	19.7	21.3	-1.2	-2.8
10:30:02 AM	19.9	16.9	23.8	3	-3.9
10:40:02 AM	20.5	19.4	25.3	1.1	-4.8
10:50:02 AM	21.2	19.7	21.6	1.5	-0.4
11:00:02 AM	21.8	21	24.2	0.8	-2.4
11:10:02 AM	22.4	22.8	23.2	-0.4	-0.8
11:20:02 AM	23.1	21.3	22.8	1.8	0.3
11:30:02 AM	22.5	23.9	25.1	-1.4	-2.6
11:40:02 AM	22.2	24.2	24.6	-2	-2.4
11:50:02 AM	22.4	24.1	23.3	-1.7	-0.9
12:00:02 PM	22.8	24.4	25.6	-1.6	-2.8
12:10:02 PM	22.4	23.4	24.6	-1	-2.2
12:20:02 PM	23.5	26.7	23.3	-3.2	0.2
12:30:02 PM	23	25.1	25.9	-2.1	-2.9
12:40:02 PM	23.1	24.9	27.4	-1.8	-4.3
12:50:02 PM	23.7	23.3	25.2	0.4	-1.5
1:00:02 PM	24.2	24.6	25	-0.4	-0.8
1:10:02 PM	22.9	26.1	26.4	-3.2	-3.5
1:20:02 PM	21.9	25.2	26.3	-3.3	-4.4
1:30:02 PM	23.6	26	23.9	-2.4	-0.3
1:40:02 PM	22.6	23.3	26.8	-0.7	-4.2
1:50:02 PM	22.9	23.4	26	-0.5	-3.1
2:00:02 PM	23.3	24.1	25.4	-0.8	-2.1
2:10:02 PM	22.1	24.9	25.1	-2.8	-3
2:20:02 PM	23.1	24.7	25.7	-1.6	-2.6
2:30:02 PM	22.8	27.3	26.5	-4.5	-3.7
2:40:02 PM	21.2	25.3	26.9	-4.1	-5.7
2:50:02 PM	22.4	24.4	25.3	-2	-2.9
3:00:02 PM	21.3	23.3	25.2	-2	-3.9
3:10:02 PM	20.3	25.2	23.4	-4.9	-3.1
3:20:02 PM	21.2	25.3	23.6	-4.1	-2.4
3:30:02 PM	20.8	25.6	24.6	-4.8	-3.8
3:40:02 PM	20.3	24	23.7	-3.7	-3.4
3:50:02 PM	18.9	21.3	23.9	-2.4	-5
4:00:02 PM	20.7	24.3	21.3	-3.6	-0.6
			Average difference	-1.279	-2.577

Table above shows further investigation into which days is appropriate to select and compare productivity with solar still without sponge. This was accomplished by finding the average difference in ambient temperature. Day 1 for solar still with sponge shows minimum average ambient temperature difference and therefore selected for comparison.

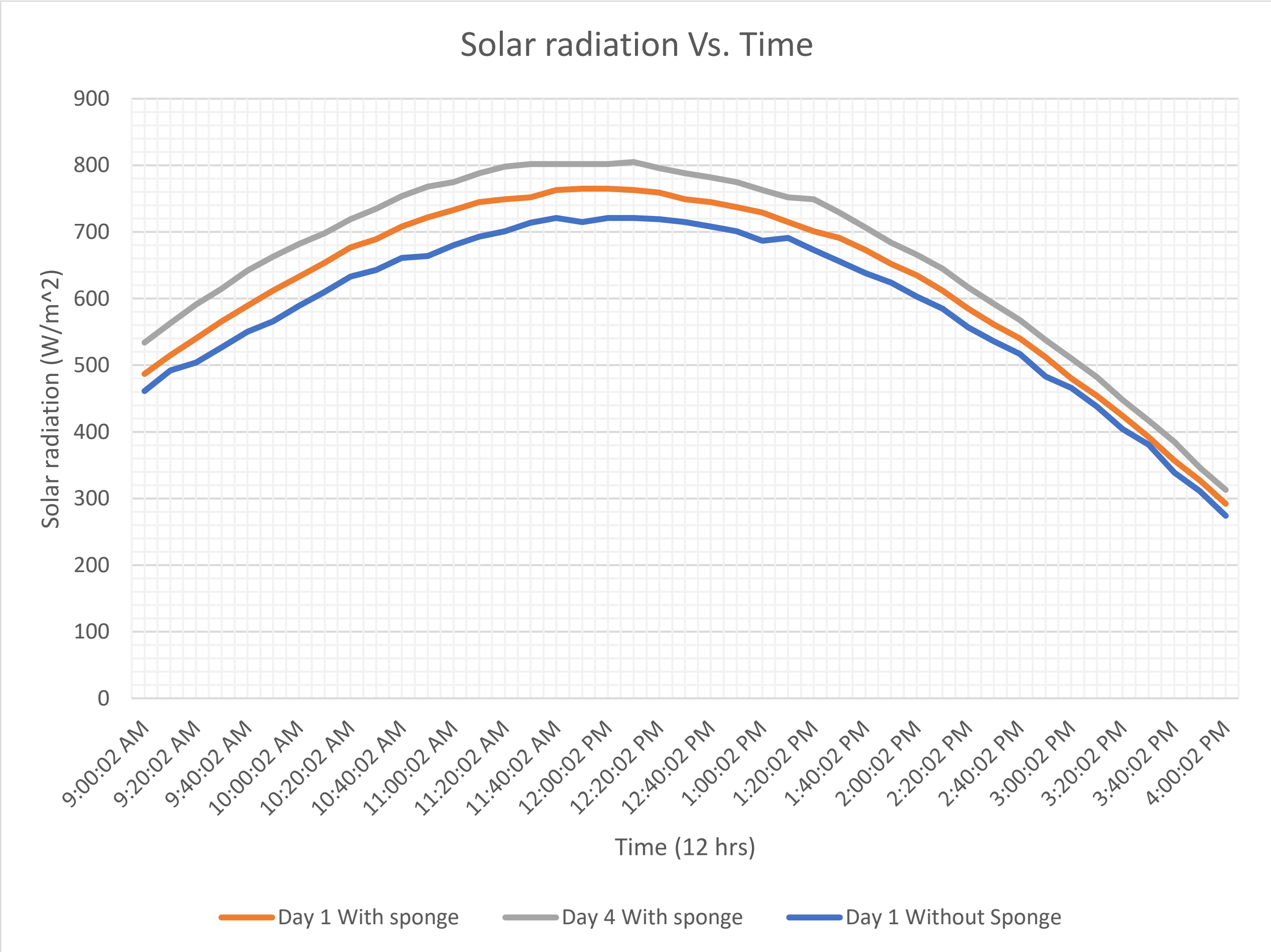

Figure 32: Solar radiation comparison

Figure above shows the hourly solar radiation of Day 1 without sponge, Day 1 with sponge and Day 4 with sponge. This figure is used to help clarify if sponge cube is the reason for increase in productivity.

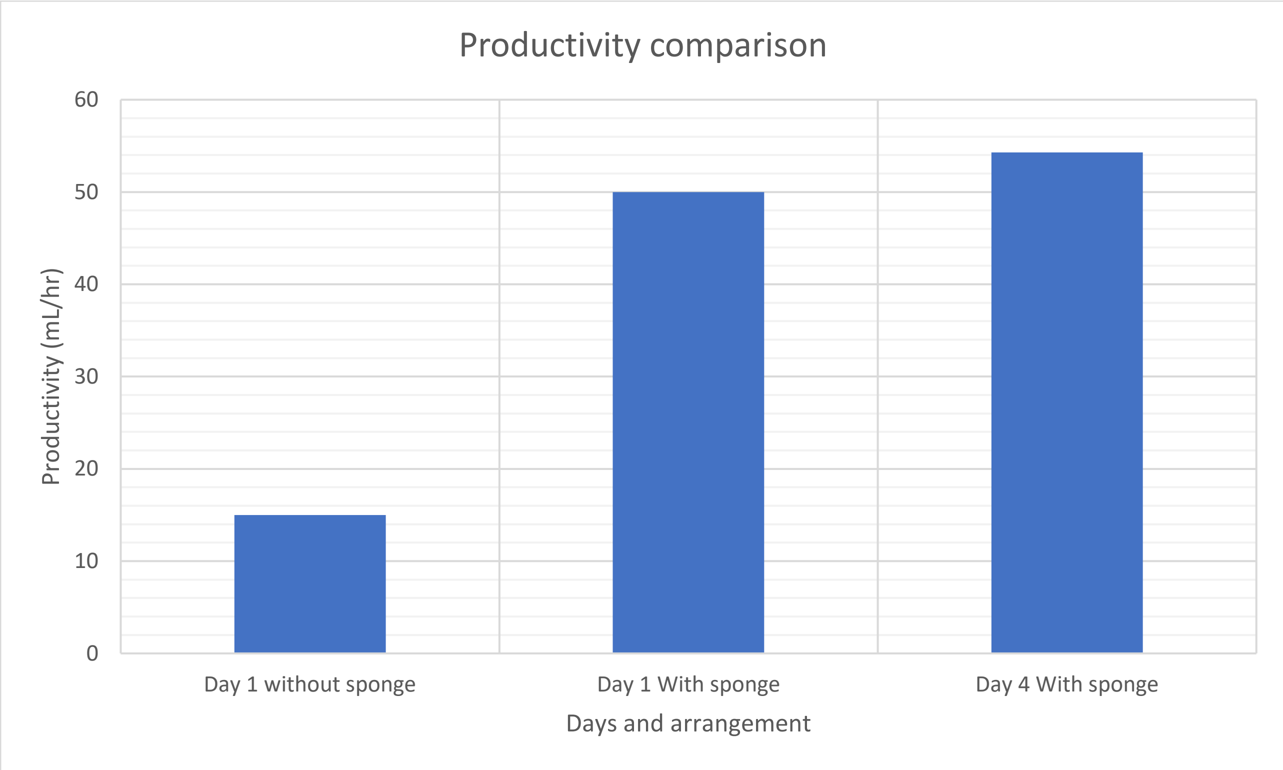

Figure 33: Production comparison

Figure 33 shows the comparison of productivity. The evaluation includes Day 1 without sponge, Day 1 with sponge and Day 4 with sponge. With the solar radiation information given in figure 32, it can be observed that the effect of solar radiation is minimum compared to effect of sponge cubes.

Day 4 with sponge have higher solar radiation than Day 1 with sponge. If compared over a 7-hour productivity, the increase in production is 30 mL. This is low compared to productivity difference of Day 1 without sponge and Day 1 with sponge which is 245 mL. This concludes that sponge cubes have significant effect compared to solar radiation.

From the selected days which are Day 1 without sponge and Day 2 with sponge, production ratio can be calculated. Without sponge the production is 105 ml and with sponge the production is 350 ml. Production ratio can be calculated as follow:

$$Production\ ratio = \frac{With\ sponge\ productivity}{Without\ sponge\ productivity}$$

$$Production\ ratio = \frac{350}{105}$$

$$Production\ ratio = 3.333\ \approx 3.33\ (dimensionless)$$

4.1.2. Water temperature

Table 2 and 3 below shows the temperature data for Vapor, Water, Glass cover and Ambient collected using a data logger.

Table 2: Day 1 - without sponge temperature log

Time (12hrs)	Vapor temperature (^{o}C)	Water temperature (^{o}C)	Glass cover temperature (^{o}C)	Ambient temperature (^{o}C)
9:00:02 AM	23.8	21.6	19.7	19.2
9:10:02 AM	23.5	23	20.1	19.2
9:20:02 AM	23	23.8	20.1	16.1
9:30:02 AM	26.4	24.5	21.1	18
9:40:02 AM	27.2	25.9	23.1	18.9
9:50:02 AM	25.5	26.7	22.6	17.2
10:00:02 AM	26.2	27.4	23.3	18.5
10:10:02 AM	27.3	27.7	24.3	19.2
10:20:02 AM	27.1	28.3	24.1	18.5
10:30:02 AM	29.3	29.2	25.4	19.9
10:40:02 AM	30.7	30.5	27.4	20.5
10:50:02 AM	32	31.5	27.7	21.2
11:00:02 AM	33.8	33.2	30.8	21.8
11:10:02 AM	35.8	35	32.1	22.4
11:20:02 AM	37.3	36.8	33.9	23.1
11:30:02 AM	38.8	38.5	34.9	22.5
11:40:02 AM	40.2	39.8	36.3	22.2
11:50:02 AM	40.8	41.4	37.1	22.4
12:00:02 PM	42	42.6	37.5	22.8
12:10:02 PM	43.2	43.5	39.3	22.4
12:20:02 PM	43.7	44.6	40.3	23.5
12:30:02 PM	44.2	45.2	40.9	23
12:40:02 PM	45.2	45.9	42.1	23.1
12:50:02 PM	45.8	46.6	43.1	23.7
1:00:02 PM	46.5	47.1	44	24.2
1:10:02 PM	47	47.6	41.1	22.9
1:20:02 PM	47.1	47.8	41.9	21.9
1:30:02 PM	47.5	48.1	44.5	23.6
1:40:02 PM	47.5	48.2	41.6	22.6
1:50:02 PM	47.7	48.3	44.9	22.9
2:00:02 PM	47.2	48.1	44.8	23.3
2:10:02 PM	46.6	47.8	44.2	22.1
2:20:02 PM	46.5	47.7	43.8	23.1
2:30:02 PM	46.7	48	43.2	22.8
2:40:02 PM	44.7	45.9	41.4	21.2
2:50:02 PM	43.9	45.2	40.3	22.4
3:00:02 PM	43.5	44.8	38.3	21.3
3:10:02 PM	42.2	44	36.5	20.3
3:20:02 PM	39	43.2	34.5	21.2
3:30:02 PM	40.4	42.7	34.7	20.8
3:40:02 PM	39.4	41.8	31.1	20.3
3:50:02 PM	38.5	40.9	31.9	18.9
4:00:02 PM	38.5	40.1	32.1	20.7

Table 3: Day 1 - with sponge temperature log

Time (12hrs)	Vapor temperature (^oC)	Water temperature (^oC)	Glass cover temperature (^oC)	Ambient temperature (^oC)
9:00:02 AM	19.8	16.4	15.5	18.8
9:10:02 AM	18.7	17.4	15.9	16.6
9:20:02 AM	21.4	18.7	17.8	17.6
9:30:02 AM	23	20.3	19	18.9
9:40:02 AM	23.2	21.6	19.3	18.2
9:50:02 AM	23.9	23.6	19.8	17.4
10:00:02 AM	22.8	24	19	17
10:10:02 AM	22.8	24	18.4	17.2
10:20:02 AM	27	25.7	21.5	19.7
10:30:02 AM	25.7	26.8	20.7	16.9
10:40:02 AM	28.5	27.6	22	19.4
10:50:02 AM	31.3	29.5	24.9	19.7
11:00:02 AM	33.1	31.3	27.1	21
11:10:02 AM	34.6	33.1	28.8	22.8
11:20:02 AM	36.7	35.1	30.3	21.3
11:30:02 AM	38.1	37	31.5	23.9
11:40:02 AM	39.8	38.7	32.8	24.2
11:50:02 AM	41.4	40.2	34	24.1
12:00:02 PM	42.5	41.6	34.7	24.4
12:10:02 PM	43.8	42.9	35.9	23.4
12:20:02 PM	45.1	44.2	37.4	26.7
12:30:02 PM	46.3	45.3	38	25.1
12:40:02 PM	47.4	46.4	38.3	24.9
12:50:02 PM	48.1	47.2	39	23.3
1:00:02 PM	48.7	48	39.4	24.6
1:10:02 PM	49.3	48.5	40	26.1
1:20:02 PM	50.1	49.1	40	25.2
1:30:02 PM	50.8	49.8	40.8	26
1:40:02 PM	50.9	50	40.9	23.3
1:50:02 PM	51.5	50.3	41.5	23.4
2:00:02 PM	51.1	50.3	40.7	24.1
2:10:02 PM	51.4	50.5	41.2	24.9
2:20:02 PM	50.6	50.2	40.4	24.7
2:30:02 PM	50.5	50.4	40.8	27.3
2:40:02 PM	50.1	49.7	40.7	25.3
2:50:02 PM	48.9	48.6	39.1	24.4
3:00:02 PM	48	47.8	38.4	23.3
3:10:02 PM	46.5	47.2	38.1	25.2
3:20:02 PM	45	46.6	37.5	25.3
3:30:02 PM	45.2	45.9	36.3	25.6
3:40:02 PM	45.1	45.3	32.8	24
3:50:02 PM	44.2	44.3	35.1	21.3
4:00:02 PM	42.9	43.2	34.4	24.3

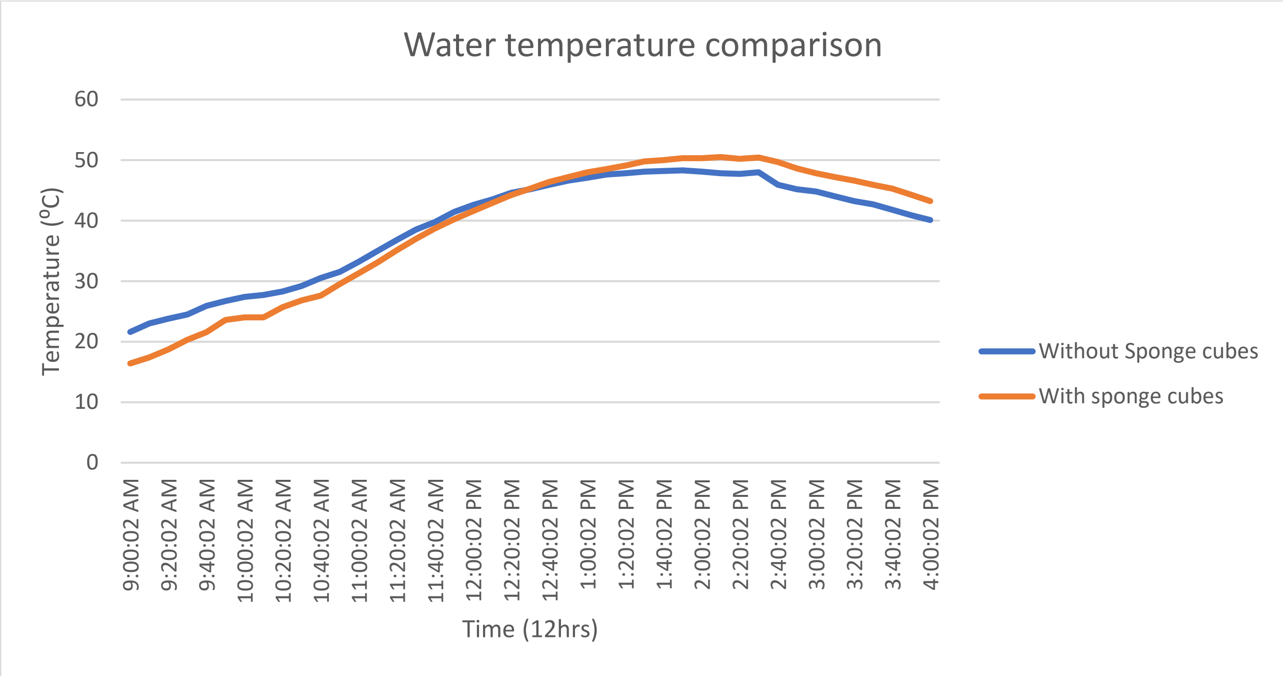

Figure 34: Water temperature comparison

Figure 34 shows the comparison of water temperature for solar still without sponge and solar still with sponge. From the graph it is observed that water temperature for solar still without sponge is greater than water temperature for solar still with sponge for the first 4 hours of operation. Water temperature for solar still with sponge is greater than water temperature for solar still without sponge for the rest of the duration of experiment.

Sponge takes longer to absorb heat energy, but it can sustain heat in the basin and water for better evaporation rate.

4.2. Effect of ambient conditions

4.2.1. Solar radiation

The effect of solar radiation contributes to the change in production for solar still desalination. This section will visualize the effect of solar radiation on the productivity of solar still and justify the assumption that if solar radiation increases, productivity will increase. This assumption is ideally true since solar radiation provides the energy required for evaporation. However, this assumption will be validated using experimental data.

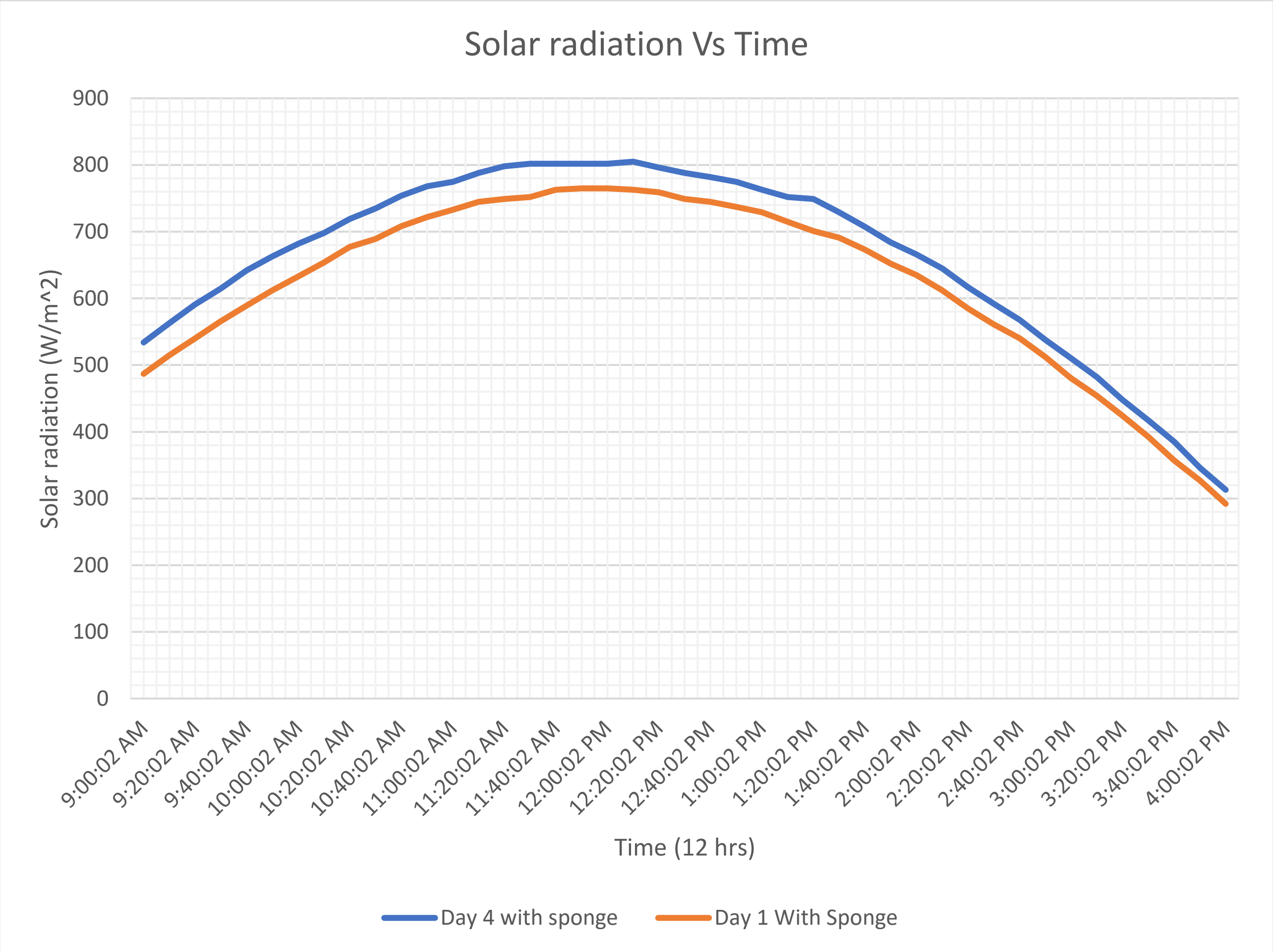

Figure 35: Solar radiation comparison for solar still with sponge

Figure above shows the solar radiation comparison between two days for solar still with sponge cubes. Day 1 and Day 4 are compared to determine the effect of increase in solar radiation. This comparison is made because ambient temperature is assumed to be same (in this case ambient temperature is relatively similar for these days). From the above figure, it is observed that solar radiation is higher for day 4 compared to solar radiation for day 1.

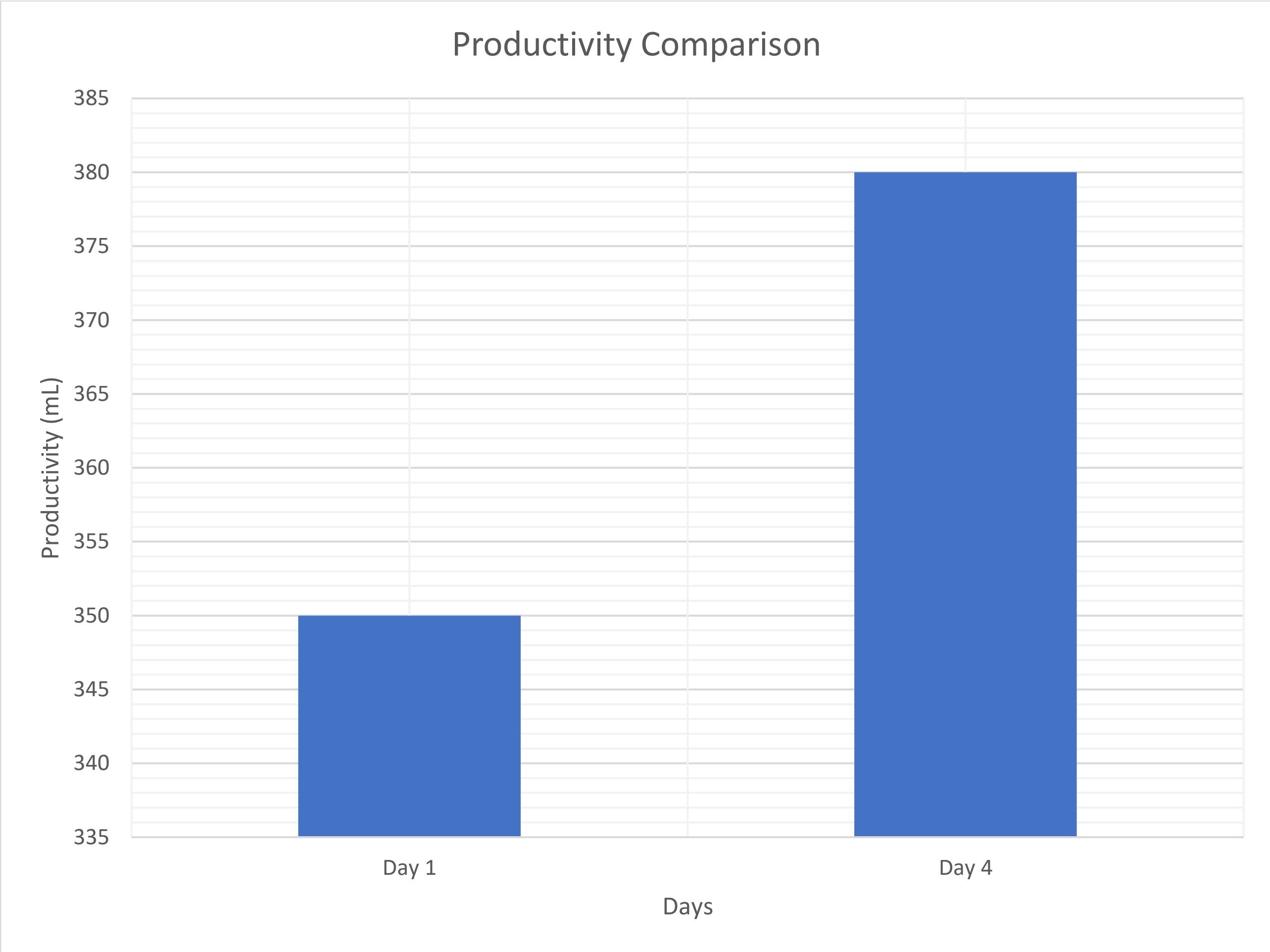

Figure 36: Productivity comparison

From the graph above, Day 4 productivity is greater than productivity in Day 1. Referring back to figure 35, it is observed that solar radiation is greater in Day 4. Therefore, the assumption for solar radiation effect is true where higher solar radiation will result in high productivity.

4.2.2. Wind Speed

Wind speed is an ambient condition that also change the productivity of solar still system. For a solar still system, it is required that temperature of water inside the basin should be high to allow evaporation, and temperature of glass cover should be low to improve condensation. This section will visualize the effect of wind speed on solar still performance. For this section, wind speed, temperature of glass cover and productivity will be analysed. Figure 36 will be referred to in terms of comparison of productivity.

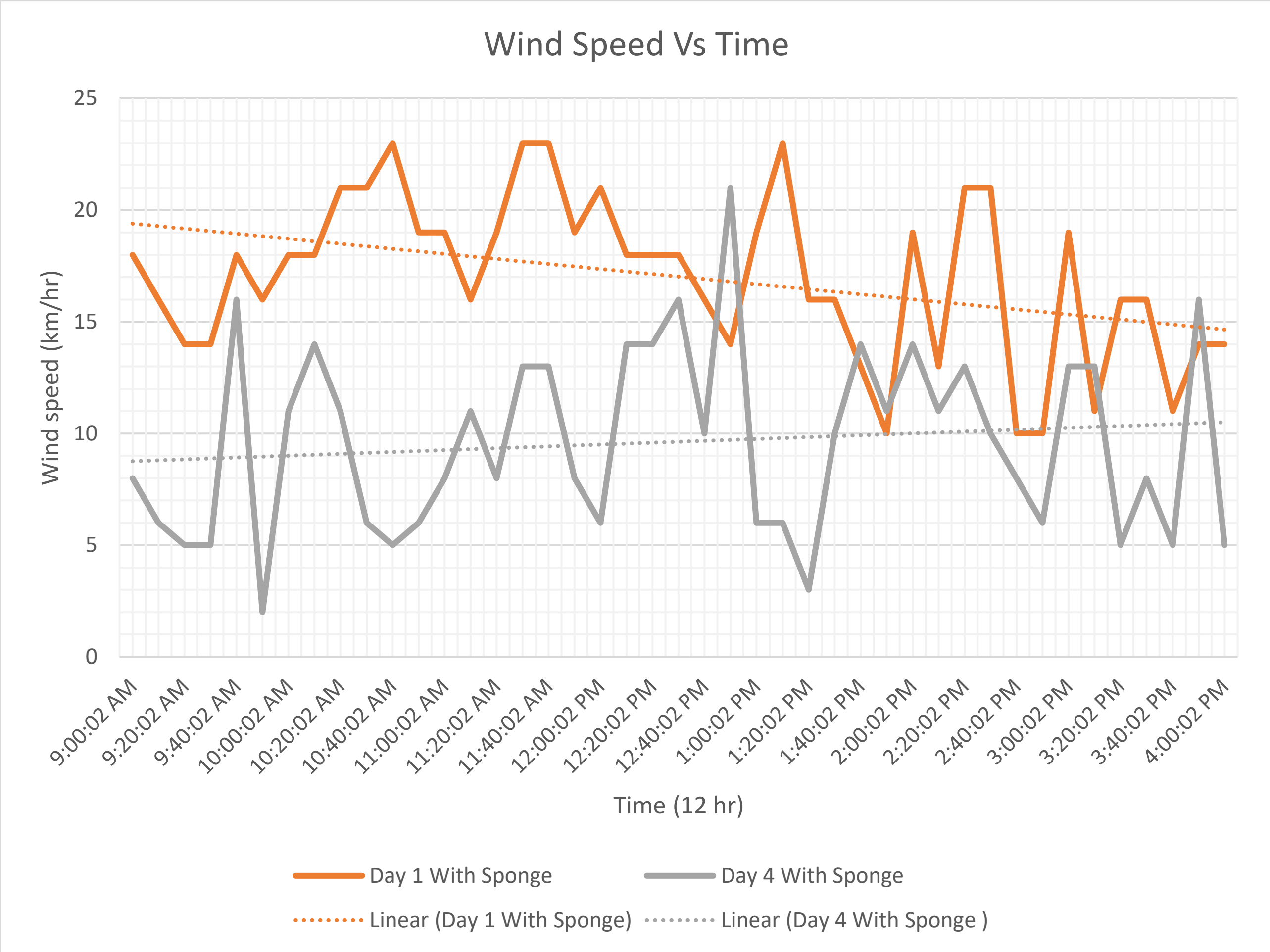

Figure 37: Wind speed comparison

Figure above shows the comparison of wind speed for day 1 and day 4 for solar still with sponge. It is observed that wind speed is high for day 1 compared to wind speed for day 4.

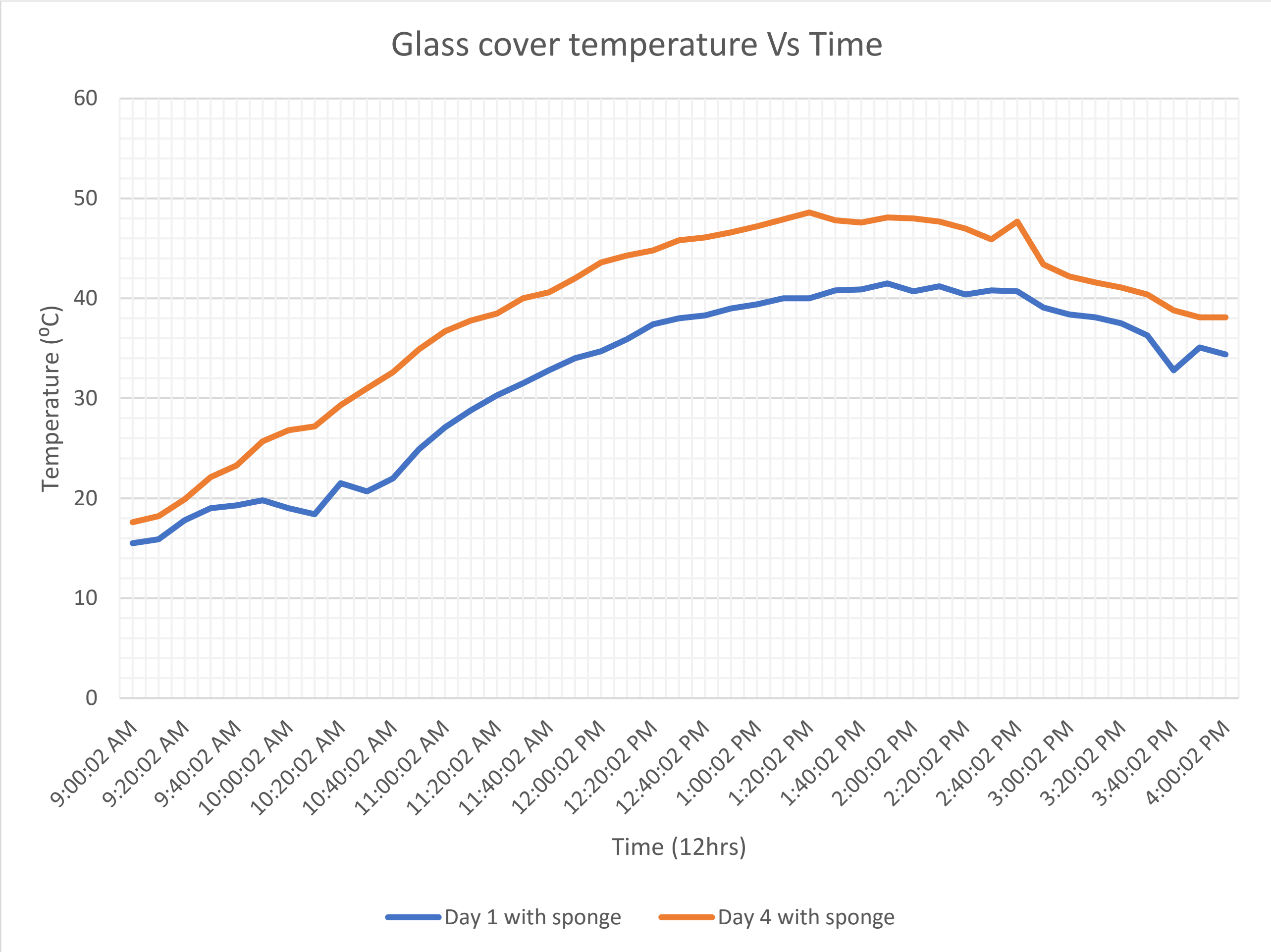

Figure 38: Glass cover temperature Comparison

Figure above shows the comparison of glass cover temperature for day 1 and day 4 solar still with sponge cubes. Temperature of glass cover is low for day 1 compared to temperature of cover for day 4.

From figure 37 and 38 it can be concluded that as wind speed increases, temperature of glass cover will decrease. Referring back to figure 36, productivity of day 1 is low compared to productivity of day 4. Therefore, wind speed will reduce the temperature of glass cover but does not have significant effect on productivity compared to solar radiation. In other words, increasing temperature of water inside basin have more contribution to increase productivity compared to reducing temperature of glass cover.

5. Conclusion

5.1. Experiment conclusion

In conclusion, this project aims to investigate the productivity of solar still with sponge cubes. To evaluate productivity of solar still with sponge, a reference still (solar still without sponge) is used and a production ratio is used to determine the productivity increase.

Because different days were used for experiment, the accuracy of the result is in question. To validate the accuracy of result, a comparison of Day 1 with sponge and Day 4 with sponge is performed to observe the increase in productivity if solar radiation increase. This difference is then compared to the productivity difference between solar still with and without sponge. It is concluded that significant productivity difference is observed between solar still with and without sponge compared to difference in solar radiation. However, this claim requires further clarification by experimenting more days with sponge and without sponge.

With the results obtained it can be concluded that productivity of solar still with sponge cube increases significantly compared to productivity of solar still without sponge cube. The production ratio is calculated to be 3.33 which states that production increase 3 times more if sponge cube is used in double slope solar still.

In addition, effect of ambient condition is also evaluated. The following observation can be made regarding ambient conditions:

- Water temperature is directly proportional to Solar radiation (i.e. increase in solar radiation result in increase in water temperature).
- Glass cover temperature is inversely proportional to Wind speed (i.e. increase in wind speed result in decrease temperature of glass cover).

It can also be concluded that the effect of solar radiation is most significant compared to effect of wind speed. More productivity is observed when solar radiation is increased. There is no significant increase in productivity if temperature of glass cover is reduced (i.e. at high wind speed). Therefore, it is more productive to find ways to increase temperature of feedwater rather than finding ways to reduce temperature of glass cover.

5.2. Experiment challenges

There are few challenges with this project that should be noted. The following points state challenges found during project:

- Different days – It is difficult to compare productivity accurately using different days of experiment.
- Water dripping – The system also shows challenges with water dripping back into the basin from the glass cover.
- Small diameter of trough and connecting tube – This results in taking more time for water to travel from solar still to storage tank. This also result in water dripping back into the basin from trough.
- Measuring Jar – Using a measuring jar to measure productivity for 7 hours is also inconsistent. The solution to this can be using sensors to measure flowrate of distilled water.

It is found that more days is required to further clarify the result of this project. The reason for this is to find productivity of solar still without sponge with lower solar radiation. What was found was difference between solar still with sponge for high and low solar radiation. If the same value is found for the difference between solar still without sponge for high and low solar radiation, it can be concluded that the effect of sponge cubes is significant.

6. Further Work

This project has developed an understanding on the use of sponge cubes to increase productivity of solar still. There are other methods to increase productivity of solar still which can be further investigated (refer to figure 10). Controlling design and operational conditions can increase productivity of solar still. The important key point that is determined from this project is water temperature should be increased, and glass cover temperature should be reduced.

Regarding the current project for double slope solar still at the University of Southern Queensland, the design can be improved in terms of increasing the diameter of the trough and changing the layout of the connection from trough to tube. Instead of connecting it in a horizontal direction, it can be connected vertically to improve flow of water from trough to tube and into storage tank.

The feedwater used for this project is tap water. Further work can evaluate the performance of solar still with sponge using sea water and observe the following:

- Productivity (Saltwater require low energy to evaporate compared to tap water)
- Effect of clogging from salt residue.

Lastly, from the experiment, it is observed that water tend to drip back into the basin from the glass cover. Further work can investigate if increasing inclination of glass cover will increase productivity or not. The research question is: Should the glass cover be perpendicular to solar radiation or can it be increased a bit to allow for easy flow of condensed water from glass cover to trough. This will also have effect of obtaining maximum solar radiation but if productivity is increased significantly it can be considered a possible solution.

7. Reference List

Abu-Hijleh, BAK & Rababa'h, HM 2003, 'Experimental study of a solar still with sponge cubes in basin', Energy Conversion and Management, vol. 44, no. 9, pp. 1411-8.

Ahsan, A, Imteaz, M, Rahman, A, Yusuf, B & Fukuhara, T 2012, 'Design, fabrication and performance analysis of an improved solar still', *Desalination*, vol. 292, pp. 105-12.

Aqua Tech, 2019, 'Does size matter? Meet six of the World's largest Desalination plant,' viewed 30/06/19, https://www.aquatechtrade.com/news/aquatech-news/worlds-largest-desalination-plants/

Arjunan, TV, Aybar, HŞ & Nedunchezhian, N 2009, 'Status of solar desalination in India', *Renewable and Sustainable Energy Reviews*, vol. 13, no. 9, pp. 2408-18.

Arunkumar, T, Jayaprakash, R, Denkenberger, D, Ahsan, A, Okundamiya, MS, kumar, S, Tanaka, H & Aybar, HŞ 2012, 'An experimental study on a hemispherical solar still', *Desalination*, vol. 286, pp. 342-8.

Badran, OO 2007, 'Experimental study of the enhancement parameters on a single slope solar still productivity', *Desalination*, vol. 209, no. 1, pp. 136-43.

Bhattacharyya, A 2013, 'Solar Stills for Desalination of Water in Rural Households', *International Journal of Environment and Sustainability*, vol. 2, pp. 21-30.

Bureau of Meteorology, 2019, 'Monthly mean daily global solar exposure', Australian Government, viewed 3/05/2019,
http://www.bom.gov.au/jsp/ncc/cdio/weatherData/av?p_nccObsCode=203&p_display_type=dataFile&p_startYear=&p_c=&p_stn_num=041553

Kabeel, AE & El-Agouz, SA 2011, 'Review of researches and developments on solar stills', *Desalination*, vol. 276, no. 1, pp. 1-12.

Kalidasa Murugavel, K, Chockalingam, KKSK & Srithar, K 2008, 'An experimental study on single basin double slope simulation solar still with thin layer of water in the basin', *Desalination*, vol. 220, no. 1, pp. 687-93.

Kalogirou, SA 2005, 'Seawater desalination using renewable energy sources', *Progress in Energy and Combustion Science*, vol. 31, no. 3, pp. 242-81. Muftah, AF, Alghoul, MA, Fudholi, A, Abdul-Majeed, MM & Sopian, K 2014, 'Factors affecting basin type solar still productivity: A detailed review', *Renewable and Sustainable Energy Reviews*, vol. 32, pp. 430-47.

Lalitha Narayana, R & Ramachandra Raju, V 2019, 'Experimental investigation of a passive solar still with and without tetrahedral sponge in basin', *International Journal of Ambient Energy*, vol. 40, no. 3, pp. 285-91.

Malaeb, L, Ayoub, GM & Al-Hindi, M 2014, 'The Effect of Cover Geometry on the Productivity of a Modified Solar Still Desalination Unit', *Energy Procedia*, vol. 50, pp. 406-13.

Muftah, AF, Alghoul, MA, Fudholi, A, Abdul-Majeed, MM & Sopian, K 2014, 'Factors affecting basin type solar still productivity: A detailed review', *Renewable and Sustainable Energy Reviews*, vol. 32, pp. 430-47.

Nayar, K. G Sharqawy, M H & Lienhard, J H V 2016, ‘Seawater thermophysical properties library’, viewed 20/07/19, http://web.mit.edu/seawater/2017_MIT_Seawater_Property_Tables_r2a.pdf

Phadatare, MK & Verma, SK 2007, 'Influence of water depth on internal heat and mass transfer in a plastic solar still', *Desalination*, vol. 217, no. 1, pp. 267-75.

Rajamanickam, MR & Ragupathy, A 2012, 'Influence of Water Depth on Internal Heat and Mass Transfer in a Double Slope Solar Still', *Energy Procedia*, vol. 14, pp. 1701-8.

Ranjan, K R & Kaushik, S. C 2016, ‘Economic feasibility evaluation of solar distillation systems based on the equivalent cost of environmental degradation and high-grade energy savings,’ International Journal of Low-Carbon Technologies, Vol. 11, Issue 1, pp. 8-15, https://doi.org/10.1093/ijlct/ctt048

RS component, 2019, ‘Everything you need to know about thermocouple’, viewed 10/07/19, https://au.rs-online.com/web/generalDisplay.html?id=ideas-and-advice/thermocouples-guide

Sellami, MH, Belkis, T, Aliouar, ML, Meddour, SD, Bouguettaia, H & Loudiyi, K 2017, 'Improvement of solar still performance by covering absorber with blackened layers of sponge', *Groundwater for Sustainable Development*, vol. 5, pp. 111-7.

Singh, HN & Tiwari, GN 2004, 'Monthly performance of passive and active solar stills for different Indian climatic conditions', *Desalination*, vol. 168, pp. 145-50.

The World Bank 2017, *Water, water, everywhere, but not a drop to drink: Adapting to life in climate change-hit Kiribati*, viewed 21/04/2019, <http://www.worldbank.org/en/news/feature/2017/03/21/adapting-to-life-in-climate-change-hit-kiribati>.

ThermExcel 2019, ‘Physical characteristic of water (at atmospheric pressure)’, viewed 20/07/19, https://www.thermexcel.com/english/tables/eau_atm.htm

Vishwanath Kumar, P, Kumar, A, Prakash, O & Kaviti, AK 2015, 'Solar stills system design: A review', *Renewable and Sustainable Energy Reviews*, vol. 51, pp. 153-81.

Appendix A

ENG 4111/4112 Research Project

Project Specification

For: Rimeta. Tabwere

Title: Investigating the effect of sponge layout on the productivity of double slope solar still

Major: Mechanical Engineering

Supervisor: Dr. Ahmad Sharifian.

Enrolment: ENG 4112

Project Aim: Make use of local available materials to improve productivity of double slope solar still at low cost. Investigate the productivity of double slope solar still when using sponge cubes and compare with similar solar still without sponge cubes. Compare production ratio with previous literature review.

Programme: Version 4, 5th September 2019.

1. Review background information on desalination, solar still and methods to improve solar still with use of sponge.

2. Develop suitable methods that can be used to improve productivity of solar still desalination system – layout of sponge on the basin.

3. Perform experiment test to analyse the productivity of modified double slope solar still and compare with simple double slope solar still.

4. Analyse the results of experiment and discuss improvement and deficiencies of the modified double slope solar still. Compare with previous literature results productivity with use of sponge cubes.

5. Write up dissertation to show the importance of desalination, the focus community for the project, the improvement methods of solar still and findings from the experiments.

If time allows:

6. Investigate the quality of water produced from the solar still system.
7. Investigate inclination angle of solar still and effect on productivity.

Appendix B

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland Print View

USQ Safety Risk Management System

Version 2.0

Safety Risk Management Plan

Risk Management Plan ID:	Status:	Current User:	Author:	Supervisor:	Approver:
RMP_2019_3679	*Approve*	i:0#.w|usq\u1083415	i:0#.w|usq\u1083415	i:0#.w|usq\sharifia	i:0#.w|usq\sharifia

Assessment Title:	Solar Still Desalination System	Assessment Date:	8/08/2019
Workplace (Division/Faculty/Section):	204070 - School of Mechanical and Electrical Engineering	Review Date:	8/08/2024 (5 years maximum)

Approver: *Ahmad Sharifian-Barforoush*	*Supervisor: (for notification of Risk Assessment only)* *Ahmad Sharifian-Barforoush*

Context

DESCRIPTION:

What is the task/event/purchase/project/procedure?	Tasks involved with the experimental tests of solar stills desalination systems
Why is it being conducted?	For Undergraduate Research Purposes
Where is it being conducted?	Z4 compound close by HES workshop
Course code (if applicable)	ENG4111/4112
Chemical Name (if applicable)	

WHAT ARE THE NOMINAL CONDITIONS?

Personnel involved	Rimeta. Tabwere
Equipment	1 solar still/ 1 power supply/ 1 data logger/ 1 silicone / 1 black paint/sharp tool
Environment	outdoor (Z4 compound)
Other	
Briefly explain the procedure/process	1 solar still (600x800x300mm) to be investigated. The experiment will include solar still without sponge and solar still with sponge (removal of glass cover to make acquire these cases).

Assessment Team - who is conducting the assessment?

Assessor(s):	Rimeta Tabwere/ Ahmad Sharifian-Barforoush
Others consulted: (eg elected health and safety representative, other personnel exposed to risks)	*Mohan Trada/ Brian Aston*

Risk Matrix

Probability	Consequence: Insignificant No Injury 0-$5K	Minor First Aid $5K-$50K	Moderate Med Treatment $50K-$100K	Major Serious Injury $100K-$250K	Catastrophic Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1,000	L	M	H	H	H
Unlikely 1 in 10,000	L	L	M	M	M
Rare 1 in 1,000,000	L	L	L	L	L

Recommended Action Guide

Extreme:	E= Extreme Risk – Task *MUST NOT* proceed
High:	H = High Risk – Special Procedures Required (Contact USQSafe) Approval by VC only
Medium:	M= Medium Risk - A Risk Management Plan/Safe Work Method Statement is required
Low:	L= Low Risk - Manage by routine procedures.

Risk Register and Analysis												
	Step 1	**Step 2**	**Step 2a**	**Step 2b**	**Step 3**			**Step 4**				
	Hazards: From step 1 or more if identified	*The Risk:* What can happen if exposed to the hazard without existing controls in place?	*Consequence:* What is the harm that can be caused by the hazard without existing controls in place?	*Existing Controls:* What are the existing controls that are already in place?	*Risk Assessment:* Consequence x Probability = Risk Level			*Additional Controls:* Enter additional controls if required to reduce the risk level	*Risk assessment with additional controls:* Has the consequence or probability changed?			
					Probability	*Risk Level*	*ALARP*		*Consequence*	*Probability*	*Risk Level*	*ALARP*
	Example											
	Working in temperatures over 35⁰ C	*Heat stress/heat stroke/exhaustion leading to serious personal injury/death*	*catastrophic*	*Regular breaks, chilled water available, loose clothing, fatigue management policy.*	*possible*	*high*	*No*	*temporary shade shelters, essential tasks only, close supervision, buddy system*	*catastrophic*	*unlikely*	*mod*	*Yes*
1	Cutting silico...	Cut injury/laceration	Minor	Wear gloves/ first aid nearby	Unlikel	Low	☑					☐
2	Removing an...	it may fall	Insignificant	two people to carefully handle glass cover when removing and replacing/ wear closed shoes at all times in the compound	Unlikel	Low	☑					☐
3	Working in th...	sunburn/ equipment can be lost if the gates are not locked after use.	Insignificant	wear long sleeves/ always lock the gate after using the compound.	Possibl	Low	☑					☐
4	Trip/Fall	injure self	Minor	Be mindful of the step up when entering the compound (raised floor)	Unlikel	Low	☑					☐
5	Using silicon...	eye damage/ skin irritation	Minor	Wear safety glasses/ use plastic gloves/ wear long sleeves/ wash skin thoroughly after use	Unlikel	Low	☑					☐
6	Using dulux ...	eye damage/ skin irritation	Minor	Wear safety glasses/ avoid skin contact/ wash skin thoroughly after use	Unlikel	Low	☑					☐

Step 5 - Action Plan (for controls not already in place)

	Additional Controls:	*Exclude from Action Plan: (repeated control)*	*Resources:*	*Persons Responsible:*	*Proposed Implementation Date:*

Supporting Attachments

Workshop Activity.docx 15.15 KB

DuraMax_Flat Black (Dulux).pdf 71.79 KB

Metal Shield_Grey (Dulux).pdf 72.75 KB

SIKASEAL ROOF GUTTER MSDS.pdf 115.92 KB

Step 6 – Request Approval

Drafters Name:	*Rimeta. Tabwere*	*Draft Date:*	*8/08/2019*
Drafters Comments:			

Assessment Approval: **All risks are marked as ALARP**

Maximum Residual Risk Level: **Low - Manager/Supervisor Approval Required**

Document Status:	*Approve*

Step 6 – Approval

Approvers Name:	*Ahmad Sharifian-Barforoush*	*Approvers Position Title:*	*Senior lecturer, student's supervisor*
Approvers Comments:	*It is reasonably safe and the same system was used safely by a PhD student*		

I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.

Approval Decision: Approve	*Approve / Reject Date:* *8/08/2019*	*Document Status:* *Approve*