CERTIFICATION OF APPROVAL

PERFORMANCE EVALUATION OF EVACUATED SOLAR WATER HEATER UNDER TROPICAL CONDITION

by

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Approved by,

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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 references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ahmad Tarmizi bin Sulong

ACKNOWLEDGEMENT

In the name of ALLAH S.W.T, the most merciful and compassionate, praise to ALLAH, he is the almighty, eternal blessing and peace upon the Glory of the Universe, our beloved Prophet Muhammad (S.A.W), and his family and companions.

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ABSTRACT

This proposal discusses about the overall performance evaluation of evacuated solar water heater. The objective of this project is to evaluate performance of evacuated solar water heater experimentally. In order to complete this project, the performance of solar water heater was evaluated under Malaysia's tropical condition, warm country, with averages temperature of the surroundings in the range of 27°C to 36°C during sunny day.

The methodology involves are device preparation, conduct experiment, data collection, analyze data from experiment, comparison of result and discussion and conclusion. A clear methodology to complete this project was also proposed in this paper.

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LIST OF ABBREVIATIONS

ETC	Evacuated Tube Collector
SWH	Solar Water Heater
FPC	Flat Plate Collector
TRNSYS	TRaNsient SYstem Simulation

NOMENCLATURE

η Efficiency

CHAPTER 1

INTRODUCTION

First chapter of this proposal will discuss about the introduction to this project, covered with background of study, problem statement, objective, scope of study and the reasons that lead to the implementation of this evaluation project.

1.1 Background of study.

Solar water heating system consists of some innovation of renewable energy technologies which have been worldwide accepted for many years. Hot water heated by sun is used in many ways. Nowadays, The world saw a rapid growth of the use of solar warm water with systems being marketed to the domestic use. Most of that, technical innovation of solar water heater has improved performance, life expectancy and ease of use of these systems.

In order to collect the sun radiation through proper way, an appropriate technology of solar collector need to be use. Two main collectors being compared to choose the best solar radiation collector. Evacuated tube collectors ETC can reduce heat loss due to convection because heat cannot cross a vacuum, it forms an efficient isolation mechanism to keep heat inside the collector pipes. Even though flat plate collectors are more efficient than ETC in full sunshine conditions, but the energy output of flat plate collectors is lower than evacuated tube collectors in cloudy or extremely cold conditions. Thus this project will choose ETC was chosen for further evaluation. The weather conditions in Malaysia is almost cloudy.

This project will focus on performance evaluation of vacuum solar water heater under tropical condition with different parameter such as flow rate level, flow system which is in series or parallel.

1.2 Problem Statement

1.2.1 Problem Identification

Energy saving and conservation are global issues. Hence, usage of solar energy which declared as ultimate free natural source of energy and renewable resource can replace the fossil fuel usage. Since the usage of fossil fuel to heat the water emit harmful gas such as carbon monoxide and carbon dioxide, solar water heater is the alternative ways to prevent this kind of gases released to the environment.

The fuel fossil price of is driven by supply and demand. In fact, global demand was actually going up and global supply not fully can support all the demands during this time. The people start to find alternative ways instead of fully depend on the fossil fuel. The world market for solar water heater has expanded significantly in the last decade. As a result, there have been very large scales of innovations for solar water heater.

Studying about solar energy conversion system performance is to investigate the possible potential improvement for domestic use. Therefore, this study is on performance evaluation of evacuated solar water heater. The system performance depends on the different parameter such as flow rate of water, solar radiation and climate condition. An existing solar water heater system would be investigated experimentally under the weather field condition of Tronoh, Perak, Malaysia.

1.2.2 Significant of the project

This project would give an opportunity to the engineering students to explore about evacuated tube solar water heater in terms of efficiency of receiving the solar radiation. The data obtained from the evaluation can help to improve solar water heater system in term of efficiency, economic and user friendly to operate the system for domestic use. The students would be able to observe the comparison of the performance for evacuated SWH between different parameter.

1.3 Objective and Scope of Study

1.3.1 Objective

The main objective of this study is to evaluate the performance of evacuated solar water heater with different parameters. The result from this experiment is very important to produce more effective in term of capability of SWH extract energy using natural sources.

1.3.2 Scope of Study

This project is to evaluate the performance of solar water heater under tropical condition. The analysis would be done using computational simulation software. This model will be conducted by varying the major parameters involved such as the flow rate of water pass through the heater, the angle of sunlight exposes and the time exposes to the sun light radiation. The data and device that will be used are solar water heater, water, solar radiation and some related device to complete the project.

1.4 Relevancy of the project

Instead of learning only in theory on how evacuated solar water heater work, students will also have the great opportunity to clearly understand on how this solar water heater work. In the society, this solar water heater can help a lot on energy saving instead of using fossil energy. This SWH is environmental friendly because zero emit of carbon dioxide and carbon monoxide. The TRNSYS computer simulation of SWH performance can be use to help engineer to improve quality if this device in the future work.

1.5 Feasibility of the project

Two semesters is the time given to complete this project. This includes research, development, improvement and discussion. The availability of hardware such as evacuated tube solar water heater, thermometer and all related material make this project can be done without any delayed. Based on the availability of software and hardware, it is very clear that this project is feasible to be completed within the time frame assign by FYP coordinator.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses about the theories and paperwork reviews related to this project.

2.1 Solar Water Heater

Solar water heating system represent the most significant growing application adopted from solar energy at this present time. Small solar water heater system are used for domestic application and for the big scale of application commonly used for industrial. There are two basic types of water heating system, natural circulation and forced circulation. Since natural circulation solar water heater is low cost and simple design of application, it is limited to non-freezing climates. Means for natural circulation, it cannot be used in the continental with winter condition. Most of forced circulation solar water heater is used on freezing climates and industrial demand (D.Yogi Goswani et al,1999).

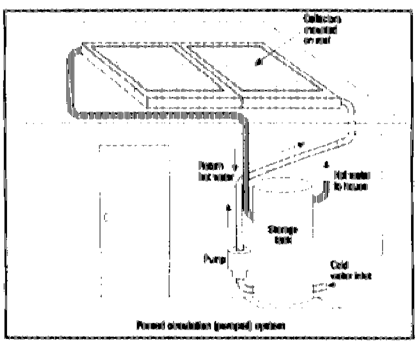


Figure 2.1: Forced Circulation

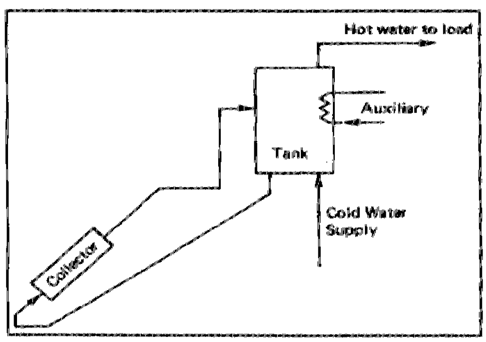


Figure 2.2: Natural Circulation

Force circulation solar water heater use pump to circulate the fluid for heat transfer exchanger and the tank can put at any level. For natural circulation solar water heater, pump is unneeded because gravitational force can help the circulation. The tank for natural circulation must be above the solar collector.

The demands of solar water heater have enjoyed a period of rapid growth in recent years, but renewable energy technologies cannot expect to replace fossil fuels on goodwill. Most studies on the economics of renewable energy systems must occur with one of the most powerful trends in their favor: the rising cost of fossil fuels (John.R, 2008).

Today, engineers and developers can extract solar energy into useful source of energy with common materials and basic technologies. The simplest version of solar water heater consists of a water tank, a sun light absorber to capture the sun's radiation effectively, and a sheet of glass to create a greenhouse effect.

In a research article (W.M. Rohsenow et al,1998), solar thermal collectors absorb and retain the heat from the sun and transfer this heat to water. There are two important physical principles combine in the technology of solar thermal collectors:

1. Any hot object will returns to thermal equilibrium with its environment, due to heat loss from the hot object. Conduction, convection and radiation are the process that occurs during heat loss. Determine the efficiency of a solar thermal collector is related to heat losses from the collector surface. Convection and radiation are the most important sources of heat loss in the context of a solar collector. The solution to slow down the heat loss from a hot object to its environment by using thermal insulation.

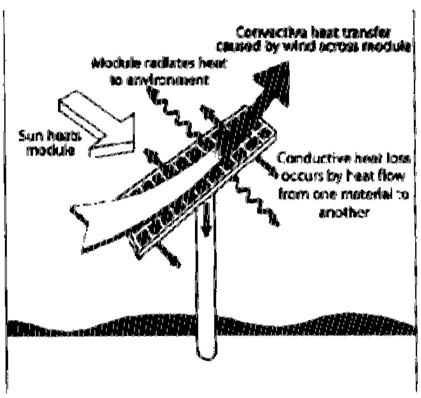


Figure 2.3: Conduction, Convection, Radiation

2. The research found that heat is lost more rapidly occur if the differences temperature between a hot object and its environment is larger. Heat loss is predominantly governed by the thermal gradient between the temperature of the collector surface and the ambient temperature. Conduction, convection as well as radiation occur more rapidly over large thermal gradients. The term that they use for this difference temperature between these two situations is the *'delta-t effect'*.

2.2 Evacuated Tube Collector

Since heat loss due to convection cannot cross a vacuum tube, ETC forms a good isolation mechanism to keep heat inside the collector pipes (Yong Kim & Taebeom Seo, 2007). In the research article, since two flat sheets of glass are not strong enough to withstand a vacuum pressure, the vacuum is created between two concentric tubes (Greg F. Naterer, 2002).

Theoretically, evacuated tube collector vacuum is created between the absorber and transparent glass cover. Completely removing the air between absorber and glass cover for evacuated tube collector can reduce the heat loss through convection. The only heat loss mechanism remains is through radiation. It is very difficult to maintain the vacuum in flat plat collector and this chance taken to invent great evacuated tube collector.

The evacuated tube collector consist of parallel of glass tube, each of them contains an absorber tube with some selective coating. Heat losses through conduction and convection mechanism are eliminated because there are no more absent of air that can cause conduct heat or convective heat losses. This great invention still cannot avoid heat loss from radiation mechanism because the heat will transfer through space from hot area to cold area, even across the vacuum. This radiation heat loss mechanism is small consequence if compared with the amount of heat absorbed by the collector (G.N Tiwari, 2002).

Evacuated tube collector can be classified in to two groups:-

1. ETC without heat pipe
2. ETC with heat pipe

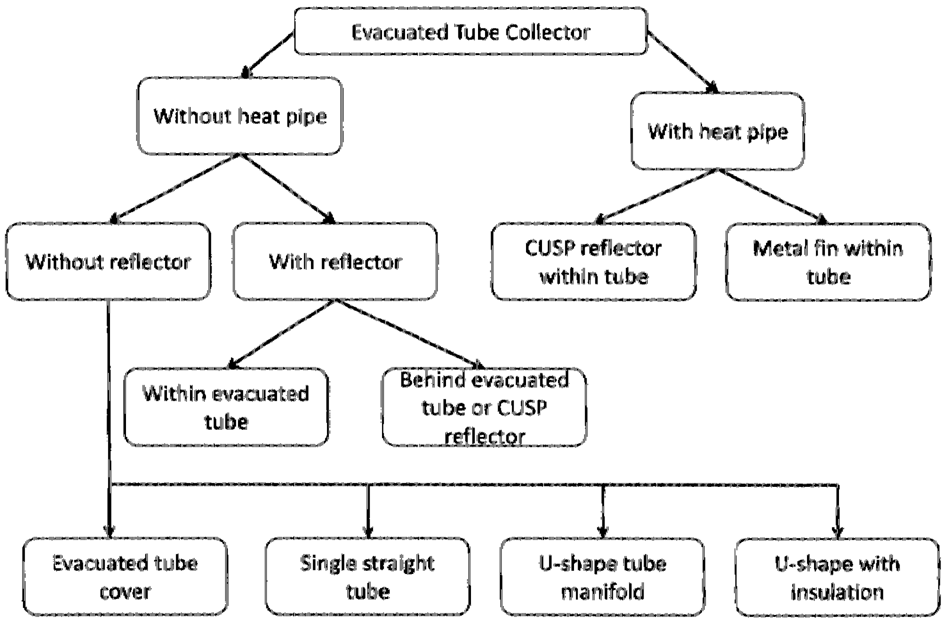


Figure 2.4: Classification of Evacuated Tube Collector

Most evacuated tube collector consists of glass tube made from borosilicate glass. This glass can withstand the vacuum pressure so the evacuated tube collector not easily broken. The transparent glass is to allow the sun radiation pass through the tube with very low amount of reflection. Commonly, the inner of the tube coated by pure copper and metal carbide for better result of absorption the heat from the sun radiation.

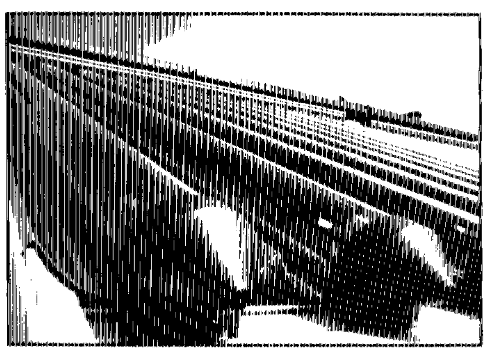
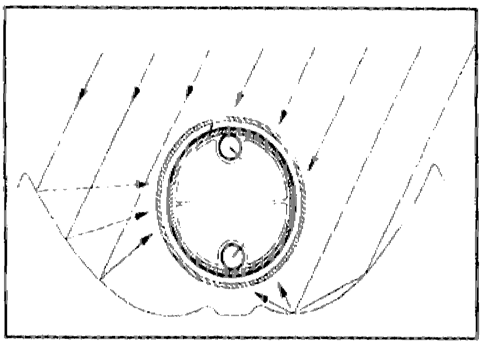
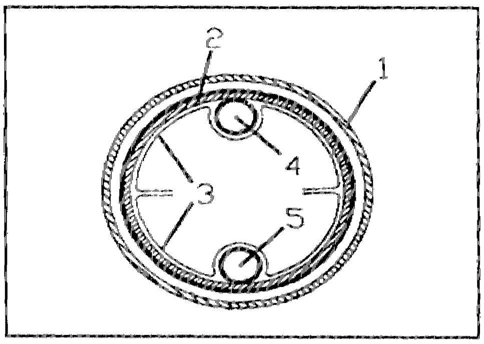


Figure 2.5: Evacuated Tube Collector

Reflectors are very important to achieve high efficiency for solar water heater system. This is due to the function of the collector itself to collect energy from a distant source and bring it to a assigned focus point. The reflector can eliminate the need of sun tracker because of wide acceptance angle for solar radiation, and the panel must face south for better result.



a) Reflector



b) Cross Sectional Evacuated Tube

Legend

1. External Glasss Tube
2. Internal Glasss Tube
3. Aluminium sheet absorbent
4. Inlet copper tube (6mm)
5. Return copper tube (6mm)

Figure 2.6: Reflector and Cross-Sectional of tube collector

2.3 Flat Plate Collector

In term of efficiency in full sunshine, FPC performs better than ETC. However, the output of energy from FPC is slightly reduced compared to ETC in cloudy or extremely cold conditions. Most flat plate collectors have two horizontal pipes at the top and bottom, called headers, and some smaller vertical pipes connecting with them, called risers. The risers are welded to thin absorber fins (D. Yogi Goswani et al, 1999).

Commonly, the type of glass used in flat plate collectors is low-iron tempered glass. Being tempered, the glass can withstand significant hail without breaking, which is one of the reasons that flat-plate collectors are considered the most durable collector type.

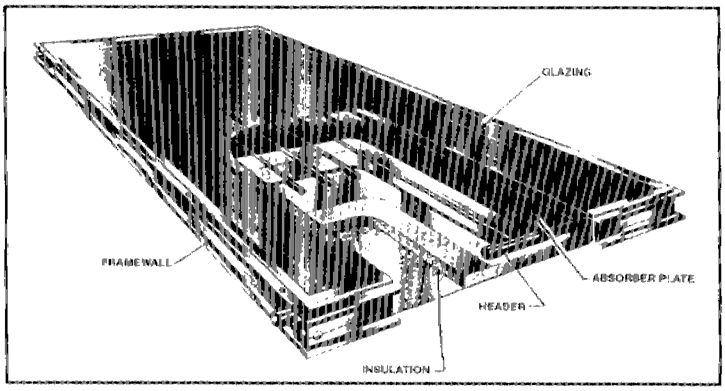


Figure 2.7: Flat Plate Solar Panel

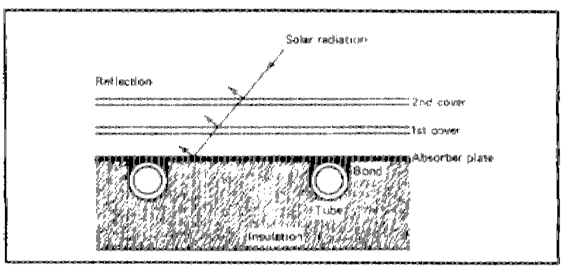


Figure 2.8: Inside Flat Plate Solar Panel

The FPC is the basic of all solar energy collection system that designed for operate in average of 60°C up to 100°C. It's used to absorb solar energy and convert the energy into heat and lastly the heat transferred to a flow of fluid. FPC absorbs the solar radiation and usually planted on the top of a building or infrastructure. Most FPC are less maintenance and does not required solar tracking system.

Figure 2.10 shows the Hottel – Whillier Bliss characteristic curve for both flat plate collector and evacuated tube collector

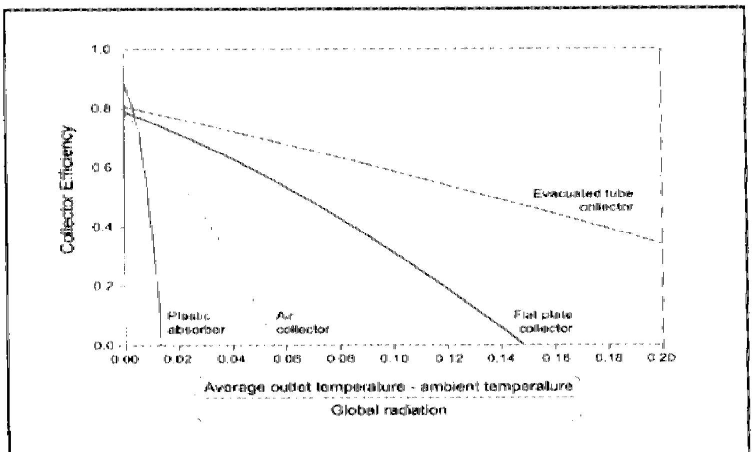


Figure 2.7b Hottel - Whillier Bliss efficiency curves [27].

Figure 2.9: Hottel – Whillier Bliss characteristic curve

In flat plate collector, the surface coating of the plate should have this two criteria, poor emissivity and high absorptive. The performance of flat plate collector evaluated base on the heat loss by convection (G.N Tiwari,2002).

2.4 Transient System Simulation

TRNSYS is a complete and extensible simulation environment for the transient simulation of systems, including multi-zone buildings. It is used by engineers and researchers around the world to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant behavior, and alternative energy system.

A TRNSYS project is typically setup by connecting components graphically in the Simulation Studio. Each type of component is described by a mathematical
model in the TRNSYS(TRNSYS 16, 2004).

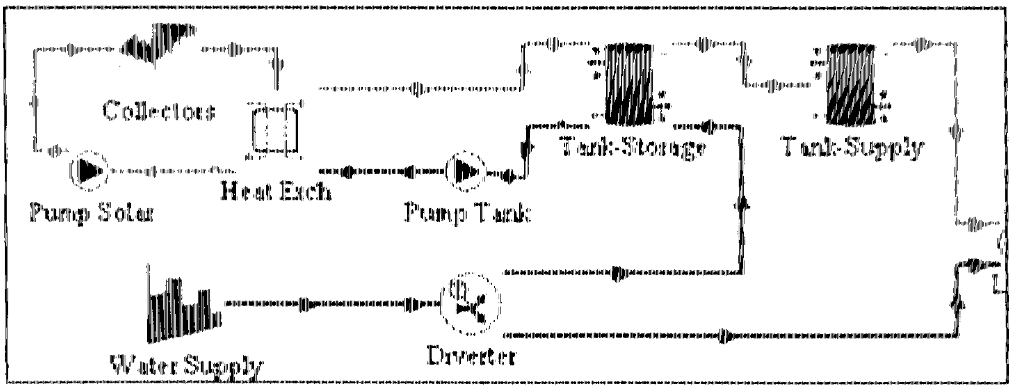


Figure 2.10: TRNSYS Simulation Studio

TRNSYS helps the engineer to calculate the transient condition of any system such as a classroom, a building even a complex solar water heater system. TRNSYS do not know about the system that it will be executed, users need to define and create the system and tell to TRNSYS with proper equipment and mathematical model equation.

2.5 Solar Azimuth Angle

Azimuth is an angular measurement in a spherical coordinate system. Azimuth angle of solar radiation can be determined by calculation different angle between projected vector and reference angle. In this case, the reference vector point is to the north, measuring from the clockwise.

The reference plane lies horizontally on the surface facing the north and the measured plane can be determined by projected perpendicularly onto a reference plane. Azimuth angle are measured in degrees (°). From the compass bearing, azimuth angle measured from the geographical relative true north (0°), of a point on the horizon directly beneath an observed object. In any measurement event, the azimuth cannot exceed the highest number of units in a circle of 360° circle.

An example of an azimuth is the measurement of the position of sun. The sun is the point of interest, the reference plane is the horizon or the surface of the ground, and the reference vector points to the north. The azimuth is the angle between the north point and the perpendicular projection of the sun down onto the horizon.

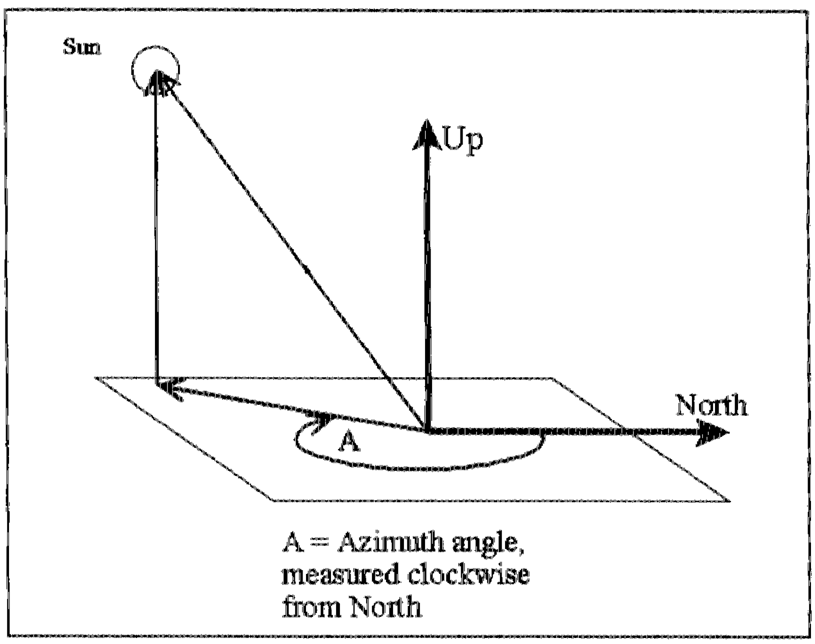


Figure 2.11: Measuring Azimuth Angle

2.6 Solar Zenith Angle

Zenith angle measured from upward vertical direction of the surface. Vertical direction here means opposite to the apparent gravitational force pull at that assigned location. The opposite direction means the direction in which the gravitational force pulls, is toward the subject.

Using simple explanations, the zenith is defined as the plane running the observer straight up to the sky reaching the celestial sphere. The celestial sphere is large radius sphere of the earth. The horizon is defined as the surface touched by the observer and perpendicular to the Zenith line.

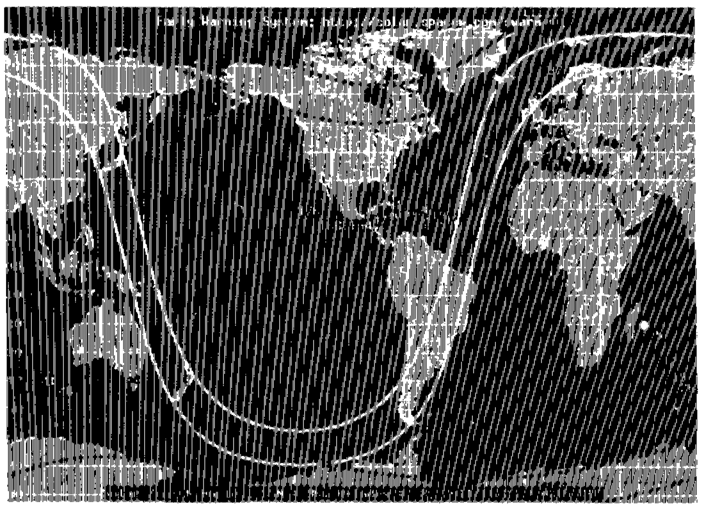


Figure 2.12: Solar Zenith Angle

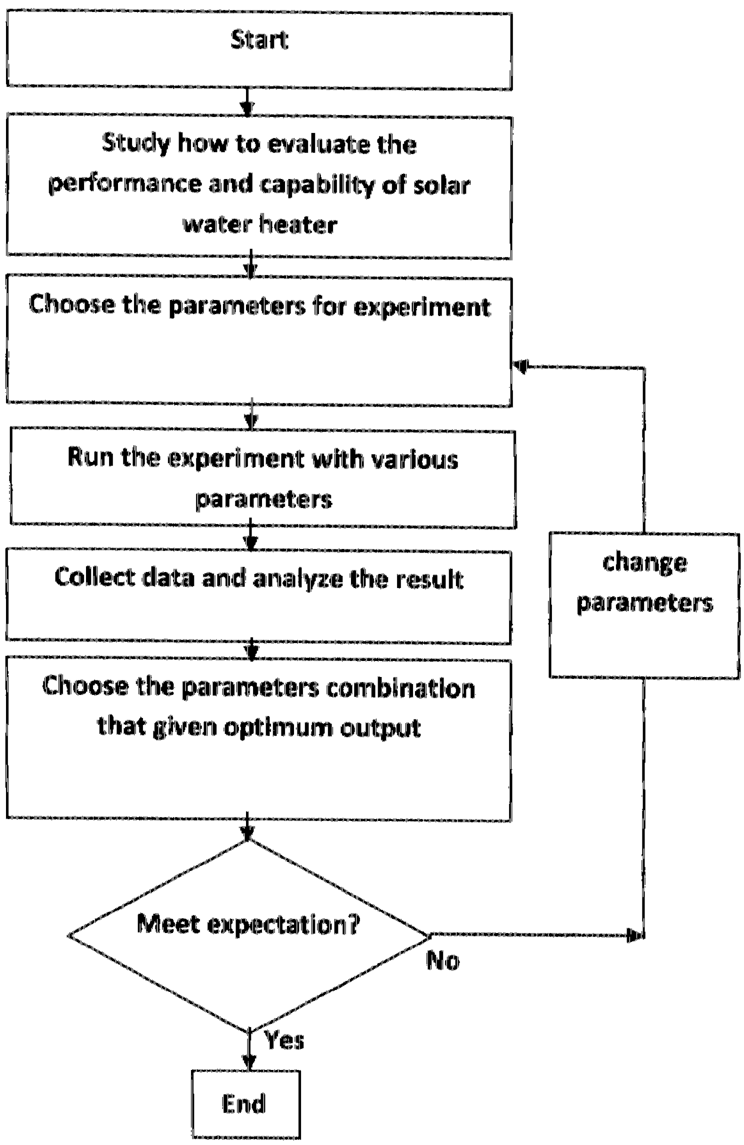
This map shows solar zenith angle at any location around the world at current time . The contours show in degrees and refer to the distance the Sun is away from the zenith. For an example, contour label 90-degrees would define all of those regions around the world where the Sun is exactly on the horizon.

CHAPTER 3

METHODOLOGY

This chapter discusses about how the project would be carried out. It includes the method of research, tools, components, and software involved.

3.1 Procedure



3.2 Experiment

Ten experiments will be conducted during this evaluation. All of the experiments were conducted under tropical weather condition. All of the parameters for solar water heater were summarize in Table 3.2. The area of collector is $2.17m^2$.

Table 3.1: Technical Specification for Evacuated Tube Collector (STEM-ISI manual)

Item	**Specification**
Absorber layer selectivity	Borosilicate glass 1. Stainless steel 2. Pure copper 3. Metal carbide
vacuum	$\leq$0.1 Pa
Transmission glass	92%
Absorption	93%
Emission	3.5%
Maximum allowable absorber temperature	530°C
Total weight	115kg
Total area	$2.17m^2$
Capability of reflector	85%

Table 3.2: Parameters Considered During The Experiment

Experiment	**System flow**	**Flow rate (l/h)**	**Condition**	**Sun radiation angle**
A1	Series	40	Tropical	90°
A2	Series	60	Tropical	90°
A3	Series	80	Tropical	90°
A4	Series	100	Tropical	90°
A5	Series	120	Tropical	90°
B1	Parallel	40	Tropical	90°
B2	Parallel	60	Tropical	90°
B3	Parallel	80	Tropical	90°
B4	Parallel	100	Tropical	90°
B5	Parallel	120	Tropical	90°

3.3 Initial preparation

The water stored in every tube of Solar Water Heater was replaced by clean water on every single experiment. The purpose of this cleaning is to remove any clogged and small particle that was contained in the water during previous experiment and every experiment should be made with fresh water. Drain valve was opened to fully drain the water as Figure 3.1. After all water drained, fresh water needed to fill the system and let it flushing the system at least for 5 minutes. Since the systems were close loop, one of the connection's pipe as shown in Figure 3.2 were unplug to release the water while flushing process. During flushing process, the system were set up in series (Figure 3.3) to make sure all space inside the system replaced with fresh water and flow rate valve were fully opened (Figure 3.4)

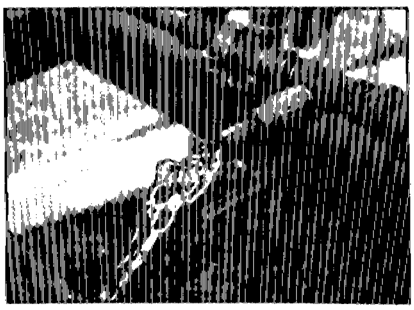


Figure 3.1: Drain valve

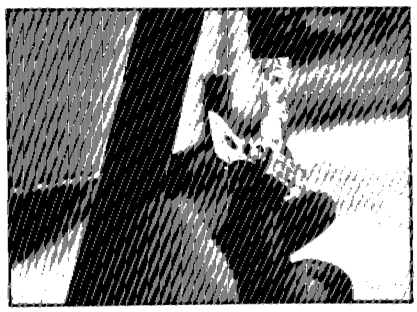


Figure 3.2: Unplug Pipe Hose

Figure 3.3: Series Flow System

Figure 3.4: Fully Open Flow rate Valve

After flushing process were done, continued to fill the system with clean water. In order to release trapped air during filling process, the top valves were fully opened. Filling process stopped when the system reach at 2 bar of pressure. The pressure inside the system was set by manufacturer for optimum performance.

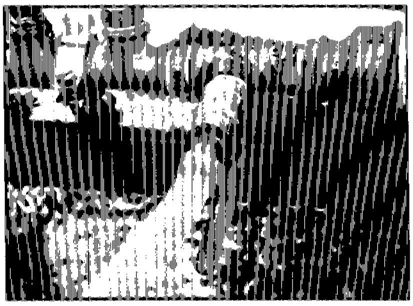


Figure 3.5: Filling Process

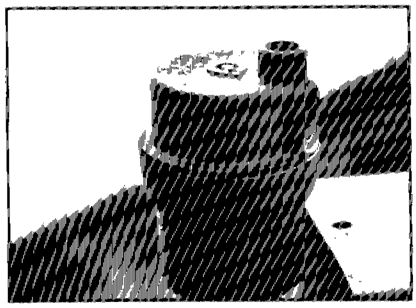


Figure 3.6: Top Release Valve

Figure 3.7: Pressure Gauge

In term of getting accurate reading, thermocouples for digital thermometer were cleaned to make sure the contact surface between thermocouple and measured area are well engaged (Figure 3.8).

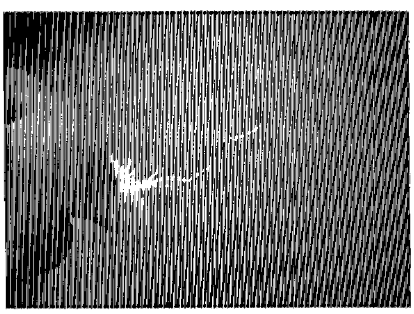


Figure 3.8: Thermocouple

The Solar Water Heater were exposed to the sun radiation between five to ten minutes before the experiment start because the temperature of body's machine need to be in equilibrium with the environment. The machines are portable and were stored in the room when not in used. Equilibrium temperatures with the environment are important to make sure the machine running in operating temperature.

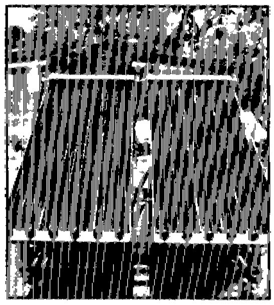


Figure 3.9: Solar Water Heater Machine

Measurement applications were check and make sure the entire device running in good condition. Since the solarimeter and digital thermometer were battery operated, alkaline batteries were recommended instead of normal battery. Tested with normal battery, the result is vary and inaccurate.

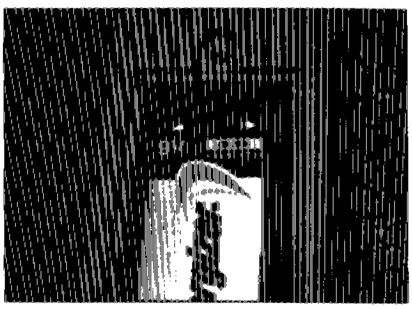


Figure 3.10: Alkaline battery

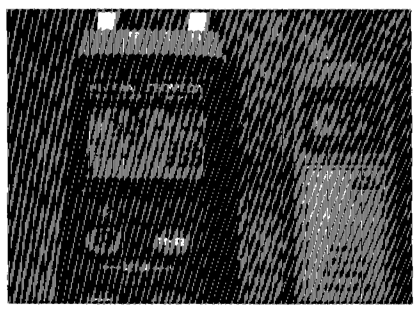


Figure 3.11: Measuring device

3.4 Tools

3.4.1 Solarimeter HD9221 DeltaOHM

Electronic instrument capable of instantaneously survey and visualize the total energy value emitted by sun, both by direct and diffuses radiation. Item consist of a silicon cell, an electronic data acquisition, conversion, display system.

3.4.2 Thermocouple and thermometer

To determine temperature of device, fluid, ambient, environment when perform the experiment.

3.4.3 Evacuated tube solar water heater

Main concern of the project. Evacuated tube solar water heater performs better in comparison with flat plate solar collectors, in particular for high temperature operations.

CHAPTER 4

DATA ANALYSIS AND DISCUSSION

4.1 Data Analysis

Ten experiments were successfully conducted in this project using Evacuated Solar Water Heater with two different flow systems which are series and parallel; with five different flow rates (40,60,80,100,120) liter per hour under tropical condition with average ambient temperature of 30°C. Period of time for one experiment is one hour and data recorded on every 10 minutes interval. The solar panels were set up perpendicular to solar radiation for better result. The water inside the system was changes frequently with clean water. All of the data taken using digital thermometer and solarimeter. Due to unstable weather condition, some of the experiments were repeated many times to acquired best result.

4.1.1 Efficiency of the solar collector

The efficiency of a collector is defined as the ratio of the power absorbed by the thermal carrier (Po) and that absorbed by the collector exposed to radiating energy (Pi); this is expressed by the formula:

$$Po = \frac{Q\left[\frac{l}{h}\right](T_{fo} - T_{fi})[C^\circ]ro\left[\frac{kg}{l}\right]c[\frac{J}{kg}{}^\circ C]}{3600[\frac{s}{h}]}$$

Where:-

Q = thermal carrier flow rate as indicated on the flow meter

T_{fo} = temperature of the same fluid at the output of the collector indicated on the appropriate thermometer

T_{fi} = fluid temperature in the input

ro = mass, assume constant, of the thermal carrier, as a first approximation for water we can consider ro = 1*kg/l*

c = specific heat, assumed constant, as first approximation for water we can consider c = $4180\frac{J}{kg}\,°C$

Using these approximations to calculate the useful power output:

Po = 1.161Q $(T_{fo} - T_{fi})$

The Power recorded by the solarimeter, P*i* [W] can be calculated using the formula

P*i* = P*s* x A

Where:-

P*s* = radiating energy measured using a solarimeter (W/m^2)

A = area of the collector ($2.17m^2$)

4.2 Calculation for Series Flow System

4.2.1 Series Flow system collector performance at 100 l/h flow rate (A4)

System flow: Series	Sun Radiation Angle: 90°	Flow rate, Q: 100l/h

Table 4.1: Raw Data for Series Flow System at 100l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)
0	30.00	30.00	580	0.00	1258.60
10	51.60	55.90	590	499.23	1280.30
20	52.10	56.10	595	464.40	1291.15
30	51.90	57.40	600	638.55	1302.00
40	52.60	57.40	600	557.28	1302.00
50	54.10	59.00	600	568.89	1302.00
60	55.80	60.70	620	568.89	1345.40

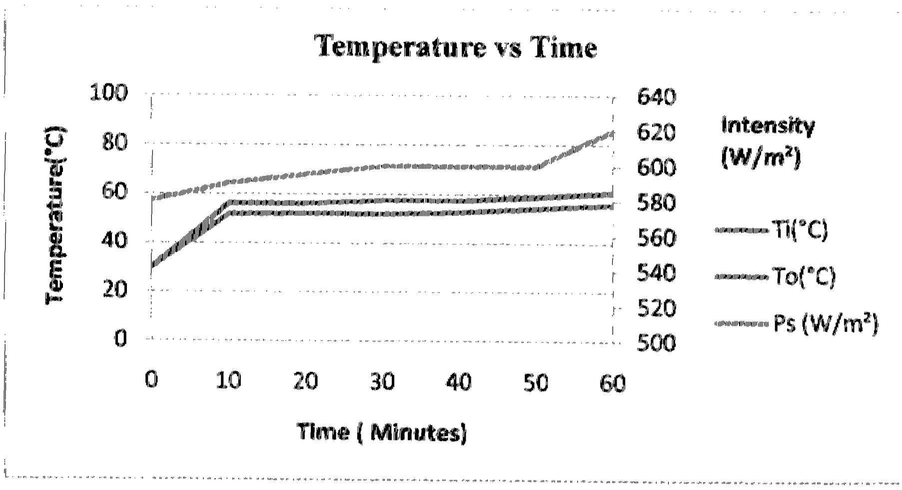


Figure 4.1: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector In Series Flow System (100l/h)

Figure 4.1 shown the sun intensity suddenly increased at the end of the experiment but the inlet and exit temperatures were changing gradually. The sudden increase of sun intensity will increase the inlet and exit temperature of the water if the experiment continued.

Power Output

$$\textbf{Po} = \frac{Q\left[\frac{l}{h}\right]\left(t_{fo-}t_{fi}\right)[C°]ro\left[\frac{kg}{l}\right]c[\frac{J}{kg}°C]}{3600[\frac{s}{h}]}$$

$$\textbf{Po} = \textbf{1.161Q}\ (T_{fo} - T_{fi})$$

At 10 minutes for Q = 100l/h, Series flow system :-

Po = 1.161 x 100 x (55.9 – 51.6) = 499.23Watt

Power Input

Pi = Ps x A

A = 2.17m²

At 10minutes for Q = $100\frac{l}{h}$, series system, Ps = $590\frac{W}{m^2}$

Pi = 590 W/m² x 2.17m² = 1280.30 Watt

Efficiency (η)

$$\eta = \frac{Po}{Pi}$$

From the calculation:- Po = 499.23Watt , Pi = 1280.30Watt

$$\eta = \frac{499.23}{1280.30} \times 100 = 38.99\%$$

The calculation shows power output, Po at time interval of 10 minutes for 100l/h series flow system were 499.23Watt and power input, Pi were 1280.30Watt. The instantaneous efficiency after 10 minutes period of time is 38.99%. Similar, input and output calculation were done for every 10 minutes interval and the result are summarized in Table 4.1

System : Series Flow

Table 4.2: Summary of the Data Analysis for Series Flow System at 100 l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	30.00	30.00	580	0.00	1258.60	0.00%
10	51.60	55.90	590	499.23	1280.30	38.99%
20	52.10	56.10	595	464.40	1291.15	35.97%
30	51.90	57.40	600	638.55	1302.00	49.04%
40	52.60	57.40	600	557.28	1302.00	42.80%
50	54.10	59.00	600	568.89	1302.00	43.69%
60	55.80	60.70	620	568.89	1345.40	42.28%

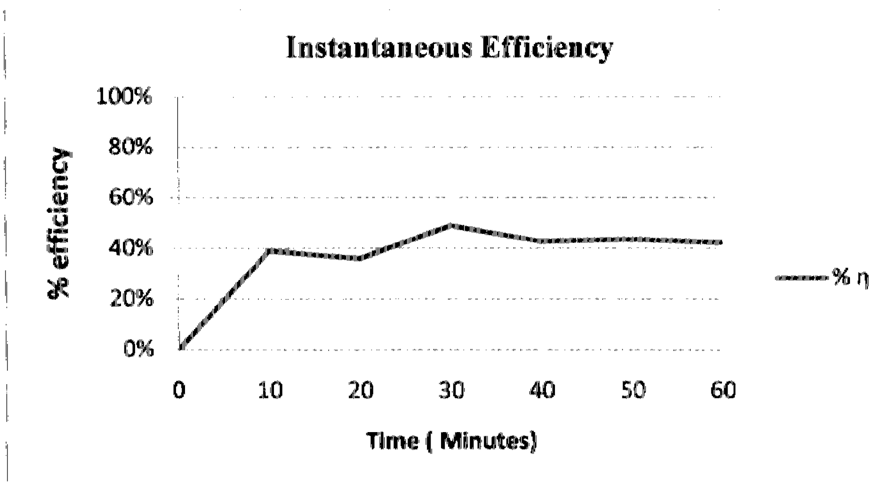


Figure 4.2: Series Flow System Instantaneous Efficiency (100l/h)

Efficiency of the collector depends on the solar irradiance and temperature different between input and output of the solar water heater. Low temperature different with high sun intensity will result low of efficiency. Figure 4.2 shows instantaneous efficiency with real time. It is increase steadily with time. The calculated instantaneous efficiency are shown in Table 4.2

Cumulative Efficiency

Table 4.3: Cumulative Data Analysis (100l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	30.00	30.00	580	0.0
10	51.60	55.90	590	4.3
20	52.10	56.10	595	4.0
30	51.90	57.40	600	5.5
40	52.60	57.40	600	4.8
50	54.10	59.00	600	4.9
60	55.80	60.70	620	4.9

$\sum \Delta T = 4.3 + 4.0 + 5.5 + 4.8 + 4.9 + 4.9 = \mathbf{28.4°C}$

$\sum Ps = 590 + 595 + 600 + 600 + 600 + 620 = \mathbf{3605 W/m^2}$

$Pi = 1.161 \times 100 \times (28.4) = \mathbf{3297.24 Watt}$

$Po = 3605 \times 2.17 = \mathbf{7822.85 Watt}$

$$\% \text{ Cumulative Efficiency} = \frac{3297.24 Watt}{7822.85\ Watt} \times 100 = 42.15\%$$

Data analysis show increasing solar irradiance intensity will increase the output temperature. Since the system were circulated, the input temperature also increased but become less than the output temperature because the heat from output temperature were absorb by water in the storage tank. Overall, experimental efficiency for series system flow at 100 liter per hour of flow rate with 90° of sun irradiation angle were 42.15%

Table 4.3 shows the outlet and inlet temperature difference for every 10 minutes time interval. The change in temperature increases steadily.

4.2.2 Series Flow system collector performance at 120 l/h flow rate (A5)

System flow: Series	Sun Radiation Angle: 90°	Flow rate, Q: 120l/h

Table 4.4: Summary of the Data Analysis for Series Flow System at 120l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	33.00	33.00	680	0.00	1475.60	0.00%
10	45.20	50.00	700	668.74	1519.00	44.02%
20	47.10	52.00	720	682.67	1562.40	43.69%
30	50.70	54.70	710	557.28	1540.70	36.17%
40	56.00	60.30	720	599.08	1562.40	38.34%
50	57.20	63.70	725	905.58	1573.25	57.56%
60	56.80	62.40	700	780.19	1519.00	51.36%

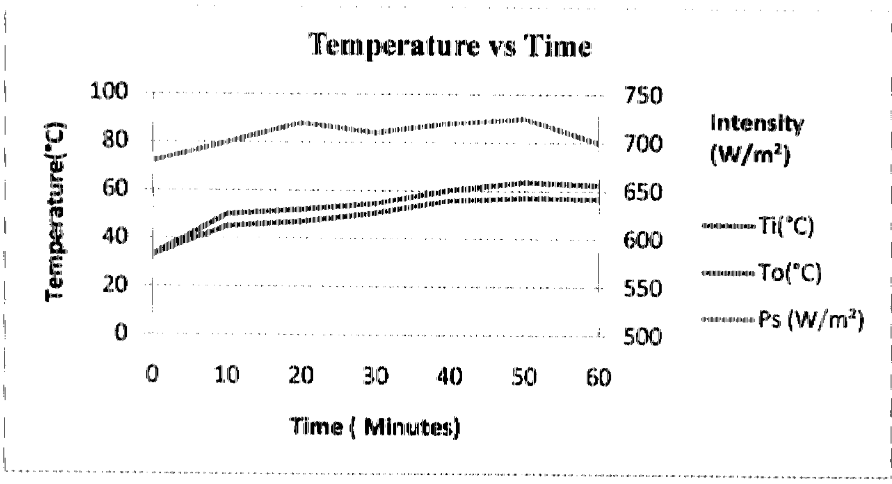


Figure 4.3: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Series Flow System (120l/h)

Figure 4.3 shows inlet and exit temperature against time interval, also solar intensity plotted above the temperature profile. Within 60 minutes of time interval, the inlet and exit temperature were continuously increasing since the solar irradiance is increasing constantly. At the end of the experiment, solar intensity dropped a bit but it did not affect both the inlet and outlet temperature trend.

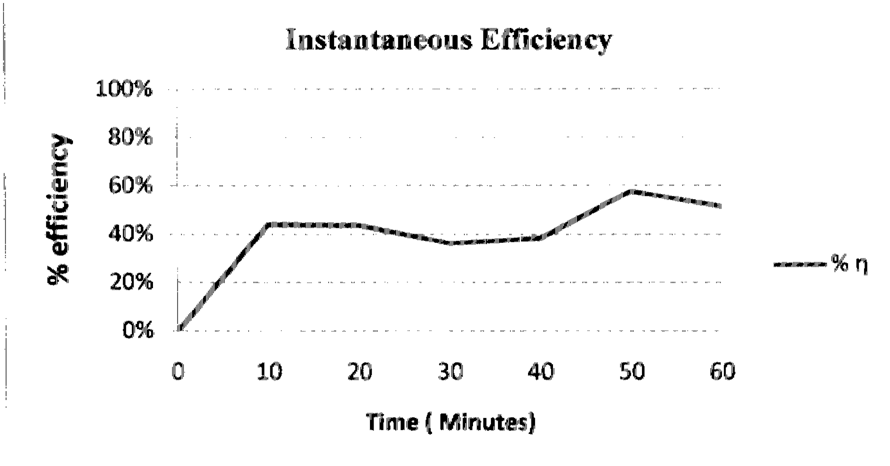


Figure 4.4: Series Flow System Instantaneous Efficiency (120l/h)

Table 4.5: Series Flow System Cumulative Data Analysis (120l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	33.00	33.00	680	0.0
10	45.20	50.00	700	4.8
20	47.10	52.00	720	4.9
30	50.70	54.70	710	4.0
40	56.00	60.30	720	4.3
50	57.20	63.70	725	6.5
60	56.80	62.40	700	5.6

$\sum \Delta T$	:	30.1	°C
$\sum Ps$	:	4275	W/m²
Pi	:	4193.53	Watt
Po	:	9276.75	Watt
$\eta_{Cumulative}$	:	45.20%	

Figure 4.4 shows instantaneous efficiency of series flow system at 120 l/h flow rate. The instantaneous efficiency trend is inconsistence. The main reason is during the experiment the weather condition was not steady. In particular intensity, inlet and outlet temperature dropped as shown in the Table 4.5. the solar radiance falling on the solar collector was varying due to cloudy condition. Due to this case, the temperature different between inlet and outlet dropped and affected the corresponding instantaneous efficiency. Cumulative efficiency for 120l/h series flow system was 45.20%.

4.2.3 Series Flow system collector performance at 80 l/h flow rate (A3)

System flow: Series	Sun Radiation Angle: 90°	Flow rate, Q: 80l/h

Table 4.6: Summary of the Data Analysis for Series Flow System at 80l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	32.00	32.00	575	0.00	1247.75	0.00%
10	42.90	47.30	580	408.67	1258.60	32.47%
20	47.00	53.60	580	613.01	1258.60	48.71%
30	48.10	54.30	590	575.86	1280.30	44.98%
40	53.60	61.50	598	733.75	1297.66	56.54%
50	54.80	61.50	594	622.30	1288.98	48.28%
60	53.90	60.00	590	566.57	1280.30	44.25%

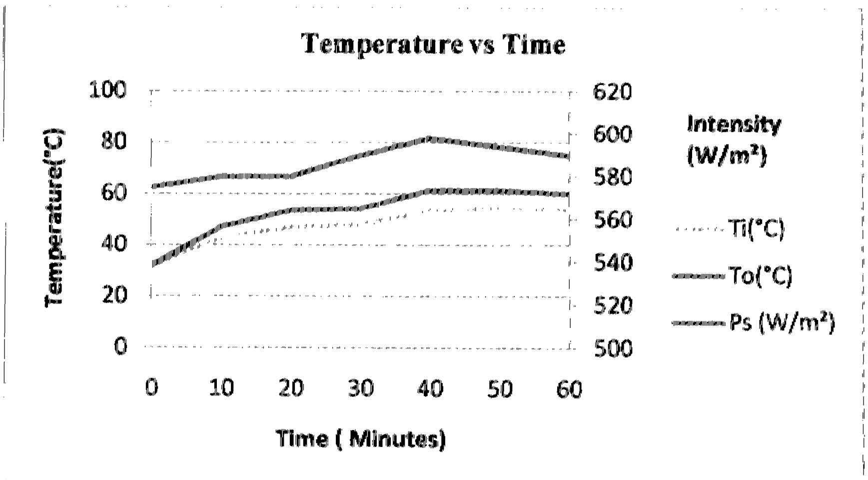


Figure 4.5: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Series Flow System (80l/h)

Figure 4.5 shows inlet and exit temperatures and solar intensity with respect to time. The inlet and exit temperatures and solar intensity continue to increase with time, the inlet and exit temperatures were continuously increasing, but 50 minutes (Table 4.6) the exit temperature remain constant and dropped since the solar intensity dropped a bit.

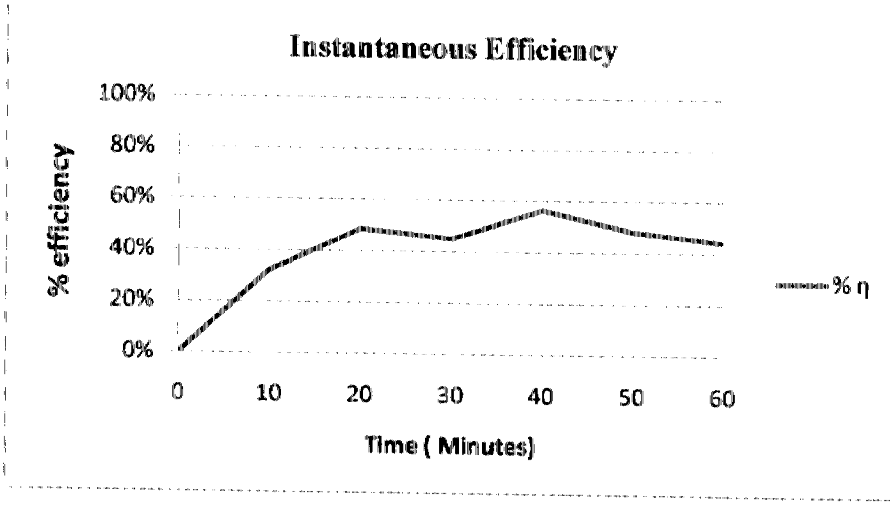


Figure 4.6: Series Flow System Instantaneous Efficiency (80l/h)

Table 4.7: Series Flow System Cumulative Data Analysis (80l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	32.00	32.00	575	0.0
10	42.90	47.30	580	4.4
20	47.00	53.60	580	6.6
30	48.10	54.30	590	6.2
40	53.60	61.50	598	7.9
50	54.80	61.50	594	6.7
60	53.90	60.00	590	6.1

$\sum \Delta T$	:	37.9	°C
$\sum Ps$	:	3532	W/m²
Pi	:	3520.15	Watt
Po	:	7664.44	Watt
$\eta_{Cumulative}$	:	45.93%	

Figure 4.6 shows instantaneous efficiency of series flow system at 80 l/h flow rate. The graph shows the efficiency drops at 30.50 and 60 minutes. The main reason was inconsistence weather condition during the experiment. The solar intensity, inlet and outlet temperatures were dropped as shown in the Table 4.7. Cumulative efficiency for 80l/h series flow system was 45.93%.

4.2.4 Series Flow system collector performance at 60 l/h flow rate (A2)

System flow: Series	Sun Radiation Angle: 90°	Flow rate, Q: 60l/h

Table 4.8: Summary of the Data Analysis for Series Flow System at 60l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	33.00	33.00	600	0.00	1302.00	0.00%
10	45.10	54.10	620	626.94	1345.40	46.60%
20	47.30	56.30	650	626.94	1410.50	44.45%
30	52.80	61.00	650	571.21	1410.50	40.50%
40	56.50	64.20	670	536.38	1453.90	36.89%
50	60.80	70.90	690	703.57	1497.30	46.99%
60	62.10	71.90	690	682.67	1497.30	45.59%

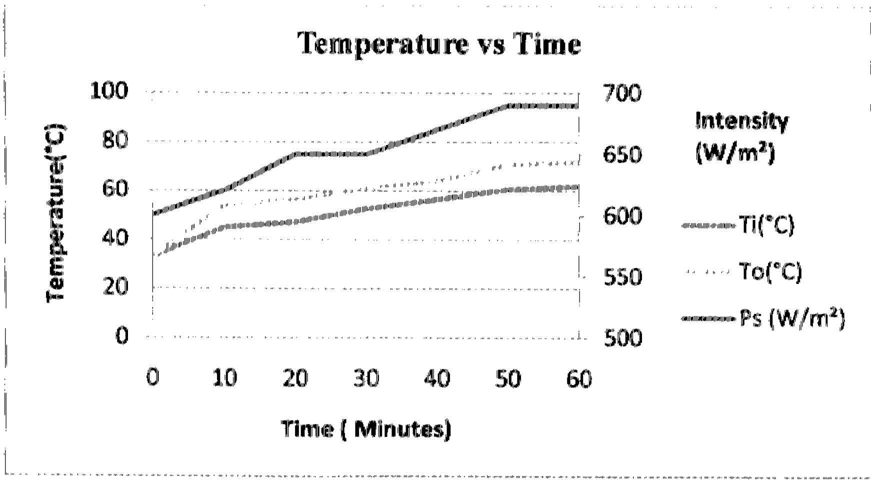


Figure 4.7: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Series Flow System (60l/h)

Figure 4.7 shows the inlet and outlet temperatures and solar irradiance trend with time. Relatively the experiment was conducted in a clear sunny day and hence the inlet and outlet temperatures and solar radiance increase with respect to time. The raw data for this experiment is shown in Table 4.8

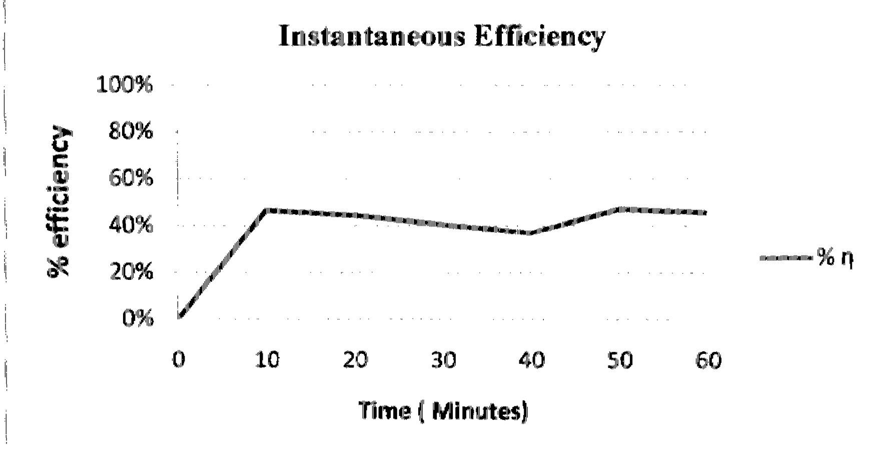


Figure 4.8: Series Flow System Instantaneous Efficiency (60l/h)

Table 4.9: Series Flow System Cumulative Data Analysis (60l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT
0	33.00	33.00	600	0.0
10	45.10	54.10	620	9.0
20	47.30	56.30	650	9.0
30	52.80	61.00	650	8.2
40	56.50	64.20	670	7.7
50	60.80	70.90	690	10.1
60	62.10	71.90	690	9.8

$\sum \Delta T$	:	53.8	°C
$\sum Ps$	:	3970	W/m²
Pi	:	3747.708	Watt
Po	:	8614.9	Watt
$\eta_{Cumulative}$	:	43.50%	

The solar collector was initially hot before the experiment conducted. So the moment of the water flow, the temperature rise was high, as result on first 10 minutes the efficiency at the initial is high. After that, the temperature rise was almost steady. Cumulative efficiency for 60 l/h series flow system was 43.50%. Table 4.9 shows the summary of the calculated power output and change in temperatures between the outlet and inlet of the collector.

4.2.5 Series Flow system collector performance at 40 l/h flow rate (A1)

System flow: Series	Sun Radiation Angle: 90°	Flow rate, Q: 40l/h

Table 4.10: Summary of the Data Analysis for Series Flow System at 40l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	30.70	30.70	530	0.00	1150.10	0.00%
10	40.30	58.90	600	863.78	1302.00	66.34%
20	45.40	61.10	666	729.11	1445.22	50.45%
30	47.10	62.50	670	715.18	1453.90	49.19%
40	48.70	63.10	690	668.74	1497.30	44.66%
50	49.40	64.30	710	691.96	1540.70	44.91%
60	51.60	67.00	700	715.18	1519.00	47.08%

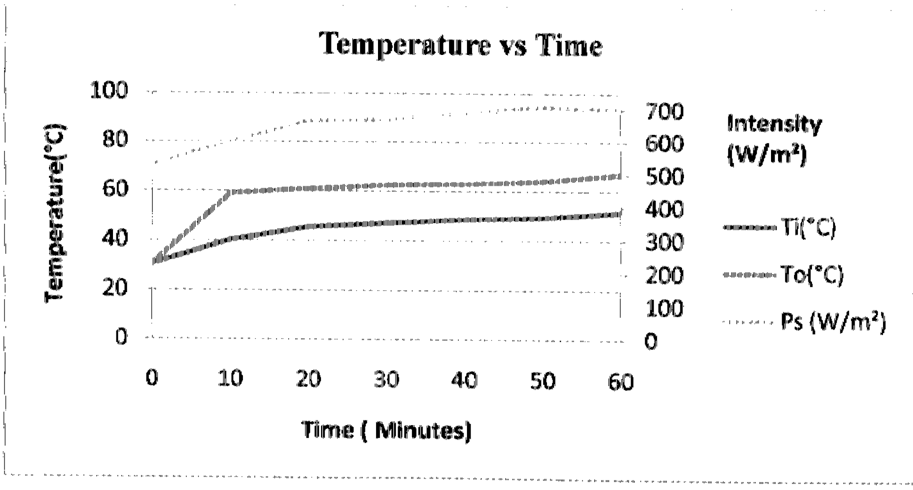


Figure 4.9: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Series Flow System (40l/h)

The experiment was conducted during good sunny day. Increasing solar intensity will increased the inlet and exit temperature at constant rate. Figure 4.9 shows the constant increasing from the beginning until the end of the experiment. But at the beginning of the experiment, the output temperature was spiked due to preheat of the solar collector by the sun. the corresponding raw data for this experiment is shown in Table 4.10.

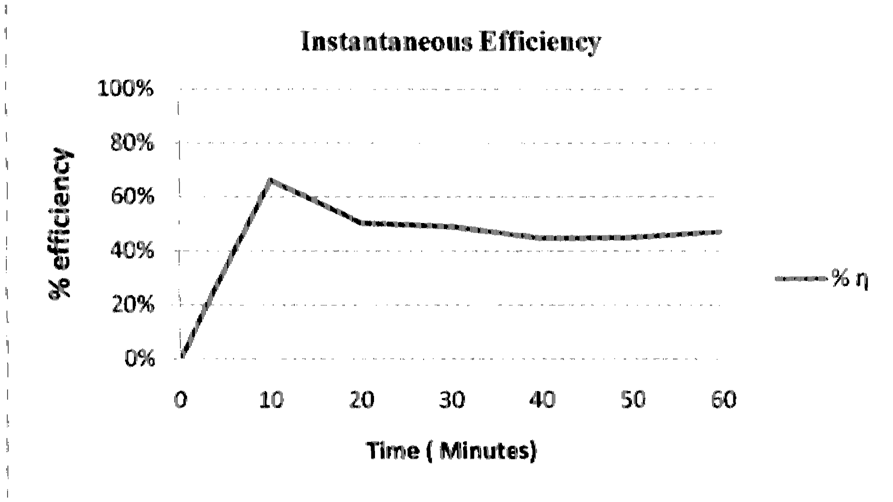


Figure 4.10: Series Flow System Instantaneous Efficiency (40l/h)

Table 4.11: Series Flow System Cumulative Data Analysis (40l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT
0	30.70	30.70	530	0
10	40.30	58.90	600	18.6
20	45.40	61.10	666	15.7
30	47.10	62.50	670	15.4
40	48.70	63.10	690	14.4
50	49.40	64.30	710	14.9
60	51.60	67.00	700	15.4

∑ΔT	:	94.4	°C
∑Ps	:	4036	W/m²
Pi	:	4383.94	Watt
Po	:	8758.12	Watt
$\eta_{Cumulative}$	:	50.06%	

As discussed earlier in Chapter 4.2.4, the same phenomena occur in this experiment. The solar collector was initially hot before the experiment conducted. As shown in Figure 4.10 the temperature rise is high during the initial water flow inside the system. As result the initial the efficiency was high and become steady after that. Cumulative efficiency for 40 l/h series flow system was 50.06%. Table 4.11 shows the tabulated data for this experiment.

4.3 Calculation for Parallel Flow System

4.3.1 Parallel Flow System collector performance at 120 l/h flow rate (B5)

System flow: Parallel	Sun Radiation Angle: 90°	Flow rate, Q: 120l/h

Table 4.12: Summary of the Data Analysis for Parallel Flow System at 120l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	33.00	33.00	506	0.00	1098.02	0.00%
10	40.70	43.70	512	417.96	1111.04	37.62%
20	43.90	46.90	513	417.96	1113.21	37.55%
30	44.60	47.70	515	431.89	1117.55	38.65%
40	46.20	49.20	530	417.96	1150.10	36.34%
50	47.90	50.50	526	362.23	1141.42	31.74%
60	48.50	51.60	555	431.89	1204.35	35.86%

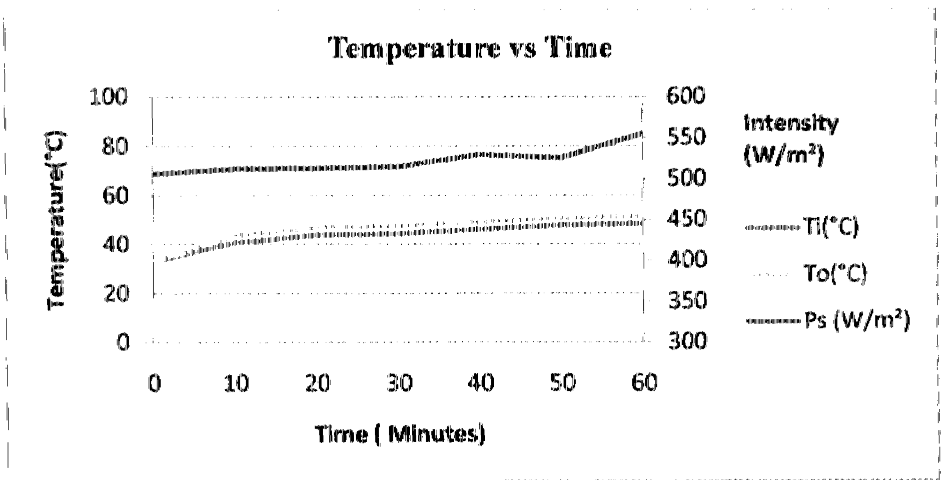


Figure 4.11: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Parallel Flow System (120l/h)

Figure 4.11 show the temperature inlet and exit temperatures, variation for almost constant solar radiation falling on the solar panel. At the end of the experiment, solar intensity increased gradually but the temperatures remains constant. This is because the sky was cleared from any cloud and the solar radiation directly hit the ground without any filtering from the cloud. Table 4.12 indicate the numerical data of this experiment.

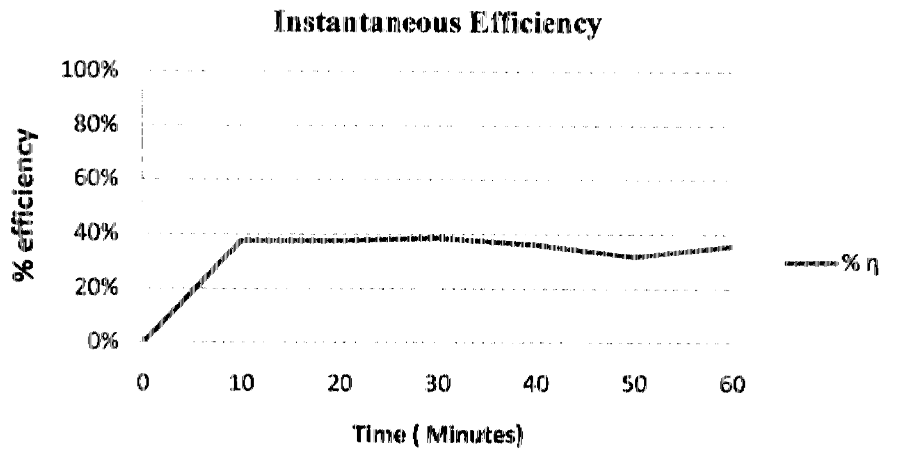


Figure 4.12: Parallel Flow System Instantaneous Efficiency (120l/h)

Table 4.13: Parallel Flow System Cumulative Data Analysis (120l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	33.00	33.00	506	0
10	40.70	43.70	512	3
20	43.90	46.90	513	3
30	44.60	47.70	515	3.1
40	46.20	49.20	530	3
50	47.90	50.50	526	2.6
60	48.50	51.60	555	3.1

$\sum \Delta T$	:	17.8	°C
$\sum Ps$	:	3151	W/m²
Pi	:	2479.9	Watt
Po	:	6837.67	Watt
$\eta_{Cumulative}$	:	36.27%	

Cumulative efficiency for 120l/h parallel flow rate system was 36.27%. The efficiency on every 10 minutes time interval was constant as shown in Figure 4.12. At the end of experiment, the efficiency drops a bit due to decreasing solar intensity. The solar intensity was recorded manually and human errors are taken into account during data recorded. The calculated power output and temperature change between the exit and inlet is tabulated in Table 4.13.

4.3.2 Parallel Flow System collector performance at 100 l/h flow rate (B4)

System flow: Parallel	Sun Radiation Angle: 90°	Flow rate, Q: 100l/h

Table 4.14: Summary of the Data Analysis for Parallel Flow System at 100l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	33.50	33.50	500	0.00	1085.00	0.00%
10	42.60	46.70	510	476.01	1106.70	43.01%
20	52.20	55.10	500	336.69	1085.00	31.03%
30	53.50	55.60	498	243.81	1080.66	22.56%
40	49.40	52.50	450	359.91	976.50	36.86%
50	48.20	50.20	425	232.20	922.25	25.18%
60	48.80	50.90	410	243.81	889.70	27.40%

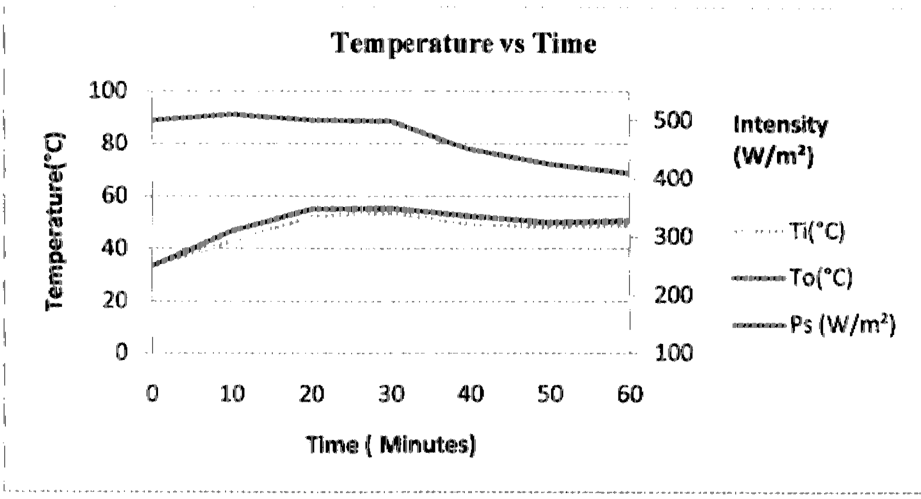


Figure 4.13: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Parallel Flow System (100l/h)

The solar intensity were drops with respect to time as show in the Figure 4.13 due to unstable weather condition when the experiment was conducted. The data trends for solar intensity was stable at the beginning and start to dropped 30 minutes after the experiment start. The cloudy sky affected receiving high solar intensity to the panel. Table 4.14 contains the summary of the calculated input and output heat rates and instantaneous efficiencies.

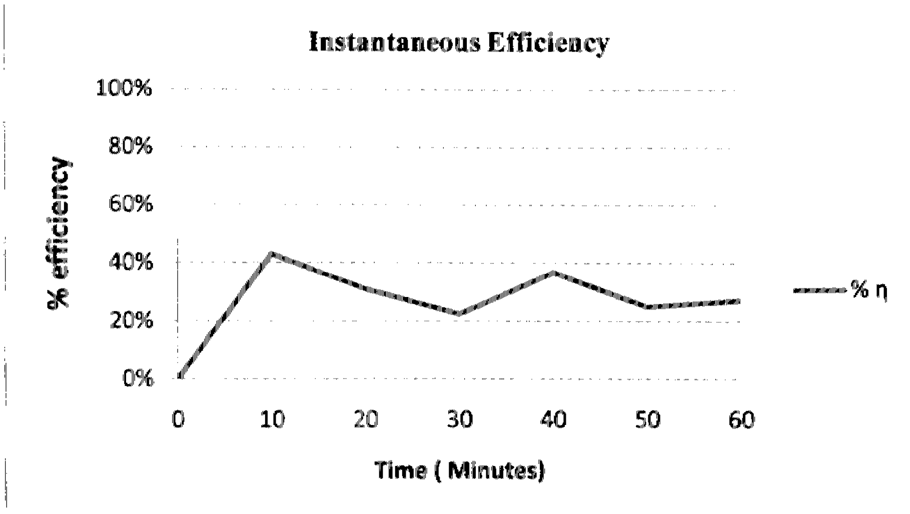


Figure 4.14: Parallel Flow System Instantaneous Efficiency (100l/h)

Table 4.15: Parallel Flow System Cumulative Data Analysis (100l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	33.50	33.50	500	0
10	42.60	46.70	510	4.1
20	52.20	55.10	500	2.9
30	53.50	55.60	498	2.1
40	49.40	52.50	450	3.1
50	48.20	50.20	425	2
60	48.80	50.90	410	2.1

$\sum \Delta T$	:	16.3	°C
$\sum Ps$	:	2793	W/m²
Pi	:	1892.43	Watt
Po	:	6060.81	Watt
$\eta_{Cumulative}$	:	31.22%	

The solar collector was initially hot before the experiment was conducted. The temperature rise was high during the moment of initial water flow inside the system as shown in Figure 4.14. The efficiency calculated in every 10 minutes were fluctuated due to unstable weather condition. The experiment was completed during cloudy and windy day. The unstable solar intensity received by the solar collector was also affect the temperature differentce between inlet and exit and also affected the efficiency of the system.

4.3.3 Parallel Flow System collector performance at 80 l/h flow rate (B3)

System flow: Parallel	Sun Radiation Angle: 90°	Flow rate, Q: 80l/h

Table 4.16: Summary of the Data Analysis for Parallel Flow System at 80l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	33.80	33.80	515	0.00	1117.55	0.00%
10	41.00	45.10	520	380.81	1128.40	33.75%
20	43.80	46.90	520	287.93	1128.40	25.52%
30	44.80	47.60	530	260.06	1150.10	22.61%
40	48.70	52.00	525	306.50	1139.25	26.90%
50	47.80	50.70	530	269.35	1150.10	23.42%
60	49.10	52.40	550	306.50	1193.50	25.68%

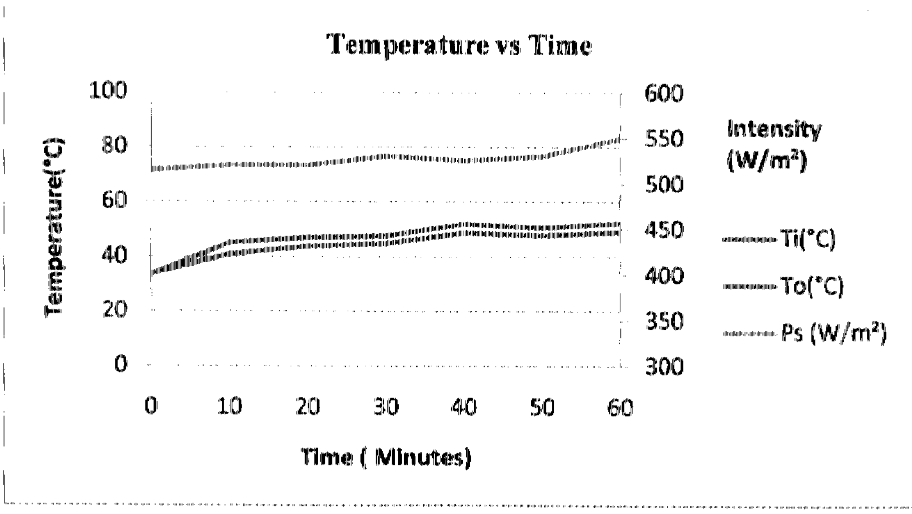


Figure 4.15: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Parallel Flow System (80l/h)

The output from this experiment was stable. Figure 4.15 shows the levels of solar intensity were constant inlet and output temperatures increase steadily. The experiment was completed during sunny day but the solar intensity level a bit lower due to thick cloud appeared over the sky. The corresponding calculated numerical values are tabulated in Table 4.16.

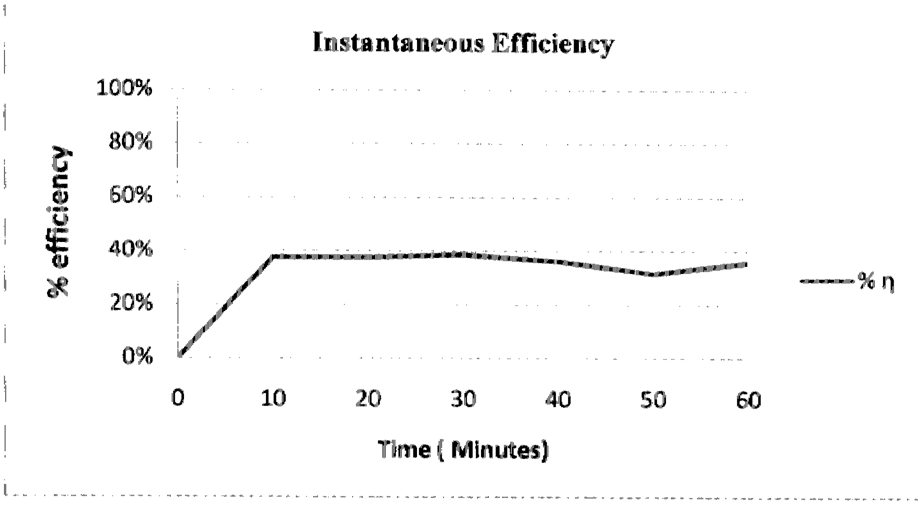


Figure 4.16: Parallel Flow System Instantaneous Efficiency (80l/h)

Table 4.17: Parallel Flow System Cumulative Data Analysis (80l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	33.80	33.80	515	0
10	41.00	45.10	520	4.1
20	43.80	46.90	520	3.1
30	44.80	47.60	530	2.8
40	48.70	52.00	525	3.3
50	47.80	50.70	530	2.9
60	49.10	52.40	550	3.3

$\sum \Delta T$	:	19.5	°C
$\sum Ps$	:	3175	W/m²
Pi	:	1811.16	Watt
Po	:	6889.75	Watt
$\eta_{Cumulative}$	:	26.29%	

Figure 4.16 shows constant efficiency during the experiment due to solar collector constant receiving the solar radiation. Cumulative efficiency was 26.29%, a bit lower compare to other experiment due to high humidity when the experiment conducted. The water heat gain rate and temperature change between exit and inlet is shown in Table 4.17.

4.3.4 Parallel Flow System collector performance at 60 l/h flow rate (B2)

System flow: Parallel	Sun Radiation Angle: 90°	Flow rate, Q: 60l/h

Table 4.18: Summary of the Data Analysis for Parallel Flow System at 60l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	32.00	32.00	590	0.00	1280.30	0.00%
10	50.80	55.80	580	348.30	1258.60	27.67%
20	54.50	60.30	600	404.03	1302.00	31.03%
30	51.10	57.90	575	473.69	1247.75	37.96%
40	52.40	58.50	580	424.93	1258.60	33.76%
50	52.90	59.10	590	431.89	1280.30	33.73%
60	53.50	60.30	585	473.69	1269.45	37.31%

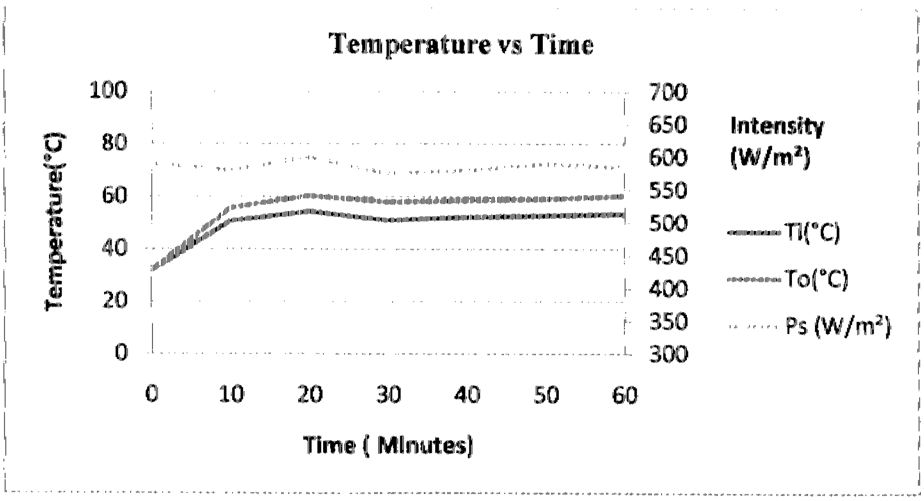


Figure 4.17: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Parallel Flow System (60l/h)

The Figure 4.17 shows that the solar intensity increased at first 20 minutes and fluctuates until the end of the experiment. Due to this situation, the inlet and exit temperature were affected and fluctuating. The exit temperature at minutes of 20 and 60 were same though the solar intensity was different. This affected the efficiency of the system during the current parameter setup. The summary of calculation for this case is shown in Table 4.18.

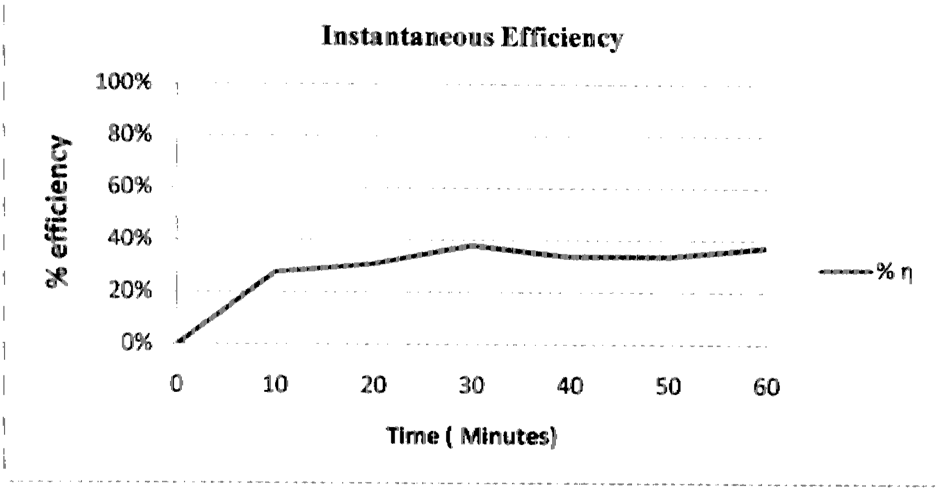


Figure 4.18: Parallel Flow System Instantaneous Efficiency (60l/h)

Table 4.19: Parallel Flow System Cumulative Data Analysis (60l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	32.00	32.00	590	0
10	50.80	55.80	580	5
20	54.50	60.30	600	5.8
30	51.10	57.90	575	6.8
40	52.40	58.50	580	6.1
50	52.90	59.10	590	6.2
60	53.50	60.30	585	6.8

$\sum\Delta T$	:	36.7	°C
$\sum Ps$	:	3510	W/m²
Pi	:	2556.52	Watt
Po	:	7616.7	Watt
$\eta_{Cumulative}$	:	33.56%	

The efficiency increase abnormally with respect to time as shows in Figure 4.18 due to unstable weather condition when the experiment were conducted. The solar intensity levels received by solar collector were uneven. As result, the temperature difference at every time interval was fluctuate as shown in Table 4.19. Cumulative efficiency for 60l/h parallel flow system was 33.56% and this was quiet high compared with previous experiment.

4.3.5 Parallel Flow System collector performance at 40 l/h flow rate (B1)

System flow: Parallel	Sun Radiation Angle: 90°	Flow rate, Q: 40l/h

Table 4.20: Summary of the Data Analysis for Parallel Flow System at 40l/h

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	Po (W)	Pi(W)	% efficiency
0	31.00	31.00	500	0.00	1085.00	0.00%
10	39.10	44.40	500	246.13	1085.00	22.68%
20	46.00	51.10	480	236.84	1041.60	22.74%
30	42.80	48.30	473	255.42	1026.41	24.88%
40	44.40	54.50	545	469.04	1182.65	39.66%
50	43.60	50.70	590	329.72	1280.30	25.75%
60	45.10	51.80	585	311.15	1269.45	24.51%

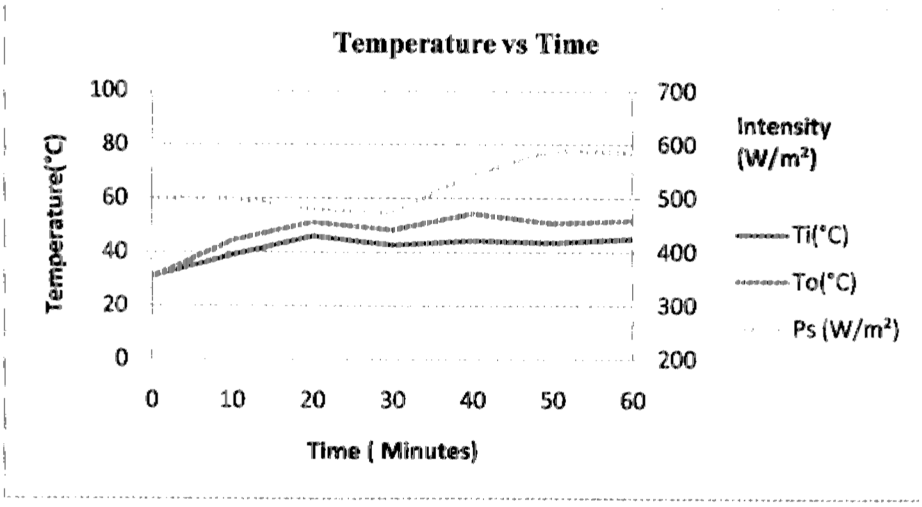


Figure 4.19: Inlet, Exit Temperature and Solar Irradiance of the Evacuated Collector in Parallel Flow System (40l/h)

As shown in Figure 4.19, the solar irradiance instead of increasing gently, it is fluctuate. The main reason is inconsistence weather condition during the experiment. The water inlet and exit temperatures vary in similar trend as they affected by the solar irradiance. The collected numerical data for this experiment are summarized in Table 4.20.

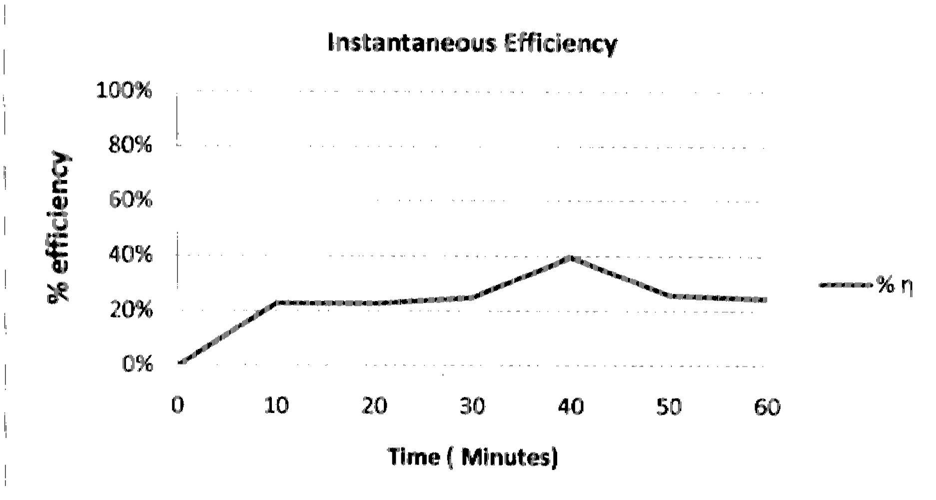


Figure 4.20: Parallel Flow System Instantaneous Efficiency (40l/h)

Table 4.21: Parallel Flow System Cumulative Data Analysis (40l/h)

Minutes	Ti(°C)	To(°C)	Ps (W/m²)	ΔT(°C)
0	31.00	31.00	500	0
10	39.10	44.40	500	5.3
20	46.00	51.10	480	5.1
30	42.80	48.30	473	5.5
40	44.40	54.50	545	10.1
50	43.60	50.70	590	7.1
60	45.10	51.80	585	6.7

$\sum\Delta T$	:	39.8	°C
$\sum Ps$	:	3673	W/m²
Pi	:	1848.31	Watt
Po	:	7970.41	Watt
$\eta_{Cumulative}$	:	23.19%	

As shown in Figure 4.20, The instantaneous efficiency 40 minutes suddenly increases due to low solar intensity level measured at the moment. When the data recorded, the sky was cloudy and the solar intensity were constant at first 30 minutes. After a few moments, the cloud was gone and solar radiation directly hit the solar collector that make the reading of solar intensity high after 30 minutes and onward. The efficiency was 23.19%. Table 4.21 indicates the calculated heat gain rate and the water temperature gain between exit and inlet.

4.4 Cumulative Efficiency in different flow rate for series and parallel flow system

Table 4.22: Cumulative Efficiency for Overall Experiments

System Flow	Angle (°)	Flowrate	η Cumulative (%) Experiment
Series	90°	40	50.06%
		60	43.50%
		80	45.93%
		100	42.15%
		120	45.20%
Parallel	90°	40	26.84%
		60	33.56%
		80	26.29%
		100	31.22%
		120	36.27%

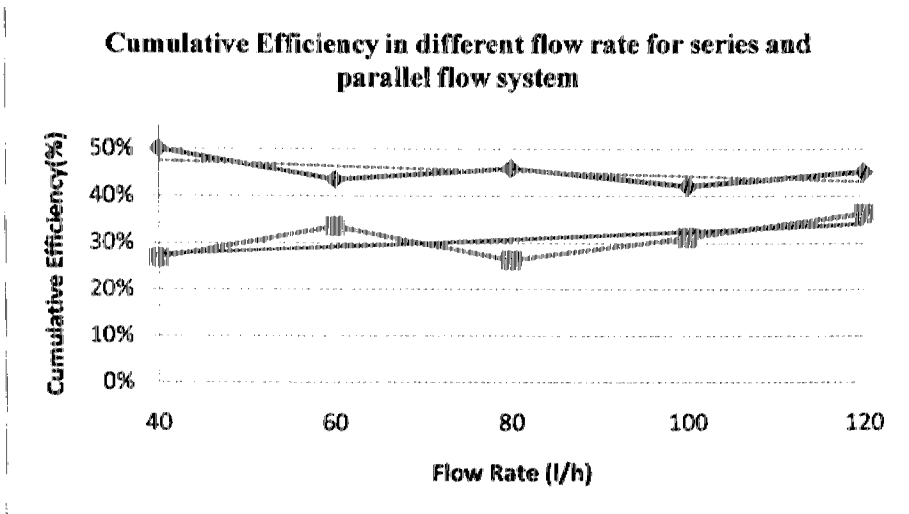


Figure 4.21: Cumulative Efficiency in different flow rate for series and parallel flow system

From the Figure 4.21, series flow system give high efficiency at lower flow rate but for the parallel flow system, higher flow rate gives high efficiency. Further discussion continued on next sub chapter on characteristic curve.

4.5 Characteristic curve

4.5.1 Characteristic curve for series flow system

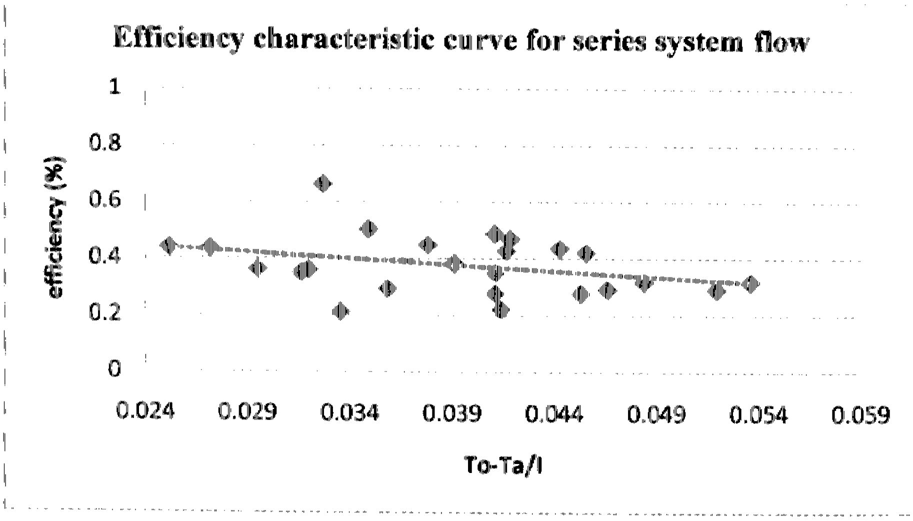


Figure 4.22: Efficiency characteristic curve for series system flow

Standard measurement were selected to be used and Hottel - Whillier Bliss characteristic curve being used to evaluated to check whether the experiment is successful or not. The plotted graph shows efficiency against standard measurement of Hottel-Whillier Bliss characteristic formula. The outlet temperature minus by average ambient temperature and divide by solar intensity. The linear line (Figure 4.22) shows the downward trend for series flow system with vary flow rate and meet the expectation for evaluation of evacuated solar water heater (G.N Tiwari, 2002).

Base on the experiment for series flow system, the best efficiency was at 40 liter per hour of flow rates, with angle of solar collector perpendicular to solar radiation.

4.5.2 Characteristic curve for parallel flow system

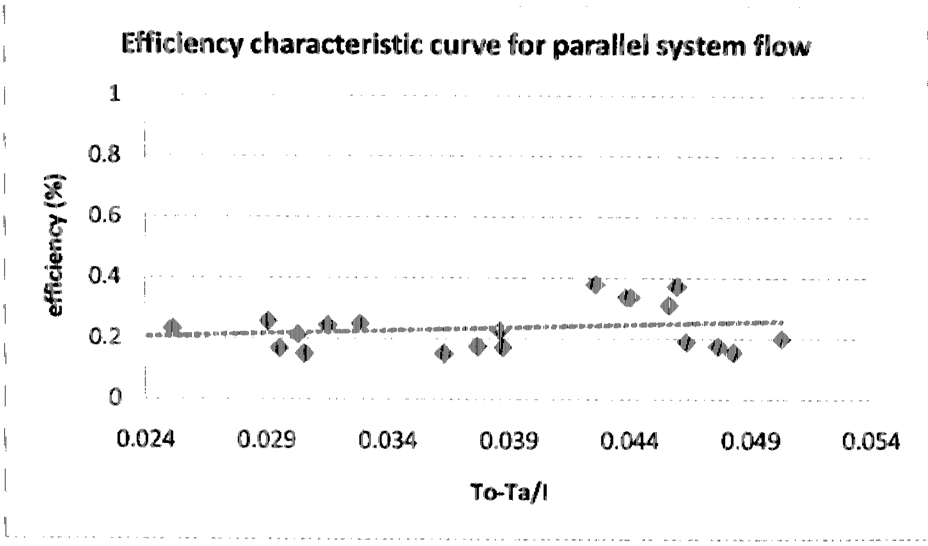


Figure 4.23: Efficiency characteristic curve for parallel system flow

The linear line (Figure 4.23) shows the upward trend for parallel flow system with flow rate, does not meet the expectation for evaluation of evacuated solar water heater (G.N Tiwari, 2002). Hence, evaluation for parallel flow system was not successful. This was due to unstable weather condition when the experiments were conducted. Malaysia was situated in equatorial zone, since the experiments were conducted during December. Furthermore every end of the year it is rainy season for equatorial zone especially Malaysia. Some of the days were raining in the morning and cloudy in the afternoon until evening, it very hard to get full sunny day during this period.

For example, the 100l/h parallel series flow experiments were conducted and the result of solar intensity and temperature were fluctuating. This is because the experiment was conducted after raining in the morning, the sun was fully shining at the beginning of the experiment, and the clouds covered the sun after a few moments. Hence, the solar radiation not uniformly radiated to the solar collector with respect to time. The problem was out of our capability to control and some recommendations were proposed to overcome this issue.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

Solar energy can be used to power electronic appliances while not polluting the environment. Our goal is to learn how solar energy works, and in which situations it can be used. This experiment tells that solar power caused no pollution to the environment. Solar energy can be used to power houses and their electronic appliances, such as flashlights, electric motors and even such things as refrigerators. But here focusing on water heating system using solar radiation.

In this project, ten experiments were conducted by varying the flow rate and flow system of solar water heater. All of the experiments were conducted at the same open area, with same device setup during November until December 2011. Hence, based on Figure 4.2.1, the series flow system gives higher efficiency compared to parallel flow system. To archive the maximum efficiency, the solar radiation must radiated perpendicular to the solar collector.

The best parameter for series flow system was 40 l/h with efficiency 50.06%, and for parallel flow system, it was not able to obtain the best parameter since the experimental data did not meet requirement of Hottel-Whillier Bliss characteristic curve. Overall, it was not able to decide yet which flow system and flow rate is the best for evacuated solar water heater. Further experiment and analysis with proper weather condition were needs to evaluate the performance of solar water heater with different parameters. Future work and recommendation were discussed in the next sub chapter.

5.2 Recommendation

There are some recommendations being made for further improvement to the solar water heater. Two-Axis Solar Tracking System needs to be assembled together with the machine to track the orientation of the sun. The purpose of the solar tracking system is to help the collector to absorb maximum solar radiation. The best orientation for fixed solar collector was facing south and latitude angle with additional of 20° of angle for solar collector measured from horizontal (Table 5.1). But the best orientation for non- fixed solar collector was always perpendicular to the sun radiation. (Figure 5.1)

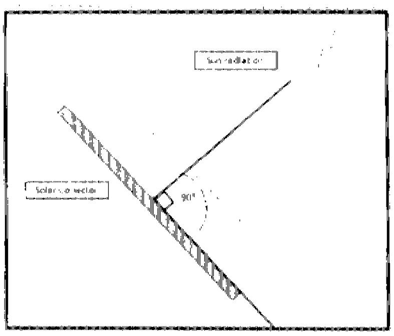


Figure 5.1: Solar Panel Orientation

Angle of solar radiation respect to solar collector	Solar Intensity (W/m²)
135°	520
112.5°	545
90°	565
67.5°	540
45°	500
latitude angle + 20° from horizontal for solar collector	450

Table 5.1: Solar intensity with different orientation

Since the experiment was conducted during rainy season, the alternative way to get constant sun radiation is by using sun radiation lamp. Constant solar radiation exposed to the solar collector will result constant increment of inlet and exit temperature (Iordanau, Grigorios, 2009). Application of solar radiation lamp will eliminate the dependence of natural solar radiation for evaluation of solar water heater.

Making some significant positive changes to SWH does not necessarily imply that need a large amount of spend. Just simply need to employ a little creativity in a few important areas. Instead of manually monitored the output from the SWH, it is necessary to use automatic data logger to overcome error of human being. The data logger can be set at any time interval to save all activity of the SWH during experiment.

Using normal thermometer maybe is not a good idea to determine exact temperature of the device. Instead of using digital thermometer to avoid human error while taking the reading, thermocouple is the other alternative temperature measurement since the temperature determine by thermocouple more accurate and precise.

TRNSYS simulation must put into account for future work of evaluated solar water heater. The result obtained from real experimental can be compared with the result from computer simulation.

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