DEVELOPMENT OF A SOLAR DISTILLING ROOFING SYSTEM FOR DRINKING WATER SUPPLY

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Dissertation submitted in partial fulfilment of the requirements for
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Universiti Teknologi PETRONAS,

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
September 2016

CERTIFICATION OF ORIGINALITY

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

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NURULAIN SA'ADAN

ABSTRACT

Lack of clean water in small remote communities in the developing world is a major health problem. Water purification and desalination systems powered by solar energy such as passive solar distillation system are potential solutions to the clean water problems in these small communities. This work investigates the quality of water purified by solar light using roof distillation system to treat the groundwater. Passive solar system has been proposed in previous research by using slanted single or double glass over with the help of solar panel. The existing system collected 4 litres/m^2 of water produced per day. However, the roof distilling system on this research would be different in term of its model. This model will be a cylindrical metal basin that will works depending on the reaction of metal heating from sunlight energy in order to have the evaporation process for water purification. There will be no additional source as solar panel involve in this system. The collected purified water will be tested under conductivity test, pH value test, and suspended solid test accordingly to ensure the quality of it meet the hygienic water standard for usage.

ACKNOWLEDGEMENTS

"In the name of Allah, The Most Gracious and The Most Merciful"

All praise and thanks are to Almighty Allah, the creator of all worlds for providing me the courage and perseverance to complete this work successfully. May there be every peace and blessings upon the holy prophet Muhammad (PBUH), his family and his companions.

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CHAPTER 1

INTRODUCTION

1.1 Background Of Study

Solar distillation technology has been changed and improved by the engineers since the first solar distillation was developed in 1872 by Carlos Wilson, the creator of the first modern sun-powered desalination plant. Solar distillation simply means using solar distillation to purify the salt water or the brackish water. The system works by heating the water till the evaporation point where water vapor will be formed and condensed on the surface of the glass and collected to the distillate tank. The fact that driven the inventors to the development of the solar distillation on the first place is due to the small amount of clean, pure water on the earth's surface. As we know, 70% on the earth's surface is covered with water which only less than 1% of water is considered clean and safe to be used by mankind. Taking account about 97% percent of the remaining is salt water; the desalination technology has been considered to be the most effective way to tackle the problem as the desalination process uses renewable solar energy that comes from the sun. Since the solar technology has been improved and varied for decades by several researchers, this project aims to evaluate all of the designs proposed by the researchers to result in with one ideal design composed of all the good aspects in each design.

1.2 Problem Statement

In the twenty-first century, water availability remains a challenging job for people in all parts of the developed or developing world. Water is the most important essential to all living organisms on Earth. People have to rely on rivers, lakes, ponds, sea and ground water. The industrial sewage water cause polluted lakes, rivers, sea and indirectly causing shortages of clean water. Studies show that about 79% of the water on Earth is salty only one percent is fresh and the rest 20% is brackish [1]. Extensive details about the distribution of water on earth as seawater and fresh water in the percentage of 96.54% and 2.53% respectively [2], and only 0.36% from 2.53% freshwater directly available to humans [3]. Lack of drinking water is one of the main problems faced by the entire world, especially in arid rural areas together with concerns now growing energy crisis, global warming and climate change. Approximately 70% of the earth's surface is covered by water, but 97% are salty water, only 0.62% of the water is in a form that can traditionally be treated for human consumption. Since the last century, the sources of drinking water from both surface water and groundwater have been decreasing due to the increase in world population resulting more pollution, exploitation of the resources. Increased levels of salinity because of rainwater and poor management of the water sources [4], [5] and [6]. A study on water deficit estimate that from about 7 billion people living on Earth, 400 million people now live in areas where there is a shortage of drinking water, and this number may grow to four billion by mid-century [7]. The year "2003" has been declared as the "United Nations International Year of Fresh Water" by the United Nations, in order to upgrade and resolve issues related to water. Fresh drinking water demand increased by six-fold in relation to three-fold increase in world population. It is common knowledge about the fact that 80% of disease in the world and 50% of total infant mortality is directly related to the shortage of clean water quality [8] and [9].

1.3 Objectives and Scope of Study

The objectives of conducting this research are to:

i. To analyze the water quality produced from solar distilling roofing system according to hygienic water standard.
ii. To compare the water production between metal cylindrical distillation system and glass cover basin distillation system.

The parameters that will be involved in the research are:

i. Sun radiation existing data.
ii. Solar measurement during experiment day.
iii. Water quality including conductivity test, pH value test and turbidity test.

CHAPTER 2 : LITERATURE REVIEW

2.1 Desalination

Desalination technology is not new in the world. Conventional desalination process based on distillation and involve a phase change is multiple flash (MSF), multiple effect distillation (MED) and vapor compression distillation (VC). In contrast, membrane processes such as reverse osmosis (RO) and electro-dialysis (ED) does not involve a phase change. This desalination technology is already established but it consumes high energy from fossil fuels. MSF and RO processes are widely used in the world: 44% and 42% of the world's desalination applications, respectively. Among all this process, the RO has the lowest energy consumption [10]. More than 90% of the plants installed worldwide for seawater desalination is based on the distillation process. One of the main advantages of the distillation process is that it requires heat only up to 120 o C that can be supplied from solar energy or other renewable energy sources [11]. Among them, MSF, MED and RO are commercially used on a large scale in cities and always have a high efficiency based on the use of electric power. However, this technology is not suitable for remote villages, arid areas and small islands [12]. To meet this requirement by using solar energy for water decontamination of brackish or salt water is really a blessing for all Humankinds as simple technology, not the will of highly skilled labor for maintenance and low energy consumption. The first application ever known solar still is in 1872 in Las Salinas in the desert of northern Chile which began its operation three decades ago to provide potable water for animals used in mining nitrate [13]. Since centuries distillation technology has been used in land-based plants and on board of ships to provide water for the crew. After World War II, the use of distillation technology accelerated as the demand for fresh water in arid countries increased [14]. The cost of solar stills for distillation decreased rapidly especially in recent years with the introduction of cost-effective technologies and more efficient. Brackish water desalination costs by passive solar still is $ 0.014 / volume (m3) for a 30-year life of the system [15].

2.2 Existing Design

Solar water distillation concept is actually a natural phenomenon which happened from the beginning of time. The solar radiation from the sun evaporates water from the sea and lakes, condense it as a clouds and return to the earth as rainwater. Basin-type solar still replicate these concepts in a small scale and are the most common type of still system used for water distillation. The water in the basin will evaporates when the absorber plate absorbs adequate amount of solar radiation that can initiate the evaporation process to occur. When the water turns into water vapor, it will condense on the inner surface of the tilted cover glass and straight into the distillate tank. The waste water or what they usually called as brine will be drained out through the drain point. The advantage of this design is the fabricating and manufacturing cost is low when compared to other methods. When considering the cost and amount of productivity by the basin-type solar still, this type is not cost-effective due to the lower distillate being produce for each interval. Comparing basin-type solar still with basin-type solar wick still, the present of wick on the surface of the plate clearly affects the amount of distillate water being produced at the end of the day. Plus with the ability of the wick to be tilted according to the position of the sun also the strong point on why a basin-type wick still is much preferable rather than the basin-type solar still.

The sun radiates energy uniformly in all directions in the form of electromagnetic waves. The temperature increases when it is absorbed by the body. It is clean, inexhaustible, many of which are universal and renewable energy. Solar energy has the potential of all renewable energy sources, and if only a few of these forms of energy can be used, it will be one of the most important supply of energy, especially when other sources in the country have decreased [16].

Solar water distillation is not a new process, but it does not get the attention it deserves. Perhaps this is because it is low-tech although it is a flexible solution to the waterproblem.

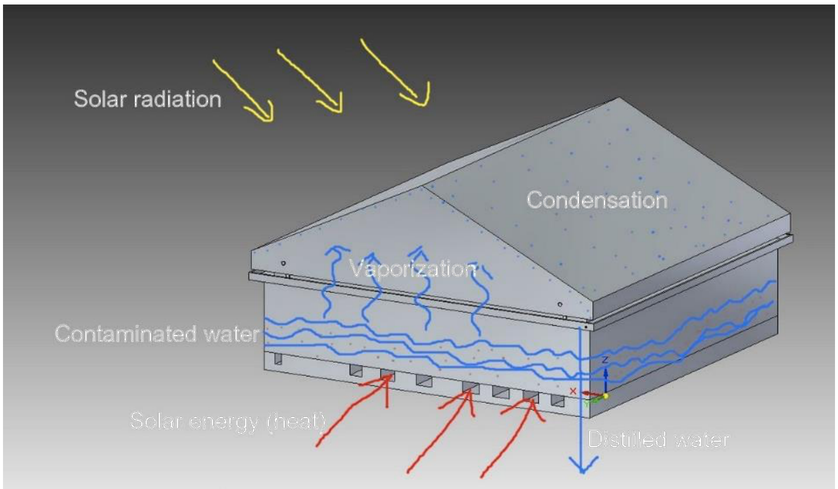


Figure 1 The slanted distilling roofing system

In solar distillation process, water is poured into the still partially filling the basin. The cover glass allows solar radiation to enter the still, which is mostly absorbed by the black base [17]. The inner surface of the material is blackened to increase absorption of sunlight. Water starts to heat and moisture content of the air trapped between the water surface and the cover glass increases. Steam from the heated water inside the basin evaporates and condenses on the inside of the glass cover [18].

In this process, salt and microbe origin in the water are left behind. Condensed water dripping down the sloping glass cover to a collection trough an interior channel comes from the distillation unit into a storage bottle. Feed water must be added each day that exceeding the gross production of distillates to give a proper flushing water basin and to clean excess salts left behind during the evaporation process. If a still produces 3 liters of water, 9 liters of make-up water must be added, of which 6 liters is left to clean the pumping basin [19].

With that, Hikmet S. Aybar has conducted an experiment to determine the amount of the distillate water being produced by varying the type of plate being used where the evaporation of water takes place [35]. The experiment was conducted under actual environment conditions of northern Cyprus and contrasting with the usual solar still design, the water will flow down the absorber plate and undergo evaporation at the same time instead of being left inside the basin and evaporate. It is assumed that the longer the water flow on the surface of the plate, the higher the productivity of the distillate water. Other than producing distillate water, the waste water or the brine will be use as a hot water if it is not too briny. All of the equipment that came in contact with water will be made from stainless steel in order to avoid corrosion to occur. The experiment used three different types of plate which is the first one is a bare plate which made of from galvanized steel and painted to form a matt black surface. The matt black surface is to ensure a maximum absorption of solar radiation by the plate (absorptivity of 0.96 and emissivity of 0.08) thus increasing the rate of evaporation by the water. The second type is by using black-cloth wick layered on top of the absorber plate. As what the author proposed, the black-cloth will act as a porous medium which is layered on top of the bare plate to ensure an even distribution of water on top of the absorber plate which in turn will increase the rate of production of the distillate when more surface area of the plate is covered with water. The amount of water on the surface of the plate can be easily control when using the black-cloth wick other than reducing the amount of solar radiation being reflected away rather than being absorb. The third type is by using a black fleece as the wick with approximately 2 cm long fur. The function of the black fleece is quite the same with the black cloth which only to increase the flowing-down time of the water from the top to the bottom of the plate and a larger heat transfer area. The plate was tilted for about 30o to allow the condensed distillate water and feed water to run down the glass cover and the plate straight into the collecting tanks. This method also to ensure the solar radiation can reach the surface of the water more frequently during the day. The experiment was repeated for four times and each time is from 9:00 am to 4:00 pm (7 hours) through 17th to 30th of May 2004. From the results, it is clearly stated that by using the wick, the productivity of the distillate increase for about two to three times when compared with bare plate. This is due to the low flowing-down time by the bare plate that reduced the rate of evaporation of the water and also the distribution of the water on top of the bare plate is not even because of the plate deformation because of its increasing temperature. Based on the theoretical and experimental result, wick type is the leading and most prefer economic option for the distillation process [36].

On the other study done by A. S. Nafey, the presence of surfactants additives can possibly enhance the boiling heat transfer of the water [37]. The surfactants usually used to change the surface properties of the water such as reducing the surface tension of the water, the skin friction in the tubes and the boiling heat transfer of the water. An experiment has been conducted to test the effects of surfactants towards the productivity of the distillate where different concentration of surfactant was used. An A.C. electric heater was used as the replacement for the solar flux used in the actual solar collector and the input power for the A.C. electric heater is controlled by the variac transformer in the range of 0 – 2000W. The power input will be set to one value once the actual condition of the surrounding being determined. It has been found that the productivity of the system during summer is around 4.18 – 7.00 kg/day/m2 while during winter is from the range of 1.04 – 1.46 kg/day/m2. It showed that during summer, the productivity of the system is 80% more than during winter. Hence, the experiment will be set based on the summer operating system together with the environmental data (solar radiation) by setting the variac transformer to quantify higher system daily productivity. The productivity of the system increase with respect to the concentration but started to decrease when the concentration reached 500ppm. The maximum concentration that can be used to increase the productivity up to 7% from the original value is only until the range of 300 – 400 ppm only. The productivity drastically decreased for about 6% when it reached 500 ppm. This is due to the formation of foam when the concentration reached 500 ppm.

2.3 Water Evaporation Rate

The evaporation coefficient of water has been the subject of many theoretical and experimental papers and is still an area of dispute. Part of the reason for this intense interest is the fact that some liquids, water included, appear to evaporate at a rate far less than the theoretical rate calculated using Knudsen's equation. This theoretical maximum value is [20]

$$= \frac{\quad}{(2 \qquad)^{\frac{1}{2}}}$$

or, if the liquid is evaporation into its own vapor.

$$= \frac{\qquad}{(2 \quad)^{\frac{1}{2}}} \left[\frac{\qquad}{\sqrt{\quad}} - \frac{\qquad}{\sqrt{\quad}} \right]$$

A conclusive explanation for the experimental departure from the Knudsen rate does not exist, although various hypotheses have been made [21-28].

These theories offer numerous explanations for the contrasting values of evaporation coefficient and include inaccurate temperature and pressure measurement, disregard of molecular collisions and chemical impurity. An important consideration is the possible effects of polarity and molecular orientation on evaporation coefficients. The theories discussing these effects [23, 24, 26], which have been derived by chemists, have agreed with empirical results of Alty [29,30], Alty and MacKay [31] and Wyllie [28], yielding c values of 0.01 0.05. However, empirical results published more recently [32, 34] indicate an evaporation coefficient for water greater than 0.5, thus contradicting the chemistry hypotheses. This led Hickman [22] to state that, "'correcting for bonding and rotational effects has already been compensated for in the vapor pressure values and these same forces should not be invoked to explain low values of Ɛ.

Table 2.1: Overview of the previous studies

Type of Design	**Year**	**Location**	**Name**	**Background**	**Result**
	2008	New Delhi, India	G.N Tiwari	Centre of Energy Studies, Indian Institute of Technology	Studies show that about 79% of the water on Earth is salty only one percent is fresh and the rest 20% is brackish
Cascade Stills with weir	2013	Iran	Fatemeh Bakhtiari Ziabari, Ashkan Zolfaghari Sharak, Hamid Moghadam, Farshad Farshchi Tabrizi	Department of Chemical and Petroleum Engineering, Sharif University of Technology, Tehran, Iran. Department of Chemical Engineering, University of Sistan and Baluchestan, Zahedan, Iran.	The average fresh water production for the modified cascade solar still is around 6.7 lit/day m2, which shows 26% increase in compare to the initial site's units.
	2013	China	Gao CJ, Chen GH.	Chemical Industry Press, China.	The distribution of water on earth as seawater and fresh water in the percentage of 96.54% and 2.53% respectively.

Solar thermal utilization	2009	China	He ZN	China: Press of University of Science and Technology of China	0.36% from 2.53% freshwater directly available to humans productivity of 4.18 – 7.00 kg/day/m2.
	1976	New Delhi, India	Garg HP, Mann HS.	Centre of Energy Studies, Indian Institute of Technology	MSF, MED and RO are commercially used on a large scale in cities and always have a high efficiency based on the use of electric power
Solar Still	1984	New Delhi, India	A.E. Kabeel, S.A. El-Agouz	Centre of Energy Studies, Indian Institute of Technology	The use of distillation technology accelerated as the demand for fresh water in arid countries increased.
Renewable Sustainability Energy	2011	New Delhi, India	V. Velmurugan, K. Srithar		Feed water must be added each day that exceeding the gross production of distillates to give a proper flushing water basin and to clean excess salts left behind during the

					evaporation process
	1950	London	Knudsen, M	The Kinetic Theory of Gases	The reason for intense interest is the fact that some liquids, water included, appear to evaporate at a rate far less than the theoretical rate calculated using Knudsen's equation
		London	Burrows. G	Journal of Applied Chemisty	Correcting for bonding and rotational effects has already been compensated for in the vapor pressure values and these same forces should not be invoked to explain low values of Ɛ.

Table 2.2: Advantage(s) and disadvantage(s) of the design

Design	Advantage(s)	Disadvantage(s)
Basin Still (single slope)	- Has less convection and radiation loss. - gives better performance in cold climate.	- Low absorption of radiation. - Need repositioning when the position of the sun changing.
Basin Still (double slope)	- Able to absorb maximum amount of radiation. - Better performance in summer climatic condition. - No need repositioning of the still.	- More convection and radiation loss.
Black-cloth Wick	- Increase radiation absorption. - lengthen the water flowing down time. - No dry spot on the absorber plate.	- Can be easily contaminate and difficult to service.
Black-fleece Wick	- Increase radiation absorption. - Lengthen the water flowing down time. - No dry spot on the absorber plate. - Better performance than black cloth.	- Can be easily contaminate and difficult to service.

Cover Cooling	- Increase the temperature difference between the glass cover and absorber plate, thus increase rate of evaporation.	- Need to regularly clean the inner cover from the contaminants from cooling water. - More reflection loss takes place.
Surfactant Additives	- Enhance the boiling heat transfer of the water.	- Only limited till 300ppm, beyond that the productivity will drastically drop.
Multi-wick	- Excess vapor can be condensed on the additional glass cover and reduce the heat load on the glass cover, hence increase temperature difference. - Better performance than single wick. - Less maintenance	- Large heat flux and large heat loss from the absorber plate to ambient.
Floating-Wick	- There will be no dry spots on the wick surface, thus increase the amount of distillate being produce.	- Difficulty to control salt accumulation on the wick surface.
Charcoal Particle	- Good absorbent of heat. - Porous medium which can enhance evaporation of water due to even distribution	- Charcoal cannot be reuse once contaminate with salts or impurity.

	of water.	
Packed Layer	- Good absorbent of thermal energy which can be reuse for evaporation process in the absence of the sun.	- Glass ball need to be regularly cleaned to ensure maximum absorption of thermal energy.
Combined Wick-Basin	- Brine undergoes evaporation twice, starts from the wick and lastly basin. - Better efficiency than basin and wick type.	
Cascade Still with weir	- Increase the residence time of the water. - Encourage force flow of water, thus avoid dry spot	
Stepped Still with Cotton Black Absorber	- Even distribution of water on top of the step.	- Difficulty in doing maintenance for the cotton black absorber

CHAPTER 3

METHODOLOGY

In completing Final Year Project, some approaches are followed in order to ensure this project is successful. After finalizing the project title Development of a Solar Distilling Roofing System For Drinking Water Supply, next is to identify and clarify the problems that are related to the project.

In order to solve the identified problems, a comprehensive engineering studies related to solar energy, process of water, and the quality of drinking water has been conducted. Preparing literature review based on reading materials as journal, books and research papers. From the information gathered through various kinds of sources, a conceptual design was proposed as a solution to the problems. Further research about the proposed solution was carried out and the design for the prototype was constructed.

3.1. Project Progression

The first step is by doing research and prepare a varieties of literature review on the past works by other people. Literature review needs to cover up all aspects in term of the type of stills that have been used by these people, the surrounding condition with respects to the productivity yield by the design, the type of additives to encourage the rate evaporation of the water and the hybrid between all the good aspects of any available designs. A tabulation of the criteria and advantages or disadvantage offered by all of the design has been done to ease the selection of the design. From this table, all of the good aspects can be simply determine and combined to come out with several conceptual designs that will be evaluate later. These conceptual designs need to have the advantage and other good aspects from various type of design by the past works and at the same time minimizing the disadvantage of the previous design. A simple improvement on the previous work also can be considered as a new conceptual design. All of these conceptual designs need to be drawn and the functionality have to go through for of each design and the advantage offered.

Later after the, all of these designs will be tabulated and evaluated according to the attributes such as the cost, the productivity, the availability, the serviceability and the life expectancy. Cost is mainly about the cost of fabricating the product, the productivity is the rate of the distillate being produce with respect to time, the serviceability is the complexity of the equipment when the service and maintenance work need to be done and the life expectancy is the life span of the design before it fail to produce and working smoothly. From all of this attributes, each design will be rated from the lowest, 1 to the highest which is 10. The total scores of the conceptual design will determine which conceptual design that will be used as the ideal design to create an efficient solar water distillation system. The evaluation of the design need to be tally with what have been done inside the literature review and need to prove with scientific theory and governing equation.

Designs that possess the highest score among the conceptual design will be choose as the final selected design and simulated inside specific software. The final governing equation need to be determined before proceeding with the experiment to make sure all the calculation is correct. An experimentation result will be obtained by conducting an experiment in order to validate the simulation result that previously been done. The simulation and experimentation result will be compare once both are done and some recommendation for the future improvements for the design will be suggested at the end of the report. A more detail and sequential view of the whole activities can be referred in the Gantt chart (Appendix 1). The process flow of the whole project can be refer to the flow of activities in Figure 3.1.

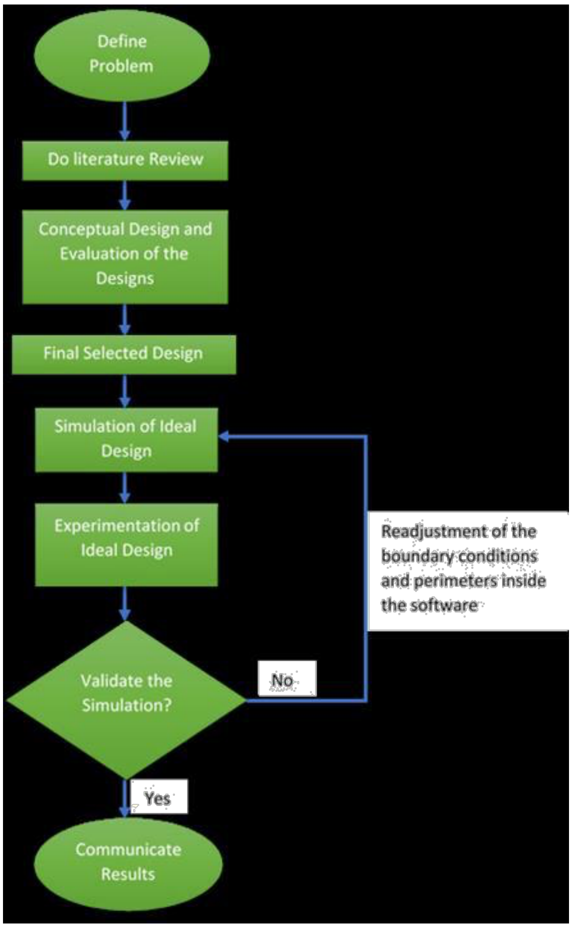


Figure 3.1: Flowchart of activities

3.2. Key Milestone

3.2.1 Final Selected Design

Final selected design came right after the evaluation of all the conceptual designs. The evaluation of the designs will be based on certain criteria or attributes that can contribute on increasing the efficiency of the solar still. By completing this final selected design only the project can be continue for the simulation or experimentation process later after that.

3.2.2 Complete Experimentation Using Prototype

The experimentation process will be done after the simulation is complete or may also can be done during the simulation process take place. The experimentation will only be conducted on the completed prototype of the design in order to determine the actual result from the actual condition of the environment. The experimentation need to be complete in order to validate the simulation result later.

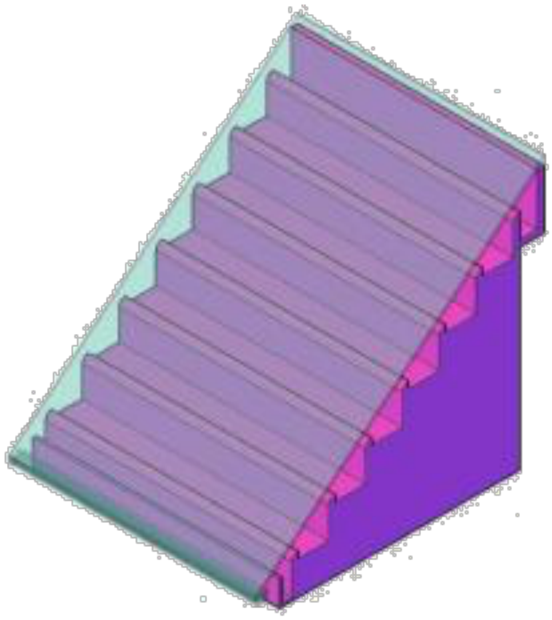
3.2.3 Complete Comparison of Experiment Result and Previous Studies

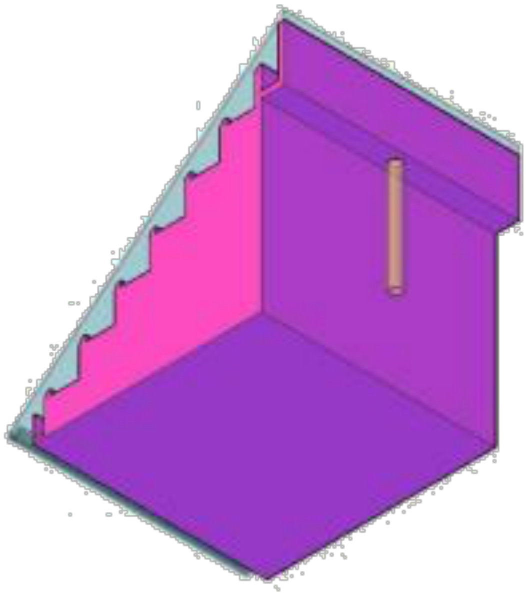
The completion of the comparison of the simulation result and the experimentation result will validate the simulation result. The experimentation result will be used to check the accuracy of the simulation result being conducted earlier. A good simulation will enable the project to be upscale in the future

3.3 Conceptual Design

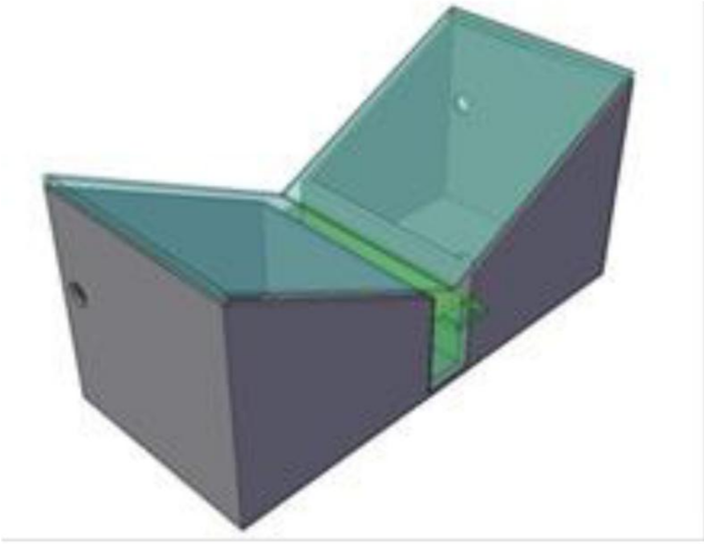
Conceptual design is the first step in determining what type of concepts or designs that shall be used upon conducting further experiment and analyzing on the final selected design. The conceptual designs will comprise of all the plusses from the literature survey that have been conducted, combined together to form a new design that can possible yield a higher efficiency from the previous design. The following are the list of conceptual designs for the project before the final selected design being chosen.

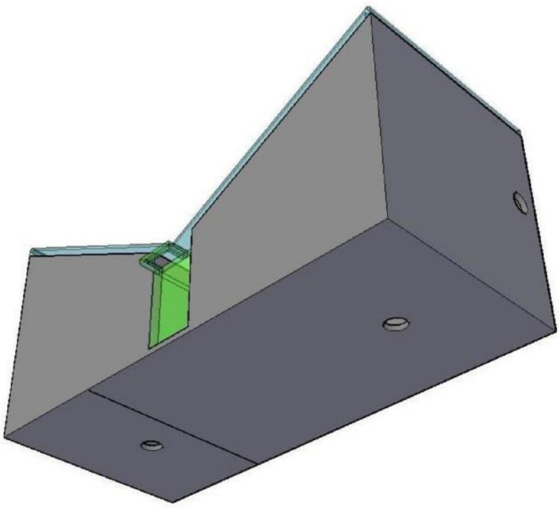
Design 1 – Single Slope of Glass Basin



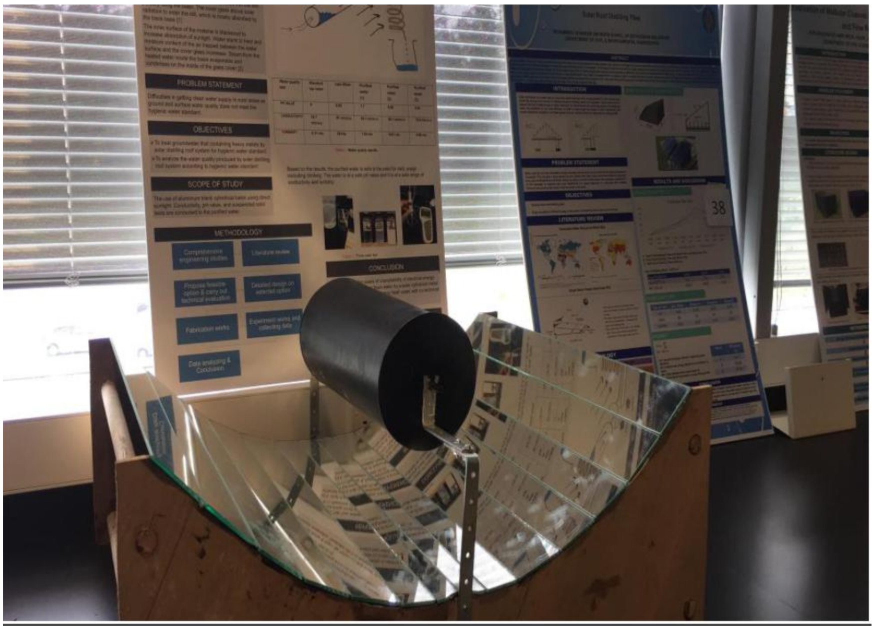


Design 2 – Double Slope of Glass Basin





Design 3 – Cylindrical Metal Water Tank



3.4 Final Selected Design

The final selected design will be selected from the previous conceptual designs by thoroughly considering all the major factors that contribute in increasing the amount of distillate being produce with respects of time. A decision matrix has been done to compute all of the designs together with the all the factors to assist on deciding and selected the final design to be used.

Design Criteria	**Unit**	**Weight Factor**	**Single Slope Glass Basin**		**Double Slope Glass Basin**		**Cylindrical Metal Tank**	
			Rank	**Score**	**Rank**	**Score**	**Rank**	**Score**
Total Area Expose	m2	4	1	4	3	16	1	12
Fabrication Complexity	n/a	2	3	8	3	8	1	4
Fabrication Cost	RM (MYR)	3	3	12	3	12	3	12
Operating Cost	RM (MYR)	3	2	9	1	6	1	6
Maintenance	n/a	2	1	4	3	8	3	8
Volume Flow Rate	l/s	3	2	9	2	9	2	9
Absorptivity	W/m2	4	3	16	2	12	3	16
Residence Time	s	4	3	16	1	8	3	16
		Raw Score	78		79		83	
		Relative Weight	24.92		25.24		26.52	
		Rank Order	3		2		1	

Figure 3.6: Decision Matrix

From the decision matrix in Figure 3.6, cylindrical metal tank has been selected as the final selected design as it has found to accumulate the highest score than other type of still. The isometric diagram for the final selected design is as follow.

3.5 Design Description

The experimental setup for the experiment will be based on the cylindrical shape tank in Figure 3.7. The bottom flat has an area of 140 x 300 mm2 and followed by the first step with a height of 140 mm. There is one hole at each ending representing inlet and outlet of the water tank. Inlet and outlet each have a diameter of approximately 80mm wide. Water to be treated will be put to the inlet and meet some of the water tank approximately 30% of volume capacity for effective evaporation process. As can be seen, metal cylindrical water tank was painted with black paint to increase the temperature of the solar energy absorption. High temperatures helps to speed up the water heating tank and the temperature in the water tank and also the process of evaporation inside the tank. Evaporation process is a process that involves the conversion of water into steam.

At the process of evaporation, vapor pressure inside the metal cylindrical tank is very high this causes the pressure was pushed out into the copper tube wrapped with a rubber tube on the water tank outlet. The condensation will occur inside the copper tube in which steam is converted to fresh water droplets and flows into the conical flask connected with a copper tube with a good seal. It is very crucial to really make a good seal in order to minimize the vapor pressure to escape from the surrounding area. This is because if the vapor pressure escape, the whole process of water production will get affected.

At first, this research only requires metal cylindrical tank and copper tube for water collection. But considering the experiment conducted during rainy season where we have a limited source sunlight in a day, parabolic mirror has been installed to help in enhancing the reflection of sunlight on the metal cylindrical tank with a limited time of getting sunlight during the experiment being conducted. There are a total of 14 pieces of mirrors with a different width to form a parabolic shape. Parabolic behavior is understood to give reflection from sunlight in all angles.

3.6 Experimental Procedure

Conductivity Test

Total dissolved solids (TDS) is defined as the quantity of dissolved material in water, and depends mainly on the solubility of rocks and soils the water contacts. For instance, water that flows through limestone and gypsum dissolves calcium, carbonate, and sulphate, resulting in high levels of total dissolved solids. A convenient way to measure TDS is to test the conductivity of the sample. Conductivity is a measure of the ability of water to pass an electrical current and is affected by the presence of dissolved solids. As the level of TDS rises, the conductivity will also increase. Discharges to water can change the conductivity depending on the discharge. A failing sewage system could raise the conductivity because of the presence of chloride, phosphate, and nitrate; an oil spill would lower the conductivity because oil does not conduct electrical current very well. Conductivity is measured in micromhos per centimeter (mhos/cm) or microsiemens per centimeter (s/cm), equivalent units of measure that can be used interchangeably. Distilled water has conductivity in the range of 0.5 to 3 mhos/cm. The conductivity of rivers in the United States generally ranges from 50 to 1500 mhos/cm.

Conductivity Test Procedures :

Step 1 Rinse the sample beaker and the meter twice with the water.

Step 2 Collect the sample. · Swirl the meter in the sample five times. · Check the bottom of the meter to be sure there are no air bubbles trapped. · If there are air bubbles, tap the bottom of the meter against the side of the beaker until the bubbles float up.

Step 3 Turn on the meter now and wait 1 ½ minutes and read and record the display on the meter. · Be sure the meter is at least one centimeter above the bottom of the beaker during the 1-½ minutes. · Also be sure that the sample and the meter are out of direct sunlight or wind.

Step 4 Record the reading.

pH Value Test

The definition of pH is that it is a measure of the activity of hydrogen ion (H+) and is reported as the reciprocal of the logarithm of the hydrogen ion activity. Therefore, a water pH of 7 has 10-7 moles per liter of hydrogen ions, whereas a pH of 6 is 10-6 moles per liter. The pH scale ranges from 0-14.

In general, a water with a pH < 7 is considered acidic and with a pH > 7 is considered basic. The normal range for pH in surface water systems is 6.5 to 8.5 and for groundwater systems 6 to 8.5. Alkalinity is a measure of the capacity of the water to resists a change in pH that would tend to make the water more acidic.

The pH of pure water (H20) is 7 at 25 ^{O} C, but when exposed to the carbon dioxide in the atmosphere this equilibrium results in a pH of approximately 5.2. Because of the association of pH with atmospheric gasses and temperature, it is strongly recommended that the water be tested as soon as possible. The pH of the water is not a measure of the strength of the acidic or basic solution and alone does not provide a full picture of the characteristics or limitations with the water supply.

In general, water with a low pH (< 6.5) could be acidic, soft, and corrosive. Therefore, the water could leach metal ions such as iron, manganese, copper, lead, and zinc from the aquifer, plumbing fixtures, and piping. Therefore, water with a low pH could contain elevated levels of toxic metals, cause premature damage to metal piping, and have associated aesthetic problems such as a metallic or sour taste, staining of laundry, and the characteristic "blue-green" staining of sinks and drains. The primary way to treat the problem of low pH water is with the use of a neutralizer. The neutralizer feeds a solution into the water to prevent the water from reacting with the house plumbing or contributing to electrolytic corrosion. A typical neutralizing chemical is soda ash. Neutralizing with soda ash increases the sodium content of the water.

pH Value Test Procedure :

Step **1** **Stir the water sample vigorously using a clean glass stirring rod.**

Step 2 **Pour a 40 mL ± 5 mL sample into the glass beaker using the watch glass for a cover.**

Step 3 **Let the sample stand for a minimum of one hour to allow the temperature to stabilize, stirring it occasionally while waiting. Measure the temperature of the sample and adjust the temperature controller of the pH meter to that of the sample temperature. This adjustment should be done just prior to testing. EB 15-025 Page 4 of 5 On meters with an automatic temperature control, follow the manufacturer's instructions.**

Step 4 **Standardize the pH meter by means of the standard solutions provided. Temperature and adjustments must be performed as stated under 3A.3.**

Step 5 **Immerse the electrode(s) of the pH meter into the water sample and turn the beaker slightly to obtain good contact between the water and the electrode(s).**

Step 6 **The electrode(s) require immersion 30 seconds or longer in the sample before reading to allow the meter to stabilize. If the meter has an auto read system, it will automatically signal when stabilized.**

Step 7 **Read and record the pH value to the nearest tenth of a whole number. If the pH meter reads to the hundredth place, a round off rule will apply as follows: If the hundredth place digit is less than 5, leave the tenth place digit as is. If it is greater than 5, round the tenth place digit up one unit. If the hundredth place digit equals 5, round the tenth place digit to the nearest even number.**

Step 8 **Rinse the electrode(s) well with distilled water, then dab lightly with tissues to remove any film formed on the electrode(s). Caution: Do**

not wipe the electrodes, as this may result in polarization of the electrode and consequent slow response.

<u>Turbidity Test</u>

The definition of Turbidity is the cloudiness or haziness of a fluid caused by suspended solids that are usually invisible to the naked eye. The measurement of Turbidity is an important test when trying to determine the quality of water. It is an aggregate optical property of the water and does not identify individual substances; it just says something is there. Water almost always contains suspended solids that consist of many different particles of varying sizes. Some of the particles are large enough and heavy enough to eventually settle to the bottom of a container if a sample is left standing.

Turbidity Test Procedure :

Step 1 **Gravimetric analysis is used to determine total suspended solids (TSS) and total volatile solids (TVS), also known as volatile suspended solids (VSS) using a four place analytical balance.**

Step 2 **Method Detection Limit (MDL) of 2.4 mg TSS/L and 0.9 mg TVS/L were determined using the Student's t value (3.14) times the standard deviation of seven replicates. If more than seven replicates are used to determine the MDL, refer to the Student's t test table for the appropriate n-1 value.**

Step 3 **The quantitation limit for TSS was set at 0.0005 mg/L TSS.**

Step 4 **This procedure should be used by analysts experienced in the theory and application of TSS. 1 month experience with an experienced analyst, certified in the analysis using the four place balance, is required.**

Step 5 **This method can be used for all programs that require analysis of total suspended and volatile solid.**

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents and compare the results obtained from the experiments by using metal cylindrical water tank and from previous studies using glass cover basin. The productivity in term of fresh water production by the solar still during the experiments is tabulated and plotted into graph. The results from the previous research by using the glass cover basin.

4.1 Results

Table 4.1: Predicted results from glass cover basin

Position	Temperature of Glass Cover Basin, Tg (^{0}C)	Fresh Water Production Rate (kg/m2.hr)
1	30.20	0.45
2	32.80	0.48
3	33.00	0.46
4	33.20	0.47
5	33.50	0.47
6	33.90	0.51
7	34.50	0.44
8	34.60	0.40
9	34.90	0.37

Table 4.2: Experimental observation for day 1 of experiment

Time (hour)	Temperature of Cylindrical Tank, Tg (^{0}C)	Fresh Water Production Per Hour (mL/hr)
0900	26.50	0
1000	27.60	15
1100	27.90	20
1200	28.80	24
1300	29.50	27
1400	32.70	30
1500	34.20	33

Figure 4.2: Graph of observation for day 1 of experiment

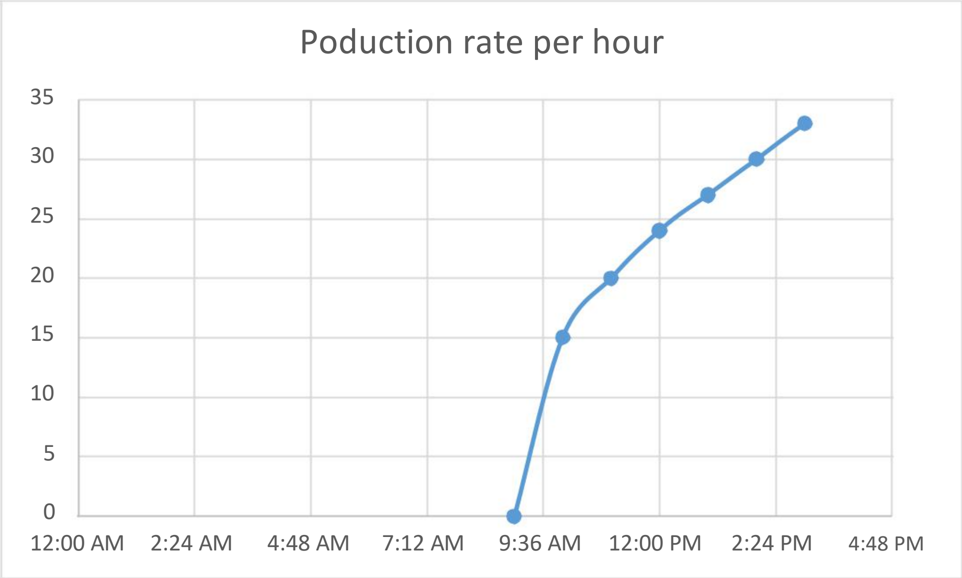


Table 4.3: Experimental observation for day 2 of experiment

Time (hour)	Temperature of Cylindrical Tank, Tg (^{o}C)	Fresh Water Production Per Hour (mL/hr)
0900	25.40	0
1000	29.10	10
1100	31.50	12
1200	33.60	23
1300	34.80	30
1400	32.90	26
1500	32.20	20

Figure 4.3: Graph of observation for day 2 of experiment

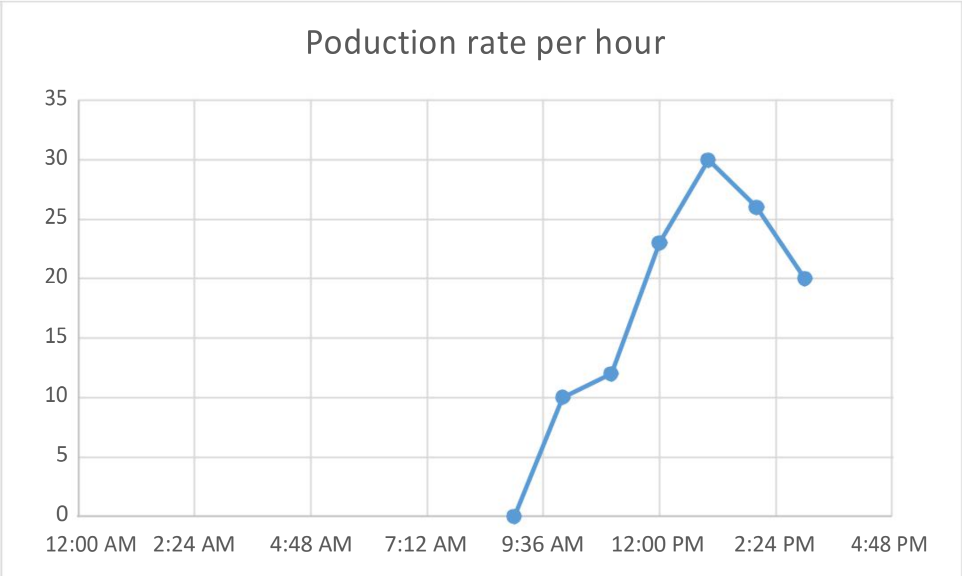


Table 4.4: Experimental observation for day 3 of experiment

Time (hour)	Temperature of Cylindrical Tank, Tg (^oC)	Fresh Water Production Per Hour (mL/hr)
0900	28.50	0
1000	29.40	16
1100	31.60	27
1200	33.80	30
1300	36.30	36
1400	36.80	37
1500	37.40	42

Figure 4.4: Graph of observation for day 3 of experiment

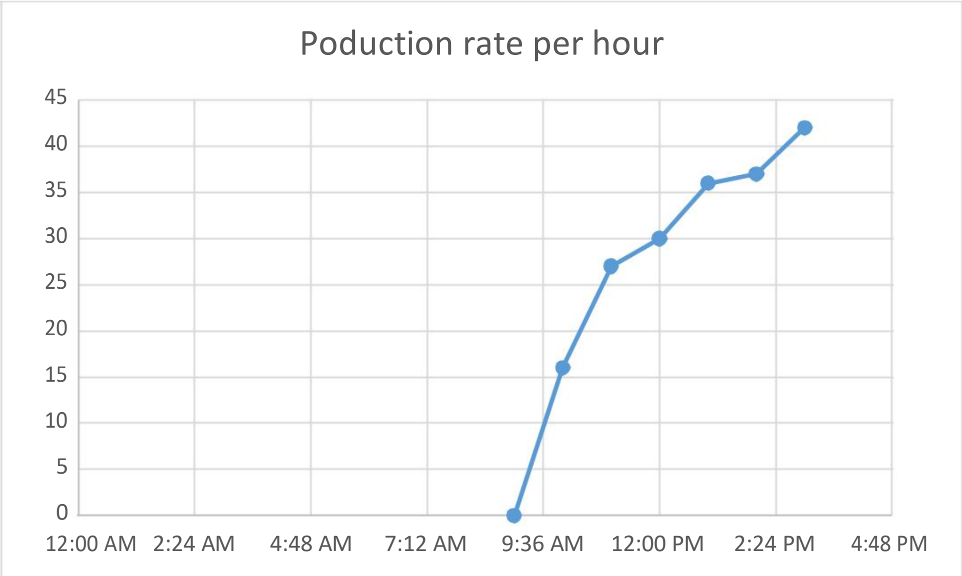


Table 4.5: Experimental observation for day 4 of experiment

Time (hour)	Temperature of Cylindrical Tank, Tg (^oC)	Fresh Water Production Per Hour (mL/hr)
0900	28.50	0
1000	29.60	18
1100	32.30	29
1200	34.80	30
1300	37.50	45
1400	37.70	45
1500	38.30	48

Figure 4.1: Graph of observation for day 4 of experiment

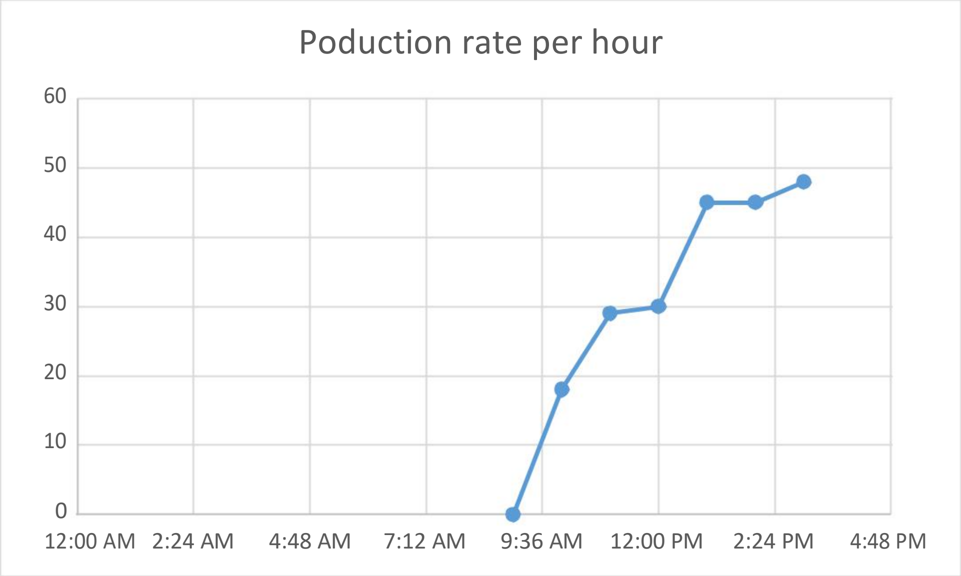


Table 4.6: Experimental observation for day 5 of experiment

Time (hour)	Temperature of Cylindrical Tank, Tg (^0C)	Fresh Water Production Per Hour (mL/hr)
0900	28.50	0
1000	29.60	19
1100	32.30	30
1200	34.80	32
1300	37.50	45
1400	37.70	45
1500	38.60	48

Figure 4.1: Graph of observation for day 5 of experiment

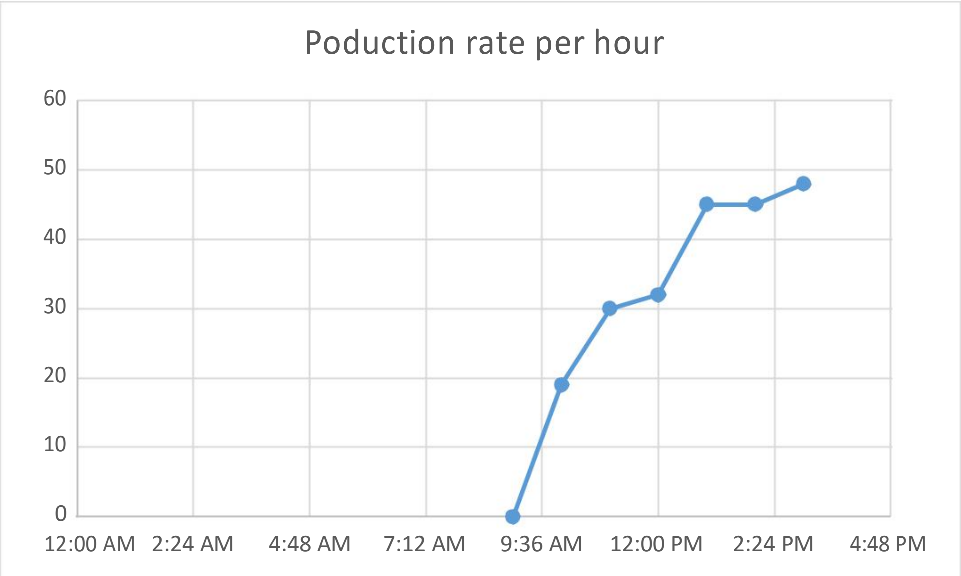
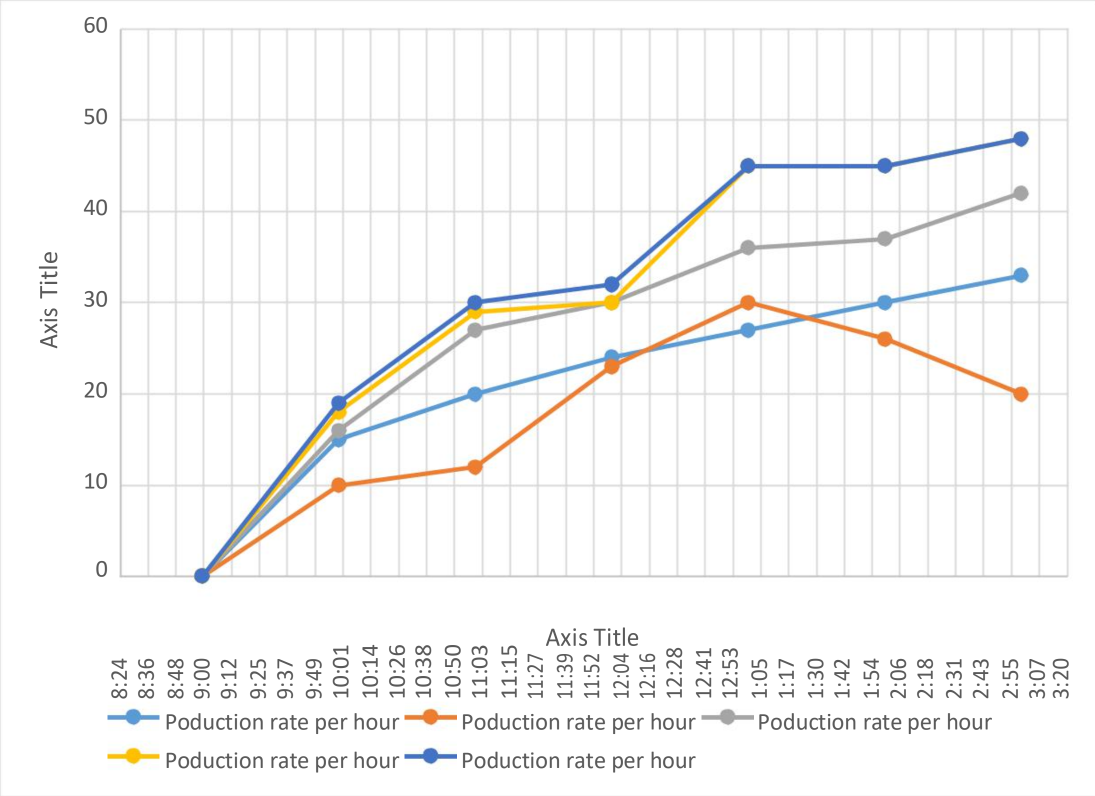


Figure 4.6 Graph of observation for the whole experiment



Water Quality Analysis

Table 4.7: Water quality analysis for 5 days of experiment

Water quality test	Standard tap water	Lake Water	Day 1 (mL)	Day 2 (mL)	Day 3 (mL)	Day 4 (mL)	Day 5 (mL)
pH Value	**6**	**6.69**	**7.7**	**6.85**	**6.93**	**6.7**	**7.0**
Conductivity	**76.7 µ.s**	**97 µ.s**	**82.1 µ.s**	**80.1 µ.s**	**78.6 µ.s**	**80.5 µ.s**	**81.6 µ.s**
Turbidity	**0.31 ntu**	**28 ntu**	**7.63 ntu**	**6.81 ntu**	**9.58 ntu**	**7.83 ntu**	**7.20 ntu**

4.2 Discussion

Area of metal cylindrical solar still : $0.042m^2$

Area/Production	Day 1 ($L/m^2/6hr$)	Day 2 ($L/m^2/6hr$)	Day 3 ($L/m^2/6hr$)	Day 4 ($L/m^2/6hr$)	Day 5 ($L/m^2/6hr$)
Per $0.042\ m^2$	**3.547**	**2.88**	**4.476**	**5.119**	**5.214**

Based on the results of the experiment was conducted, fresh water production per hour increases due to the increasing in surrounding temperature of the cylindrical tank. From day one observation, the maximum fresh water produced was 33 mL / hour with the temperature of the cylindrical tank ranges in between 26.5 to 34.2 degree Celsius in 6 hours. For day 2, the maximum fresh water produced was 20ml / hour with the temperature of the cylindrical tank ranges in between 25.4 to 32.2 degree Celsius. For day 3, the maximum fresh water produced was 42mL / hour with the temperature of the cylindrical tank ranges between 28.5 to 37.4 degree Celsius. For day 4, the maximum fresh water produced was 48 mL / hour with the temperature of the cylindrical tank ranges in between 28.5 to 38.3 degree Celsius. For day 5, the maximum fresh water produced was 48 mL / hour with the temperature of the cylindrical tank ranges in between 28.5 to 38.6 degree Celsius. Based on previous research by using glass cover basin, the fresh water produced was in between 0.37kg/m2.hr to 0.51 kg/m2.hr while for metal cylindrical tank, the fresh water produced was in between 2.88 L/m2/6hr to 5.214 L/m2/6hr from calculation based on area of cylindrical water tank.

For water quality results, pH value for fresh water collected was in the range of 6.7 to 7.7 for five different days. It is considered as acceptable range and safe to be used. For conductivity results, it ranges from 78.6 micro.s to 81.6 micro.s for 5 different sample. Finally, the turbidity test conducted on the collected freshwater. The reading ranges from 6.81 ntu to 9.58 ntu as compared to original turbidity before it was purified which is 28ntu.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

As the experiment and water quality analysis completed, it can be observed that the evaporation of water takes place inside the metal cylindrical tank due to the difference in temperature between the temperature inside metal cylindrical tank and the surrounding temperature. A higher rate of evaporation of water will significantly affect the rate of fresh water production by the solar still.

The production of fresh water also depends on the temperature of the solar energy. Higher temperatures will accelerate warming of cylindrical metal tank and accelerates the process of converting water to steam. When conducting this experiment, I observed that the temperature is not as high temperatures prevail in the experiment using cover glass basin by the previous researcher. Technically, the water production might be higher if the temperature when the experiment was run much higher than this. For the previous research, the duration of water collection is also different because they collect the water in a period of 8 hours a day for collection as shown in the graph compared to this experiment that only lasts for 6 to 7 hours in a day due to weather constraints.

The highest rate of fresh water production by the glass cover basin solar still recorded during the experiment is 0.51 kg/m2.hr with the highest temperature of water among all recorded data which is 51^{O}C.

5.2 Recommendations

Upon the completion of this project, several ideas for improvement are gathered for the future works on this project. The list of the recommendations are as follow:

1. The evaporation and condensation process could be triggered with external wind source. A fan could be placed to enhance the process and indirectly increase the production of fresh water.

2. The seal between copper tube that wrapped by rubber tube and glass collector can be improved to reduce the vapor pressure to go out into the surrounding air in order to increase the efficiency of water production.

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