FINAL YEAR PROJECT 2: DISSERTATION

OPTIMIZATION OF SOLAR STILL FOR POTABLE WATER PRODUCTION USING DOUBLE SLOPE

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ABSTRACT

Distillation under normal conditions occurs by boiling water and collecting the condensed liquid droplets formed. The impurities inside the boiled water can be separated which means that even sea water or river water can be distilled for safe drinking. However, this method is highly costly and is difficult to be produced continuously in remote areas. Another alternative is to use solar stills to produce clean and safe drinking water.

Solar stills are a simple way of obtaining distilled water using radiation from the sun. Some solar still models also enhance the evaporative properties of the stills such as air velocity and water depth to produce a larger amount of yield. The experiments done was purposed to compare the efficiency between glass and plastic stills. The models were double sided stills $50 \times 60cm$ of glass and plastic cover materials. The efficiency of the model was evaluated by the yield produced and production cost. The results showed that although the glass still model was able to reach higher temperatures of water in the basin, the plastic solar still was still producing even higher production, durable, and more cost effective.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

The project is related to water treatment methods focusing particularly on distillation which is used by most countries, especially those with lack of fresh water sources such as Saudi Arabia and Algeria. However, commercial distillation requires a large plot of land and high cost. In some countries the cost of water outweighs even petroleum. The model used in this experiment will be a solar still which is considerably low in cost and can be used in remote areas. According to M. Feilizadeh, M. Soltanieh, K. Jafarpur, & M.R. Karimi Estahbanati (2010), solar stills directly utilize solar energy to desalinate brackish water and do not need other expensive and unsustainable energy sources such as fossil fuel. There are many methods used in improving solar stills by modifying basin adsorption, water depth, type of cover material, external heaters and so on. Basically, solar stills are divided into two types either active or passive. Active solar stills supply external heat energy to the solar still whereas passive solar stills receive solar radiation directly from the sun without being supplier by other external energy(Arslan, 2012). In order to overcome this problem, many active (indirect) solar stills were developed. The purpose of this experiment is to evaluate the efficiency of a $50 \times 60cm$ wide double slope solar still with plastic and glass material. The water used in this experiment is obtained from a nearby lake to simulate actual situations in which this model may be used.

1.2 Problem Statement

The most important issues faced in developing countries are prolonged shortage of potable water and using contaminated sources for daily use will cause serious health diseases (Anil Kr. Tiwari & G.N Tiwari, 2007). Numerous studies on solar stills have been conducted in order to increase its efficiency and productivity.

However, the experiments done beforehand have yet to determine the effect of plastic or glass materials in the yield of solar stills. M.K. Phadatare and S.K. Verma performed an experiment to determine the influence of water depth on internal heat and mass transfer in a plastic solar still using a solar still model made from Plexiglas while Pr. Kaabi Abdenacer and Smakdji conducted an experiment on the impact of temperature difference on global solar stills using a solar still constructed from glass but these experiments failed to show the effect of the materials on the product yield. Moreover, the yield obtained from a small scale model does not necessarily produce the same amount in a larger scale model. According to Rajaseenivasan, T. and Kalidasa Murugavel, K. (2013), the usage of double basin in a single solar still is able to produce 85% more yield as compared to a single basin which was explained such that the radiation from the sun was fully utilized.

Moreover, Younis, S. M. et al. (2010) stated in “Effect of some factors on water distillation by solar energy” that salinity of water may reduce the production rate considerably. This results in different yields obtained from different water sources.

Therefore, in order to obtain the most efficient model of solar still, the effect of both Plexiglas and glass materials on the efficiency of solar still models have to be determined and the experiment will also have to be compared in both large and small scale. Other than that, the solar still model will also have to be tested with both single and double basin as well as tested in terms of water quality.

1.3 Objectives

The objective of this experiment is to determine the maximum output of water that is able to be produced from the effect of using plastic or glass still using double slope method with black painted steel basin and compare their efficiency.

1.4 Scope of Study

The experiment will involve the distillation process of water using solar stills which utilizes the radiation from the sun to produce clean water safe for drinking. Several enhancements are to be tested and the experiment is conducted for the following parameters:

1. Plastic solar still and glass solar still
2. Use of black painted steel basin.
3. Use of double slope solar still method.

CHAPTER 2
LITERATURE REVIEW

2.1 Factors Affecting the Efficiency of Solar Stills

There are a few factors which contribute to the yield produced by solar stills which are air velocity, water depth, heat radiation, solar angle, basin absorption, water impurities and atmospheric temperature and pressure. In some countries which have more than one season, the yield acquired in one season will differ to the other. However, Malaysia does not undergo seasonal changes and therefore the environmental conditions throughout the year will be constant.

The water depths used in a solar still have an effect in the amount of yield obtained by solar stills (Phadatare & Verma, 2007). It was concluded from experiments that by increasing the water depth, the yield produced is reduced significantly up to 32% less yield if compared between 0.02m and 0.18m depth. It was also concluded that the effect of seasonal changes can affect the efficiency of solar stills up to 66.9% when compared between summer and winter.The dominant evaporative fraction revolves around 35°C for optimum efficiency. Basin absorptivity and air velocity can also increase production of yield for solar stills (Tiwari & Tiwari, 2007). From the research done, we can observe the influence of water depth, air velocity and basin absorptivity the yield production of solar stills.

It was also found that providing a larger temperature difference between the glass and brine produces a more efficient and productive solar still which could be obtained by preliminary heating of the brine before bringing it into the solar still , cooling the glass using a fan powered by photovoltaic energy, cooling outside of the glass by flowing the first the brine through the glass before bringing it into the solar still, and installing blades at the sides of the glass to encourage heat loss by convection leading to cooler temperatures on the inner side of the glass (Abdenacer & Nafila, 2007).

Moreover, Younis, S. M. et al. (2010) mentioned that salinity of the water sample used has an effect towards the final yield. Wassouf, Peska, Singh, & Akbarzadeh (2011) stated the conditional effect of turbidity not more than 3 NTU in their cost analysis for low cost solar stills. This can be concluded that quality of water to be distillated has a significant effect towards the production of solar distillate.

According to Ahsan, A. et.al (2013), solar radiation is the most affecting factor in solar still production in which the productivity is proportional to the solar intensity. However, other criteria such as water, glass, and atmospheric temperature also affect the daily yield produced (Murugavel, K. et al (2010).

2.2 Enhancements on Solar Stills

M. Feilizadeh et al. (2010) proposed a new model for a single-slope solar still which takes into account the effect of all walls of the still on the amount of incident solar radiation on the water surface and each wall by allowing the walls to project towards the cover in order to calculate the amount of beam radiation received by any components inside the still. The results show that the effect of the back and side walls were significant in improving the accuracy of the thermal radiation analysis of single-slope solar stills' performance. The maximum and minimum amount of radiation was observed on the back wall and side walls at mid-day. Moreover, the experiments show that the radiated beam solar radiation at the back wall value is low at the beginning and end of the day but high on the side walls. It was also observed that the radiated beam solar ratio of the back wall is significant in the winter and insignificant in the summer.

El-Samadony, Y. A. F. and Kabeel, A. E. researched the enhancement of solar stills using a stepped basin. The experiment compared the conventional single slope solar still with a modified stepped solar still to determine the influence of the depth and width of trays on the performance of the still. The results show that the influence of tray depth and width affects the productivity of the solar still greatly. Moreover, the maximum productivity was achieved at tray depth and width of 5 mm and 120 mm respectively which was about 57.3% higher than a conventional still. It was also concluded that the productivity of the stepped still decreases with increasing water depth and that the usage of wicks on the vertical sides of the still increase the daily productivity from 3% to 5%.

An experiment on the improvement of solar still by installing a flexible packed stretched media installed in the bottom of the basin and a resonator in the middle of the system structure was done by Eldalil, K. M. S. (2010). The purpose of the arrangement was that the flexible packed stretched media helps in absorption, transference, and storage of heat while the resonator helps break the boundary layer and surface tension of the saline water to improve the convective heat transfer. It was also used to vibrate the condensed polycarbonate glass cover and improve water vaporization and condensation. The results show the productivity due to added backed helical wires produced an efficiency of about 35%, and the productivity with vibration is increased the average daily efficiency by about 60%. However, in another solar still experiment which uses Plexiglas as building material for the solar still allows the cover temperature of a solar still to exceed the basin water temperature when solar intensity exceeds 550 W/m3 and the evaporative heat transfer coefficient is highest over radiative heat transfer coefficient which is higher than the convective heat transfer coefficient (Phadatare & Verma, 2007).

Khalifa, A. J. N. and Hamood, A. M. (2009) showed in their experiment that the correlation developed using a single slope solar still differs to the correlation done using a double slope solar still whereby a double slope solar still is more productive as compared to a single slope still. This claim also supports the experiment on various solar still designs conducted by Arunkumar, T., Vinothkumar, K., Ahsan, A., Jayaprakash, R., & Kumar, S. (2012) which states that a pyramid shaped solar still has the highest productivity as compared to other models which includes single slope stills. Therefore, it is concluded that the more efficient solar still is the double slope model.

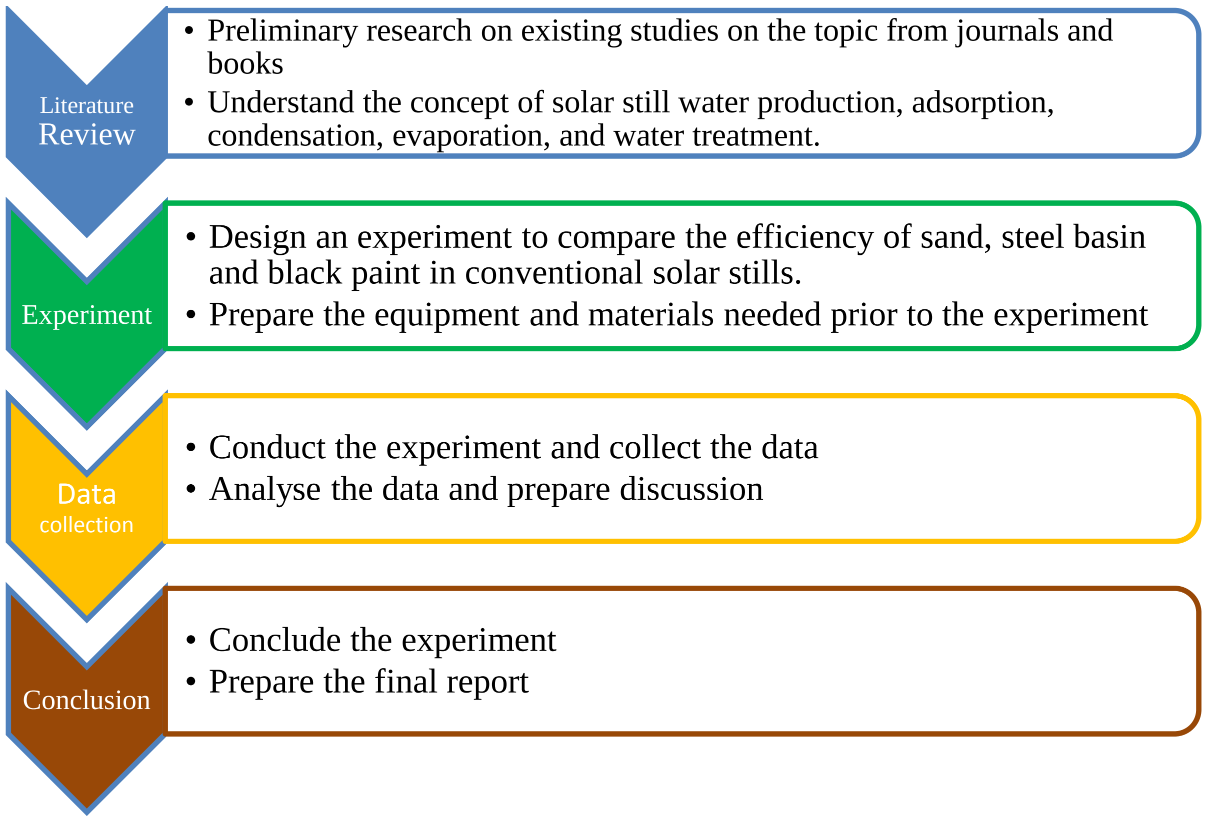
There were also previous studies made to test the efficiency of double basin as compared to single basin solar stills when layered. The results supported the theory which the use of double basins provided a larger yield as compared to single basins because the radiation from the sun is fully utilized and that the production increases with increase in global radiation and decrease in mass (Rajaseenivasan & Kalidasa Murugavel, 2013). However, it was noted that the experiment was done with the upper basin being transparent and the bottom was coated black to promote maximum heat absorption.

There are many different factors and enhancements suggested for the improvement of solar stills. However, some research has yet to compare the efficiency of the prototypes with each other which provides a grey area in determining the most efficient method or enhancement. Therefore it is important to determine the most effective material in building a better solar still.

Chapter 3

Methodology

3.1 Project Flow Chart



3.2 Gantt Chart and Key Milestone

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

Process

Suggested Key Milestone

3.3 Experiment Methodology

The experiment will be conducted in Universiti Teknologi Petronas, Tronoh, Perak in Malaysia. Water from the nearby lake will be used as the water input in order to produce distillates and the solar still will be placed near block 13 of the civil engineering department to allow convenient access as well as provide a control environment. The models of solar stills created will only be in the form double slope or pyramid shaped of base $50 \times 60cm$ with black painted steel basin of $50 \times 30cm$ created, the plastic stills were created from plastic polythene film of thickness 0.15mm, PVC pipe frames tied with nylon ropes and the glass still with glass of 4mm thickness. The water depth used should be around 0.3m to allow for significant production. The glass still will be of the same dimensions with base of $50 \times 60cm$ and black painted steel basin. During experimentation, variables such as daily wind speeds, weather patterns, heat radiation from the Sun, and internal and external temperatures of the still will be taken into account in for future references. In order to provide a more accurate reading, both models will be tested simultaneously and placed in relatively the same area and temperature readings will be measured every hour from 8a.m to 6p.m for 1 day using a digital thermocouple. The temperature readings consisted of ambient temperature, outer cover, inner cover, humidity in still, basin water and basin. Theoretical calculations of internal heat transfer will be done manually using thermodynamic equations. Both input and output water sample in the solar still will be tested for water quality using the procedures stated below. The yield distillate water quality will be compared to World Health Organization (Ed.). (2004). Guidelines for drinking-water quality: recommendations (Vol. 1). The final yield and results of the solar stills will be compared graphically using Microsoft Excel for the small scale and large scale solar still. The equipment which may be used to determine the respective parametric variables are as follows:

1) Measuring cylinder (Distillate output)
2) Copper constantan thermocouples with digital temperature indicator
   (Temperature of water, glass cover, and vapor)

Items	Quantity	Cost/Unit	Cost (RM)
PVC pipe (15 mm diameter)	6.5m	RM10.80/m	70.2
Basin (50cmx30cm)	1	RM50/unit	50
Polythene cover (0.15 thickness)	1.12m^2	RM1.50/m^2	1.68
Nylon rope	50m	RM12/roll	6
Transparent scotch tape	2m	Rm2/roll	0.5
Total			128.38

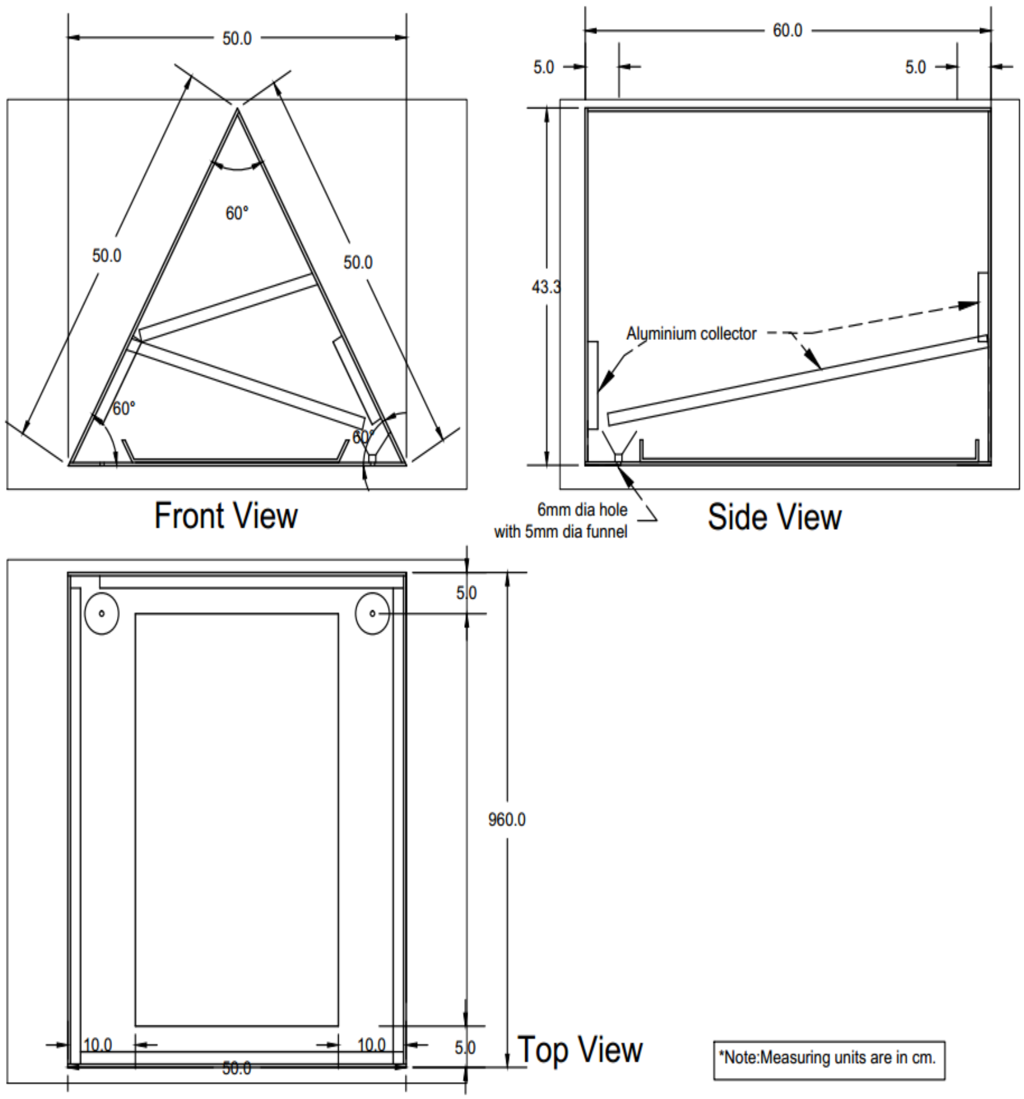
Table 1: Fabrication cost of plastic still

Items	Quantity	Cost/Unit	Cost (RM)
Glass still	1	RM180/unit	180
Basin (50cmx30cm)	1	RM50/unit	50
Aluminium collector	2	RM5/m	10
Rubber tubes	0.5	RM5/m	2.5
Funnel	2	Rm5/roll	10
Total			252.5

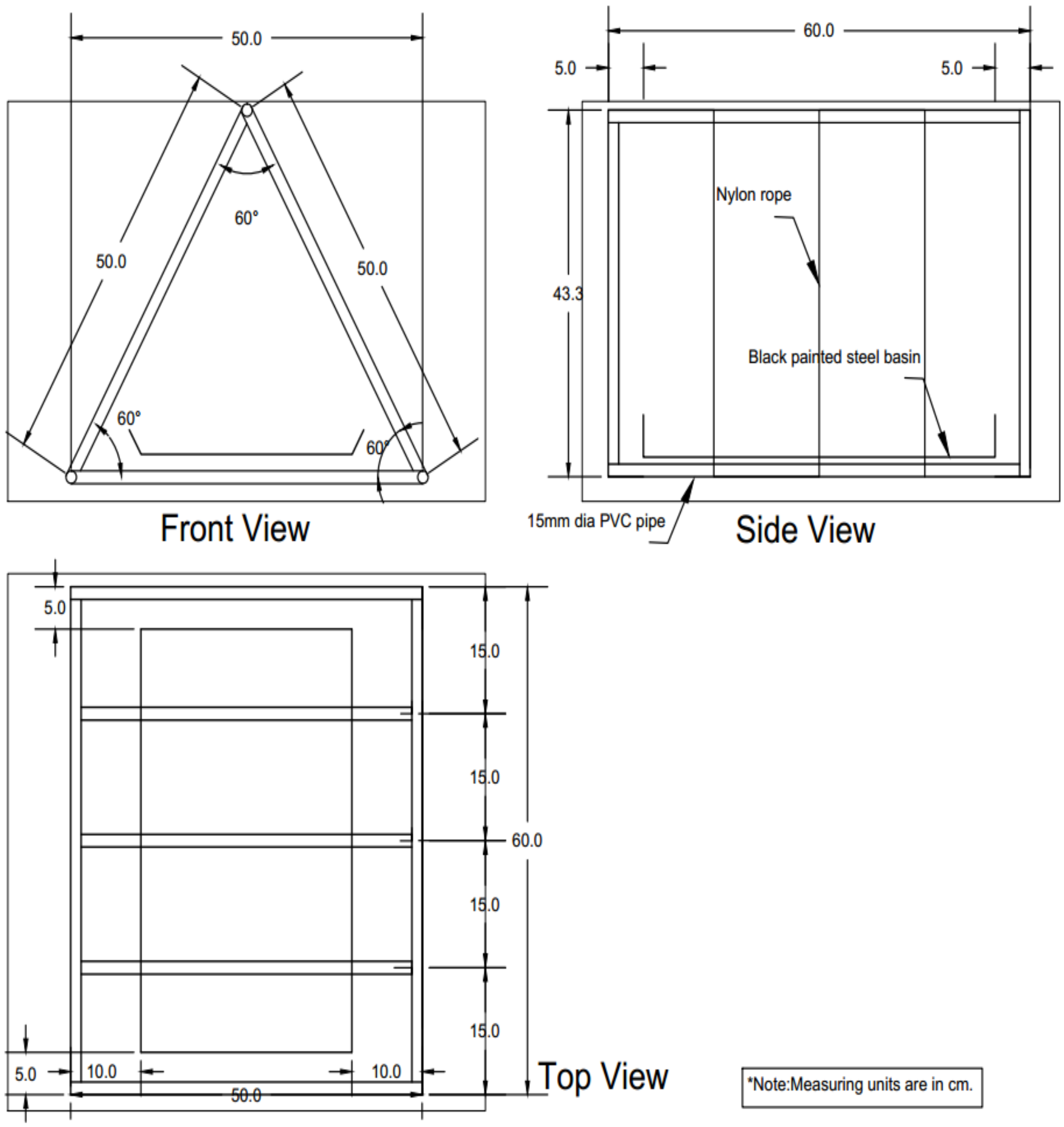
Table 2: Fabrication cost of glass still

The plastic and glass solar still were both made from locally supplied materials and fabrication services. The plastic still was made from PVC pipe, nylon rope and polythene film because of their lightweight, availability, ease of handling and durability. According to Ahsan A. et al(2013) on the life cycle cost analysis of a sustainable solar water distillation technique, the life cycle for PVC pipe, nylon rope, and polythene film was 3, 5, 5 years respectively. The glass still was made using normal glass to reduce cost but increase heat to the basin due to its higher radiative transmittance as compared to plastic and was fabricated at a glass shop near Batu Gajah, Perak. There were some doubts on the integrity of the glass still but a change in glass material from normal to fibre glass would increase the glass production cost to RM780.00 which would be almost four times the cost. The collectors installed were made of aluminium working together with the funnel and rubber tubes to help flow the distilled water into the collector. The basin inside the two stills was made from stainless steel but was painted black in order to increase productivity due to adsorption of basin. This was also proven from a previously conducted experiment involving black sand, sea sand, conventional, and black paint where black paint produced the highest yield.

Glass Still Layout



Plastic Still Layout



Procedure in Determining Water Quality of Sample:

AIR TEMPERATURE

1. Place thermometer in the shade.
2. Wait 2- 3 min.
3. Record air temperature in degrees C to the nearest 0.5° C.

WATER TEMPERATURE

1. Place thermometer in the water.

2. Wait 2 -3 minutes.

4. Read water temperature with the bulb still in the water.

5. Record water temperature to the nearest 0.5 ° C.

DISSOLVED OXYGEN

Calculation of dissolved oxygen will be by machine equipment.

POST TEST CALIBRATION (TDS)

1. Place meter in beaker used for calibration.
2. Turn meter on. Do not allow meter to touch the bottom or sides of the beaker during reading.
3. Allow reading to stabilize and record value in the post test space on the data sheet.
4. Rinse meter probe with DI water. Cap and turn off.

pH

1. Rinse test tube and cap twice with water to be tested.

2. Fill a test tube to the 5.0 mL line with sample water.

3. While holding dropper bottle or pipet vertically, add 10 drops of indicator solution.

4. Cap and mix

5. Insert test tube into Octet comparator. Match sample color to a color standard. Record as pH.

6. Dispose of waste in proper waste container.

7. Rinse test tube and cap with distilled water

NITRATE

1. Rinse square test tube and cap twice with water to be test ed.

2. Fill the test tube so bottom of meniscus sits on the 5 mL line.

3. Add one Nitrate #1 TesTab. Cap the tube & mix until the tablet has disintegrated.

4. Add a #2 tablet. Mix by inverting test tube until it dissolves.

5. Wait 5 minutes. Using a white background, compare prepared sample with color comparator and record results as ppm Nitrate.

6. Dispose of waste in proper waste container.

7. Rinse test tube and cap with distilled water.

Theoretical Study

The following equations will be used in the experiment:

Heat transfer inside the lid

$$q_{cw} = h_{cw} (T_w - T_g)$$

Where,

$$h_{cw} = 0.884 [(T_w - T_g) + (P_w - P_g) (T_w + 273) / (268.9\times10^3 - P_w)]^{1/3}$$

Radiative heat transfer

$$q_{rw} = h_{rw} (T_w - T_g)$$

$$h_{rw} = \varepsilon_{eff} \sigma[(T_w + 273)^2 + (T_g + 273)^2] [T_w + T_g + 546]$$

$$\sigma = 5.669\times10^{-8} \text{ W/m}^2.\text{K}^4$$

$$\varepsilon_{eff} = [1/\varepsilon_g + 1/\varepsilon_w - 1]^{-1}$$

$$\varepsilon_g = \varepsilon_w = 0.9$$

Evaporative heat transfer

$$q_{ew} = h_{ew} (T_w - T_g)$$

$$h_{ew} = 16.273\times10^{-3}\ h_{cw} (P_w - P_g)/(T_w - T_g)$$

Where the total inner heat transfer coefficient from water surface to the condensing cover is;

$$h_{1w} = h_{cw} + h_{rw} + h_{ew}$$

Energy Balance for cover

$$\alpha'_g I(t) + (q_{rw} + q_{cw} + q_{rw}) = q_{rg} + q_{cg}$$

Energy Balance for basin water

$$\alpha'_w I(t) + q_w = (MC)_w T_w/\mathrm{d}t + q_{rw} + q_{cw} + q_{ew}$$

Energy Balance for basin

$$\alpha'_b I(t) = q_w + [q_{cb} + q_s (Ass/As)]$$

Heat transfer coefficients

$$hl_g = 5.7 + 3.8\ \mathrm{V}$$

$$U_b = [1/h_w + 1/(Ki/Li) + 1/(h_{cb} + h_{rb})]^{-1}$$

$$U_t = [1/hl_g + 1/hl_w]^{-1}$$

$$U_L = U_t + U_b$$

$$q_{\mathrm{loss}} = U_L (T_w - T_a)$$

Hourly Yield,

$$M_{ew} = (q_{ew}/L) \times 3600 = [h_{ew} (T_w - T_g)/L] \times 3600$$

Instantaneous Efficiency

$$\eta_i = q_{ew}/I_{(t)} = [(h_{ew}\, hl_g)/(h_{1w} + hl_g)]\, (T_w - T_a)$$

CHAPTER 5

RESULTS

The results show the effect of difference between internal cover temperature and basin water , and ambient temperature on the hourly and daily water production were observed.

Water Quality

Lake Water	
pH	6.78
Turbidity	33.57 NTU
Nitrate	2.37 mg/L
Sulphate	18.67 mg/L
Iron	0.98 mg/L

Plastic still production	
pH	6.63
Turbidity	2.62NTU
Nitrate	1 mg/L
Sulphate	0 mg/L
Iron	0.15 mg/L

Glass still production	
pH	6.61
Turbidity	1.40 NTU
Nitrate	0.4 mg/L
Sulphate	0 mg/L
Iron	0.08 mg/L

Table 3, 4, and 5: Water quality test conducted on Lake Water, and distilled water from plastic and glass still.

The above table shows the results from the water quality test conducted for both the input lake water and also the production. These results were compared with the World Health Organization (WHO) standard for drinking water and were found to be well within the safe drinking water standards (refer to appendix for WHO standard).


Figure 1 and 2: Arrangement of plastic and glass still during experimentation.

Time	Ta	Toc	Th	Tic	Tw	Tb	Whexp (ml)	Whexp (ml/m²)	Whexp (ml/m²)
9.00 am	26	25	27	26	28	28	0	0	0
10.00 am	29	28	35	35	39	39	10	66.7	66.7
11.00 am	31	28	40	38	48	48	17	113.4	180.1
12.00 pm	34	36	41	39	49	49	29	193.4	373.5
1.00 pm	33	30	42	39	50	50	45	300	673.5
2.00 pm	32	34	42	40	50	50	48	320	993.5
3.00 pm	31	33	40	39	48	48	46	306.7	1300.2
4.00 pm	33	35	40	39	46	46	32	213.4	1513.6
5.00 pm	31	34	36	34	42	42	57	380	1893.6
6.00 pm	31	32	35	34	40	40	17	113.4	2007

Table 6: the results of daily production in plastic solar still

Time	Ta	Toc	Th	Tic	Tw	Tb	Whexp (ml)	Whexp (ml/m²)	Whexp (ml/m²)
9.00 am	26	24	33	29	26	27	0	0	0
10.00 am	29	33	40	39	38	38	4	26.7	26.7
11.00 am	31	35	54	46	49	49	6	40	66.7
12.00 pm	34	34	52	45	53	53	10	66.7	133.4
1.00 pm	33	33	50	44	52	52	24	160	293.4
2.00 pm	32	34	52	46	52	52	22	146.7	440.1
3.00 pm	31	35	50	46	50	50	10	66.7	506.8
4.00 pm	33	36	48	46	47	50	6	40	546.8
5.00 pm	31	34	44	40	42	45	2	13.4	560.2
6.00 pm	31	34	37	36	43	43	5	33.4	593.6

Table 7: the results of daily production in glass solar still

Figure 3shows the difference in production rate between plastic and glass solar still in which plastic still produced a higher yield even though the temperature is generally higher in glass stills than in plastic. This can be explained from figure 4 and 5 which shows the temperature variations for internal, external and basin water on the plastic and glass solar stills. It can be seen that the highest temperature and difference in temperature of internal cover, T_i and basin water temperature; T_w is between 12p.m to 4p.m peaked between 12p.m and 1p.m for both glass and plastic stills. During the peak difference in temperature is where production is highest as discussed in the literature review. However, the gap of temperature difference in the plastic still is higher than in glass. This is due to the plastic still having a thinner layer of cover allowing it to cool faster and thus increasing the production by promoting condensation near the cover.

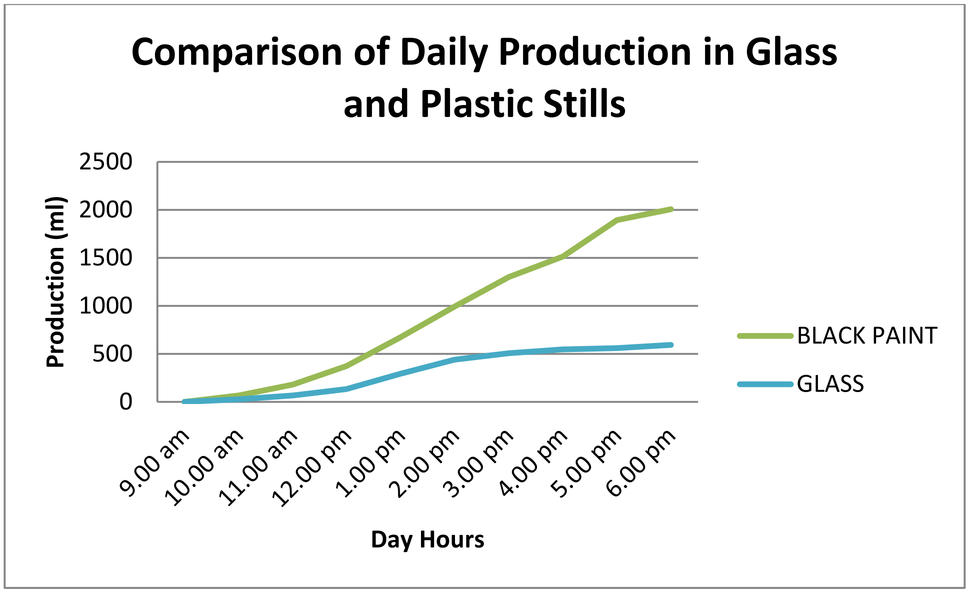


Figure 3: Graph of comparison in production yield between glass and plastic stills.

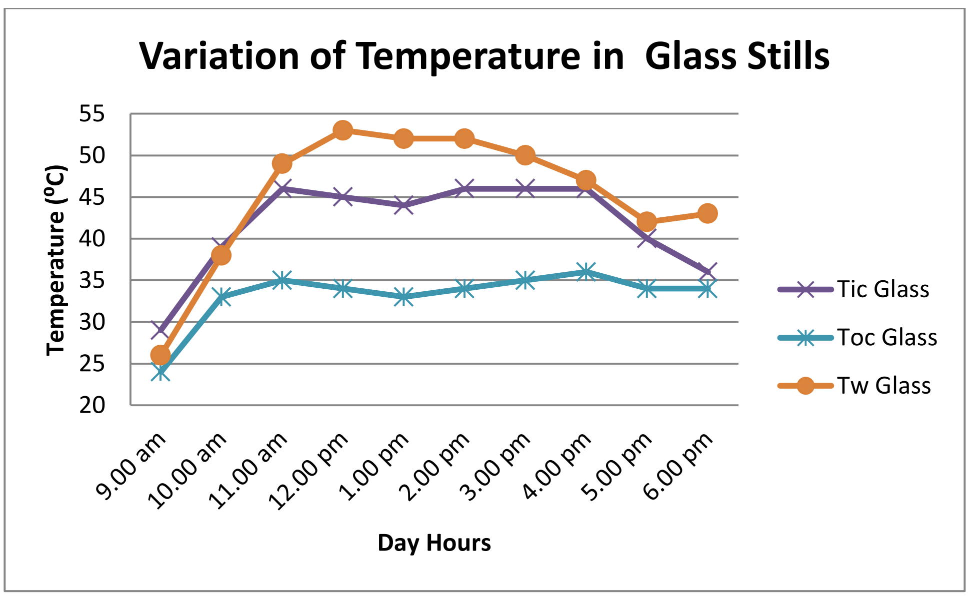


Figure 4: Graph of variation in temperature in glass still.

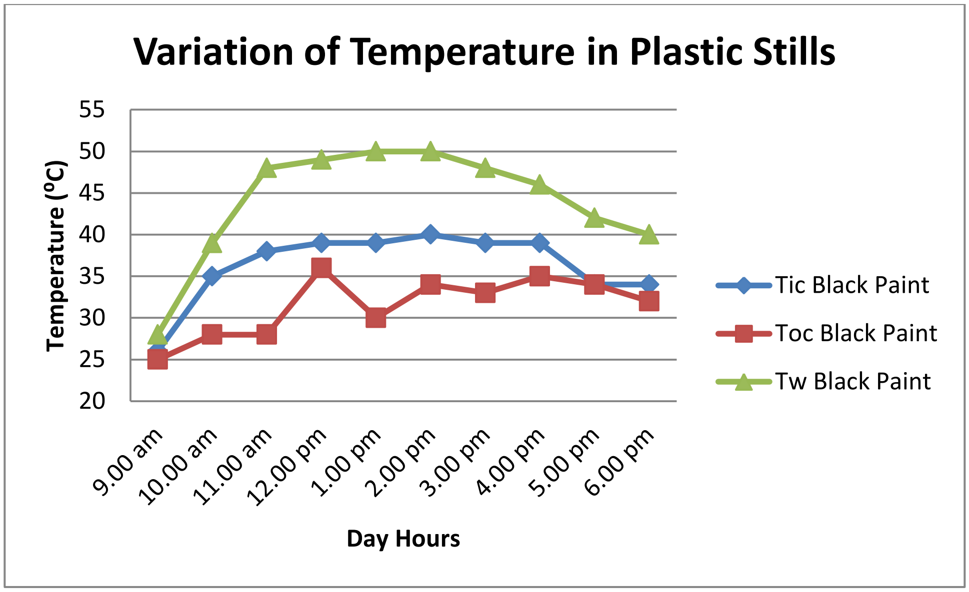


Figure 5: Graph of variation in temperature within the plastic still.

CHAPTER 4
CONCLUSION

In conclusion, this project deals with experimentation of alternative models of solar stills in order to treat unclean water and determine the most efficient and cost effective materials between them. A low cost triangular solar still was designed and developed with the cheapest and lightest locally available materials. The effects of solar radiation intensity, ambient air temperature and the initial water depth on the daily productivity of the still were observed for the climatic condition of Malaysia. The still productivity is nearly proportional to the difference in temperature of water in the basin and the temperature of internal cover. The product water quality parameters are within the Accepted ranges of drinking water guidelines of the world health Organization. Therefore, it is concluded that the solar still is able to provide potable water from saline water for the drinking purpose.

It was determined that the plastic solar still was able to produce a three times more daily yield and is more cost efficient by producing 2.01 liters per metre cube of distilled water a day with material cost of RM128.38 as compared to the glass still which produced 0.6 liters per metre cube a day with material cost of RM 252.5. It was also noticed that the plastic model was more durable and easily handled as compared to the glass model which was heavier and constantly cracking under the hot sun. Other than that, the glass still was also troublesome to fabricate and mobilise due to lack of specialist available, cost constraints, and heavy weightage.

RECOMMENDATIONS

A Few following recommendations are proposed. The highest performance of the solar still was obtained during the hours between 12 noon to 1p.m which is when the solar radiation is highest. This also means that highest production could be obtained during the summer season meaning the suitable months would be between March and May in Malaysia. It is also important to be able to circulate the water inside the still to promote evaporation maybe by pump or motorized stirrer to stimulate evaporation in the still.

Acknowledgement

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Appendix

Symbols

A_c	—	Area of cover, m^2
A_s	—	Area of basin liner, m^2
A_{ss}	—	Area of solar still sides, m^2
h_{cw}	—	Convective heat transfer coefficient from water to cover, $W/m^2\ °C$
h_w	—	Convective heat transfer coefficient from basin liner to water, $W/m^2\ °C$
h_{cb}	—	Convective heat transfer coefficient from bottom insulation to ambient, $W/m^2\ °C$
h_{rb}	—	Radiative heat transfer coefficient from bottom insulation to ambient, $W/m^2\ °C$
h_{rw}	—	Radiative heat transfer coefficient from water to cover, $W/m^2\ °C$
h_{ew}	—	Evaporative heat transfer coefficient from water to cover, $W/m^2\ °C$
h_{1w}	—	Total heat transfer coefficient from water to cover, $W/m^2\ °C$
h_{1g}	—	Total heat transfer coefficient from cover to atmosphere, $W/m^2\ °C$
$I(t)$	—	Total solar radiation, W/m^2
K_i	—	Thermal conductivity of insulating material, W/m °C
L	—	Latent heat of vaporization, J/kg
L_i	—	Thickness of insulation, m
$(MC)_w$	—	Heat capacity of water mass in basin, $J/m^2\ °C$
M_{ew}	—	Distillate output from still, $L/m^2/day$
P_g	—	Partial pressure at cover temperature, N/m^2
P_w	—	Partial pressure at basin water temperature, N/m^2
q_{cw}	—	Convective heat transfer from water to cover, W/m^2
q_{rw}	—	Radiative heat transfer from water to cover, W/m^2

q_{ew}	—	Evaporative heat transfer from water to cover, W/m^2
q_{loss}	—	Overall heat loss from water surface to ambient through top and bottom, W/m^2
q_{cb}	—	Heat transfer from base to ambient by conduction, W/m^2
q_s	—	Side heat loss to ambient by conduction, W/m^2
q_{cg}	—	Convective heat loss from cover to ambient, W/m^2
q_{rg}	—	Radiative heat loss from cover to ambient, W/m^2
T_a	—	Ambient temperature, °C
T_g	—	Cover temperature, °C
T_w	—	Basin water temperature, °C
U_b	—	Overall bottom loss coefficient, W/m^2, °C
U_L	—	Overall heat transfer coefficient, W/m^2 °C
U_t	—	Overall top loss coefficient, W/m^2 °C
v	—	Wind speed, m/s
α'_g	—	Solar flux absorbed by cover
α'_w	—	Solar flux absorbed by basin water
α'_b	—	Solar flux absorbed by basin
ε_{eff}	—	Effective emissivity, dimensionless
ε_g	—	Emissivity of cover, dimensionless
ε_w	—	Emissivity of water , dimensionless
σ	—	Stefan-Boltzmann constant
η_i	—	Instantaneous efficiency, %

PARAMETER	UNIT	LIMIT
Aluminium	mg Al/l	0.2
Arsenic	mg As/l	0.05
Barium	mg Ba/l	0.05
Berylium	ug Be/l	0.2
Cadmium	ug Cd/l	5.0
Calcium	mg Ca/l	200.0
Chromium	mg Cr/l	0.05
Copper	mg Cu/l	1.0
Iron Total	mg Fe/l	0.3
Lead	mg Pb/l	0.01
Magnesium	mg Mg/l	150.0
Manganese	mg Mn/l	0.1
Mercury	ug Hg/l	1.0
Selenium	mg Se/l	0.01
Sodium	mg Na/l	200.0
Zinc	mg Zn/l	5.0
Chlorides	mg Cl/l	250.0
Cyanide	mg Cn/l	0.1
Fluorides	mg F/l	1.5
Nitrates	mg NO_3/l	10.0
Nitrites	mg NO_2/l	-
Sulphates	mg SO_4/l	400.0
Suphides	mg H_2S/l	0
TOTAL "drins"	ug/l	0.03
TOTAL "ddt"	ug/l	1.0
Hydrocarbons	mg/l	0.1
Anionic Detergents	mg/l	0
pH		9.2
Total dissolved solids	mg/l	1500
Total hardness	mg/l	500
Alkalinity	mg/l	500
MICROBIOLOGICAL PARAMETERS		
Total Bacteria	Count/ml	100
Coliform	Count/100ml	0
E. Coli	Count/100ml	0
Salmonella	Count/100ml	0

ug = microgram or ppb
mg = milligram or ppm

Table 8: WHO standard of drinking water.

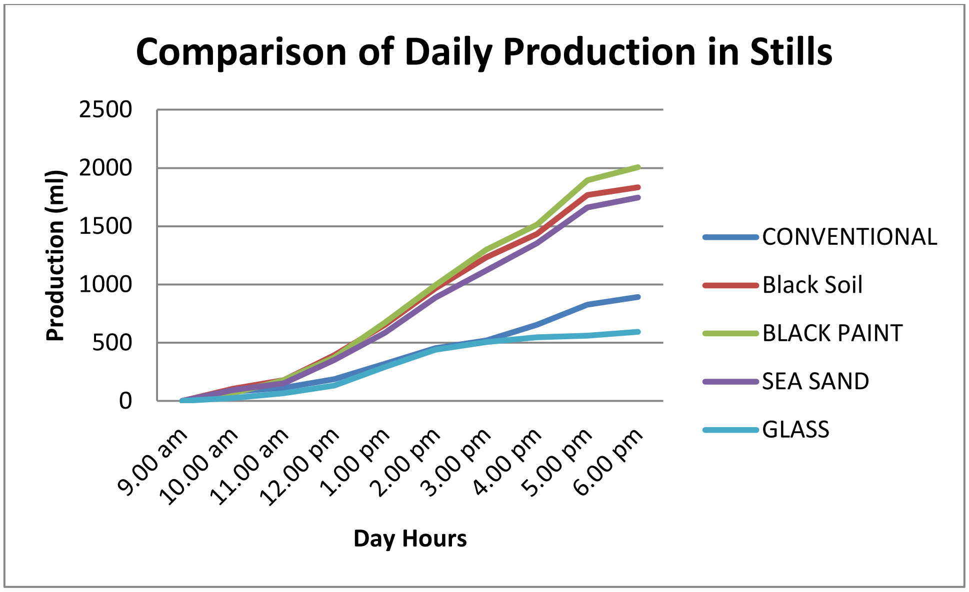

Figure 6: Graph of comparison in production yield of stills from a previously conducted experiment.

Figure 7: Experimentation using sea sand, black soil, black paint, and conventional in plastic stills.