Experimental investigation of open loop thermosyphoning in evacuated tube receiver under varying heat flux

by

Arief Farhan Bin Mat Arifin

23169

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Mechanical Engineering

with Honours

JANUARY 2020

Universiti Teknologi PETRONAS

32610 Bandar Seri Iskandar

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Experimental investigation of open loop thermosyphoning in evacuated tube receiver under varying heat flux

by

Arief Farhan Bin Mat Arifin

23169

A project dissertation submitted to

Mechanical Engineering Programme

Universiti Teknologi Petronas

in partial fulfilment of the requirements for the

Bachelor of Mechanical Engineering with Honours

Approved by,

…………………………………………………

(AP DR. SYED IHTSHAM UL-HAQ GILANI)

UNIVERSITI TEKNOLOGI PETRONAS

Bandar Seri Iskandar, PERAK

January 2020

CERTIFICATION OF ORIGINALITY

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

………………………………………..

(ARIEF FARHAN BIN MAT ARIFIN)

Mechanical Engineering Department

Universiti Teknologi PETRONAS.

ABSTRACT

Thermosyphon is a mechanism involving passive heat exchange by principle of natural convection, which used to transfer fluids without any use of mechanical pump. In solar water heating system, principle of thermosyphon is applied by evacuated tube receiver (ETR). ETR is an efficient solar collector responsible of collecting and transmit the thermal energy in this process. This heating system is used heavily in the production of hot water domestically, but it also can be applied for industrial purpose, if proper innovation is designed. However, this process of optimization is expensive and time-consuming. It becomes more challenging when variables such as geographical location, solar radiation and sky condition can affect the thermosyphon performance. Hence, the performance of ETR depends on many variables and parameters that need numerous experiments. The objective of this research is to investigate the effect of varying heat flux on thermosyphon performance of ETR. The absorber tube and outlet water temperature of a solar ETR with straight riser is investigated. The scope of this study is a field investigation for actual ETR which operates in an open loop solar water heating system at a solar site in Universiti Teknologi PETRONAS, Seri Iskandar. The solar water heating system's thermal efficiency is observed to increase with ambient temperature, solar heat flux and water mass flow rate. The thermal efficiency however decreases as the temperature of the inlet water increases. The present study offers useful tools to measure the effectiveness of ETR for Seri Iskandar city.

ACKNOWLEDGEMENT

In the Name of Allah, Most Gracious, Most Merciful

First and foremost, I wish to express my gratitude to Allah S.W.T for His kindness and blessing which enlighten me to successfully complete this final year project.

I have been grateful to many personnel, academicians and industry practitioners during working on this project. They have been helpful assisting me in my comprehension and reflecting myself. In particular, I would like to express my profound gratitude to my FYP supervisor, AP Dr Syed Ihtsham Ul-Haq Gilani, for his continuous guidance, motivation and review for my project .I am also very thankful to my partner in this project, Muhammad Rameez-ud-Din for his assistance in sharing the data and information. The project would not have been the same as described here, without their unwavering support and involvement.

I also would like to recognise Universiti Teknologi PETRONAS for giving me such a great opportunity to work on this project where implementation from this project outcome into real industrial application can improve the current design of ETR that can operate more efficiently for future innovative technologies

My sincere gratitude also applies to all my colleagues and others who have on different occasions provided assistance. Finally, I am grateful to my beloved parents and family who are always beside me and giving the morale booster in this new chapter of life.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL i
CERTIFICATION OF ORIGINALITY ii
ABSTRACT iii
ACKNOWLEDGEMENT iv
LIST OF FIGURES vii
LIST OF TABLES ix
CHAPTER 1 1
INTRODUCTION 1
1.1 Background 1
1.2 Problem Statement 4
1.3 Objectives 5
1.4 Scope of Study 6
CHAPTER 2 7
LITERATURE REVIEW 7
2.1 Compound Parabolic Collectors (CPCs) 7
2.2 Thermosyphon 9
2.3 Single Phase Closed Loop Thermosyphon 11
2.4 Evacuated Tube Receiver 12
2.5 The Effect of the Input of Heat Flux on the Rate of Thermosyphon 13
CHAPTER 3 17
METHODOLOGY 17
3.1 Developed Evacuated Tube Receiver 18
3.2 Experimental setup 20
3.3 Gantt Chart 22
CHAPTER 4 24
RESULT AND DISCUSSION 24
4.1 Variations of flow rate as a function of daylight hours 25
.... 29
4.2 Variations of radiation, G_t and outlet temperature, T_{out} as a function of daylight hours 30

4.3 Variations of efficiency as a function of daylight hours 35
CHAPTER 5 41
CONCLUSION AND RECOMMENDATION.. 41
5.1 Conclusion.. 41
5.2 Recommendation.. 42
REFERENCES.. 43

LIST OF FIGURES

Figure 1. 1 Types of evacuated tube receivers. 3

Figure 2. 1 Basic geometry of a CPC. 7
Figure 2. 2 Schematic diagram of the thermosyphon solar water heater 10
Figure 2. 3 Types of thermosyphon. 11

Figure 3. 1 Schematic diagram of riser and header pipe. 18
Figure 3. 2 Schematic diagram of the experimental setup. 20
Figure 3. 3 Photograph of the open loop solar heating system. 21
Figure 3. 4 Gantt chart FYP I. 22
Figure 3. 5 Gantt chart FYP II. 23

Figure 4. 1 Variations of flow rate as a function of daylight hours for angle 15° at (a) 25th February, (b) 26th February and (c) 27th February. 26
Figure 4. 2 Variations of flow rate as a function of daylight hours for angle 45° at (a) 2nd March, (b) 3rd March and (c) 4th March. 28
Figure 4. 3 Variations of flow rate as a function of daylight hours for angle 35° at (a) 10th March, (b) 12th March and (c) 16th March 29
Figure 4. 4 Variations of radiation, Gt and outlet temperature, Tout as a function of daylight hours for angle 15° at (a) 25th February, (b) 26th February and (c) 27th February. 32
Figure 4. 5 Variations of radiation, Gt and outlet temperature, Tout as a function of daylight hours for angle 45° at (a) 2nd March, (b) 3rd March and (c) 4th March 33
Figure 4. 6 Variations of flow rate as a function of daylight hours for angle 35° at (a) 10th March, (b) 12th March and (c) 16th March 35

Figure 4. 7 Variations efficieny as a function of daylight hours for angle 15° at (a) 25th February, (b) 26th February and (c) 27th February. 37
Figure 4. 8 Variations of effiency as a function of daylight hours for angle 45° at (a) 2nd March, (b) 3rd March and (c) 4th March.. 38
Figure 4. 9 Variations of efficiency as a function of daylight hours for angle 35° at (a) 10th March, (b) 12th March and (c) 16th March... 40

LIST OF TABLES

Table 3. 1 Detailed specifications fabricated solar collector. 19

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 Background

Energy that have does not have limit to its source is termed renewable energy. It has become a heated discussion on how to properly utilize this kind of energy source. Choosing the right energy source to use is very critical and a lot of factors need to be considered such as sustainability, cost, efficiency, cleanliness and environmental impacts. Unfortunately for electricity generation, energy from fossil fuels are still the main choice for most of the industries globally. Fossil fuel are undoubtedly the most effective source for energy in terms of the quality of power production, but they are not beneficial in the long run. One day, fossil fuels will ran out and the sectors will have to switch to renewable sources without delaying it anymore. In fact, these fossil fuels are increasingly becoming a major threat to the health of the atmosphere and are becoming a source of many environmental hazards [1].

The earth is facing global warming from end to end of our poles. These vulnerable regions have been recording an increase of 1.6 °F (about 0.9 °C) after year 1906 in the global average surface temperature. The effect of this phenomenon can be felt these days and it does not have to wait for the future for its to become more visible. The glaciers and the sea ice have been melted by the heat and it has caused an unpredictable weather patterns and making the wildlife to run from their usual habitat. Peoples have been mistakenly viewed climate change and global warming as one same thing, but the term "climate change" have been used by the scientist to define the complex shifts on this planet that are affecting the climate and weather systems. This term involves rising in the global average surface temperature also the evolving ecosystem and populations of the animals, sea level rising and a number of different effects such as extreme climate occurrences. As human continue contributing in the increase of dangerous greenhouse gases to this planet, these changes are becoming more severe because the heat are being trapped by the atmosphere.

With the technology becoming more advanced and the cost are being reduced, the consumers and businesses are starting to view solar energy as an option that is more sustainable. An estimation from the Department of Energy's National Renewable Energy Laboratories in Unites States of America, stated that the cost to utilize the solar energy has dropped by 30 percent in 1 year and more application of solar roof from Tesla in the solar residential technology. These alternatives are expected to be in demand when the fossil fuel becomes high in the coming future, but even now many advantages can be taken from harnessing the solar energy.

Growing demand for energy and emerging environmental issues related to the use of traditional fossil fuel-based energy resources have rekindled interest in renewable and sustainable energy assets. Solar energy is the primary resource for renewable energy that can be used either with photovoltaic panels or solar thermal collectors. Study in this area has followed this expansion and an important subject of the research is the evacuated tube receiver. As a result, several works were published to represent the stratification of the fluid inside the tubes and reservoir, as well as analytical modelling for the problem of heat flow.

Figure 1.1 is from [2] the various types of evacuated tube receivers used by users in this modern era.

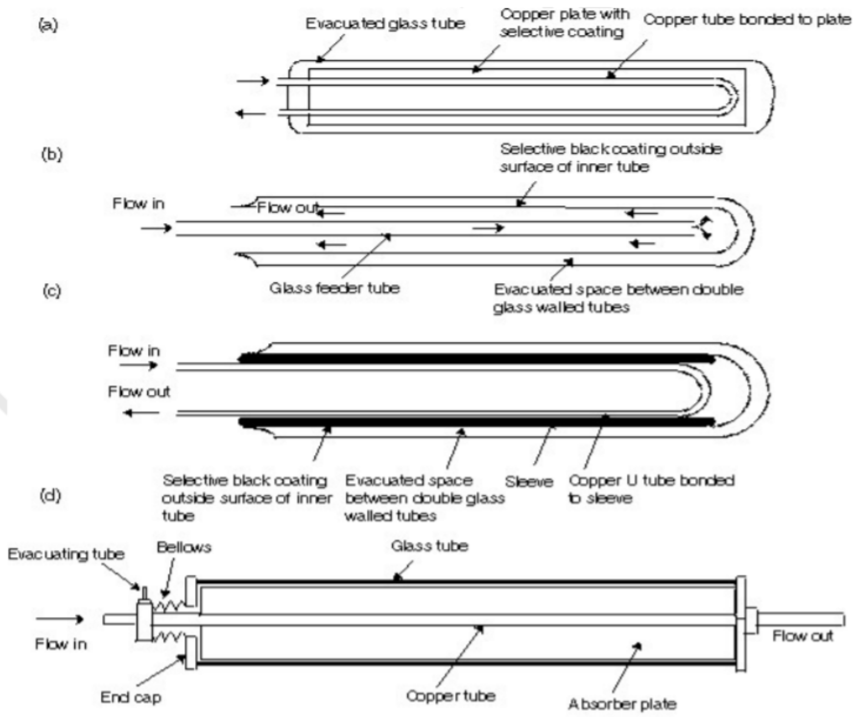


Figure 1. 1 Types of evacuated tube receivers.

Using solar thermal collectors at different temperature rates can provide thermal energy demand for many applications. Due to their simple structure and stationary design, evacuated tube receivers (ETR) have seen exponential growth in recent decades. ETR, however, are limited to applications of low temperature such as domestic hot water supply and space heating. The combination of evacuated tube receivers (ETR) with compound parabolic concentrators (CPC) could produce medium-temperature thermal energy by concentrating incident solar radiation on recipients without tracking requirements.

1.2 Problem Statement

Two most used solar collector used globally are the traditional flat plate collectors and modern evacuated tube receivers. Each of them has their own pros and cons. The recently developed evacuated tube receivers have the advantages in the winter, where they can maintain a relatively high temperature at ambient temperature that is sufficient for operating below the freezing point. As example, the inside temperature these tubes can surpass 45°C for an ambient temperature of higher than –10°C. In large scale system however, these tubes are prone to crack under mechanical stress [3].

Sometimes, under lack of routine maintenance and unprofessional handling, the temperature inside the tubes can reach extremely high temperature which can also make the tubes crack due to thermal shock. If crack happens, the tubes will lose its vacuum and this will make the system fails [4]. Maintaining the vacuum inside tube is the important in the design of tubes. It is because deterioration in vacuum can maximize the thermal losses due to convection. An implication of this is the tube needs a new replacement [5].This can lead to unnecessary increment in cost and that is something that needs to be avoided.

Taking safety awareness and efficiency concerns regarding the current design of evacuated tube receivers, which can lead to more degradation if it continues, new design must be designed to replace the old one. Thermosyphoning in the evacuated tube receivers can make system simple by removing external pumping power requirements. However, on the open loop single-phase thermosyphoning, very limited literature is available that merits further investigation in this field.

Rate of thermosyphon is influenced by many geometric parameters, an important parameter taken account in this research is the heat flux input. Monitoring the thermosyphon rate in the evacuated tube receiver have been the interest of this research because improving the current design of evacuated tube receiver can prevent future environmental implications and economic losses.

This paper suggests the study of solar water heating system with evacuated tube receiver, their operating characteristics and operating parameters based on recent publications. To investigate the thermal efficiency and observe the resulting flow patterns a series of experiments are performed. The current experimental approach promotes the design of an ETR working under ambient conditions. The ambient temperature provides the source of cooling required to recondense the fluid to successfully operate the system.

1.3 Objectives

This research is intended to study the single-phase open loop thermosyphoning phenomenon inside the evacuated tube receiver using experimental approach. This research will be accomplished by:

- Understand the influence of the heat flux on the effect of thermosyphoning phenomenon inside the evacuated tube receiver using experimental approach.
- Evaluate the performance of ETR in open loop solar water heating system that can generate medium-temperature thermal energy with further innovation.

1.4 Scope of Study

This study is intended to experiment a phenomenon of single-phase open loop thermosyphon in evacuated tube receivers under ambient environmental conditions. Different experiment case with different inclination angle on different days will be conducted. Water will be used as operating fluids and the varying heat flux is studied as the geometric parameter that can influence the rate of thermosyphon.

The main attention of this study in the comparative simulation between same evacuated tube receiver model under several varying heat fluxes. This is to evaluate the performance of thermosyphon inside the tubes, where under varying heat fluxes, it will result to difference in fluid's velocity and temperature. Heat are being transferred by three means which is conduction, radiation and convection. These methods were applied in most models of solar collector and heat transfer by radiation from the sun is the main concern in these collectors. Through many progressive years, five radiation simulation model in heat transfer simulations also was successfully developed on ANSYS-FLUENT, which allow inclusion of radiation, with or without a participating medium that can be used as a tools in simulation approach [6].

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 Compound Parabolic Collectors (CPCs)

Compound parabolic collectors (CPCs) can be classified as non-imaging concentrators. They have this great ability to reflect all of the incident radiation from the sun to the solar collectors used within limits that is quite wide. This strong point has made them established their reputation as a good solar energy collector. By using this component, the need to relocate the solar collectors can be eliminated as the solar orientation that has been shifted can be compensated with the two parabolic plates.

Figure 2.1 shows the basic geometry of a CPC used by users globally from [7].

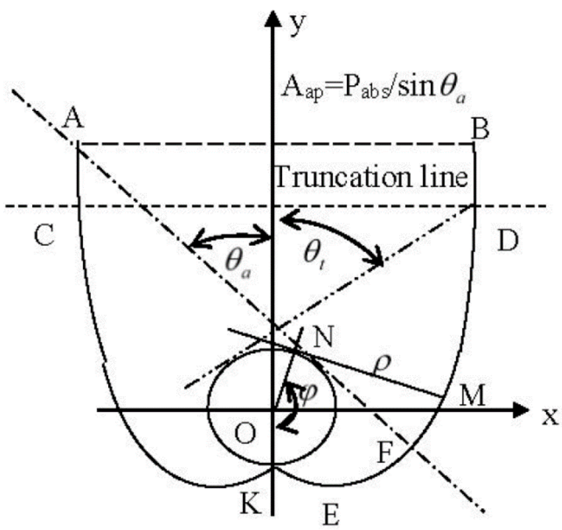


Figure 2. 1 Basic geometry of a CPC.

Collectors of this type can receive radiation that comes from various type of angles. By utilising multiple internal reflection, radiation can enter the aperture of the collector within its acceptance angle to be collected by the solar collector. The solar collector used can be of various types such as flat or tubular.

By applying the principles of edge-ray and identical optical length, collector of this type is the most ideal concentrator for solar collectors because its simple structure and the elimination of the need for system to track the solar orientation. Throughout the years of researches, solar collectors that used CPC has been identified as the most promising collector to provide heat with temperature ranges from 200°C to 250°C. This contributes to more studies by the researchers to analyse their design and performance. First experiment was done in 1974 by Rabl and Winston [8] to investigate non-evacuated CPC collectors and heat loss through the reflectors was considered high due the contact of tube absorber with the parabolic plates of CPC making it function as the fin of the tube absorber [9]. A different approach was taken by [10] to reduce heat loss to the surrounding air from the solar collectors, where an all-glass solar evacuated tubes were used with the CPC collectors and were put to test. A test using two CPC collectors to reduce the loss of solar ray between the CPC's gaps also was developed by Oomen [11] to generate steam for heating purposes. However, comparative analysis between the designs have not been made.

2.2 Thermosyphon

Thermosyphon is a passive natural convection based heat transfer method where the need for mechanical pump is eliminated to circulate the liquid. Thermosyphon works based on the principle where the hot liquid rise above the cold liquid due to its difference in specific gravity (density), hot liquid is less dense than cold liquid. Therefore, in basic system of solar water heater, the solar collector is always located below the water tank. This is to make the cold water is able to exit the tank by gravity through a downstream pipe and then enters the solar collector to collect the heat from the solar. When enough solar energy has been collected to heat the cold water, it becomes hot water. This makes the water rise and re-enters the water tank through a rising pipe. This is repeated by the cold liquid at the bottom of the water tank and thus making a natural circulation possible even without any mechanical device and ensures continuous liquid heating until an equilibrium is achieved.

Two layers will be developed within the water tank which hot water will occupy the upper layer and the lower layer will be occupied by the cold liquid due to the density differences. Hot water at the top layer can be utilized by user, with the cold water at the bottom layer will be heated by the solar collector to replace the used hot water due to the continuous heating process. Due to high temperature differences between high and low solar irradiances, the rising of hot water is faster. Consequently, irradiance rate of the solar does affect the water flow. To ensure no backflow happens, the water tank must be located high enough, at a higher level that the thermosyphon device.

Figure 2.2 shows the schematic diagram of solar water heater using thermosyphon [12].

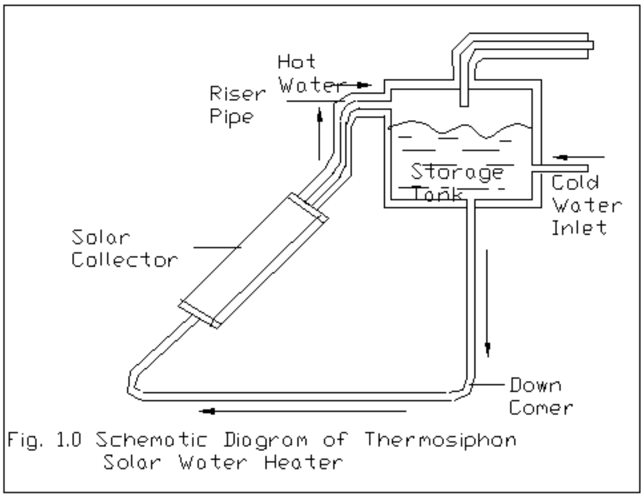


Figure 2. 2 Schematic diagram of the thermosyphon solar water heater

Solar water heater using thermosyphon are mainly utilized in domestic applications. Due to its complexity in flow rate and thermal stratification in water tank, the design of the system was developed through numerous trials. There are many parameters need to be considered like the geometric parameter, design specification and operating conditions that can affect the performance of the system. Numerous researches have been done to enhance the performance of the system like Gupta and Garg [13] studied how the design specification affect the performance, and [14] have conducted an investigation on several parameters that influence the system's performance. Not many have chosen varying heat flux as the variable geometric parameter. The author decided to work on this project due to lack of information on the research of this area.

2.3 Single Phase Closed Loop Thermosyphon

Thermosyphon can be classified to several types such as:

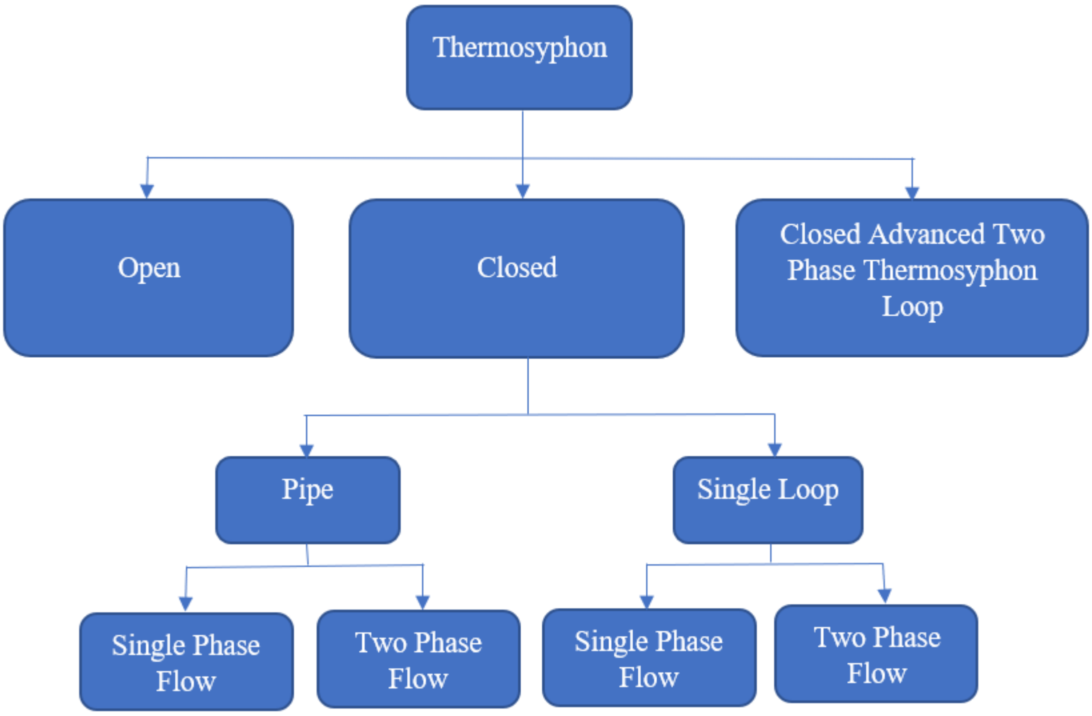


Figure 2. 3 Types of thermosyphon.

In this analysis, the author of this research emphasizes on single phase flow closed loop thermosyphon. This system works by continuous process of heating and cooling. The operating fluid circulates within the loop. Through extensive studies, this system can be developed even more as by choosing the right operating liquid and material, the operating temperature for the thermosyphon can be as high as 4 K to 2300 K.

Temperature difference is formed in the work fluid inside the loop and thus a density gradient is generated. Thus, the lighter fluid rises and falls and replaces the heavier fluid on it. Closed loop thermosyphon applications include solar heat, geothermal energy, energy storage, nuclear reactor core heat rejection, internal combustion engines cooling, turbine blades and computers. In modeling different types of thermosyphons, development of these engineering applications is needed [15].

Single phase flow closed loop thermosyphon is utilized extensively in wide range of system especially in energy related areas [16]. All of these contributes to a lot of investigation of various approaches done by Vijayan et al. [17], Pilkhwal et al. [18] and Rao et al. [19]. Approach using analytical and numerical refers to thermosyphon's unsteady and steady conditions, stability elements and second-law analysis. Recent studies is about the how the thermosyphon behave under unsteady condition but most experiments emphasized more on steady-state operating conditions (Saha et al. [20]; Misale [21]; Cheng et al. [22]).

The author of this paper investigates the single phase flow closed loop thermosyphon under transient and steady conditions. Water is selected as the operating fluid and supported the study done by Misale [21]; who study the behavior of single phase flow closed loop thermosyphon with combination of heating and cooling part placed horizontally.

2.4 Evacuated Tube Receiver

The most important components in harnessing the solar energy efficiently is the evacuated tube receiver. Evacuated tube receiver (ETR) is made of an outer glass tube and an inner steel tube where a vacuum space is introduced between the two tubes. By being transparent, the outer glass tube allows the absorption of solar rays by inner steel tube and the heat generated is transferred to operating fluid inside steel tube. The type of solar collectors is called evacuated because of the existing vacuum space between the tubes. These tubes reduce heat loss to the surrounding because heat loss by convection cannot happen across vacuum and it creates an excellent isolation mechanism that trapped the heat within the tubes.

ETR proved to be more efficient than flat plate collectors where they can produce more heat due to the combination of highly absorptive coating and insulative vacuum space. Temperature ranges from 70° to 120°C can be easily generated by these tubes. With technology of vacuum becoming more advance these days, it is possible to mass-produce evacuated tube receivers. Their high temperature efficiency is critical for harnessing the solar energy.

A schematic diagram of an ETR is given in Figure 2.4 [23].

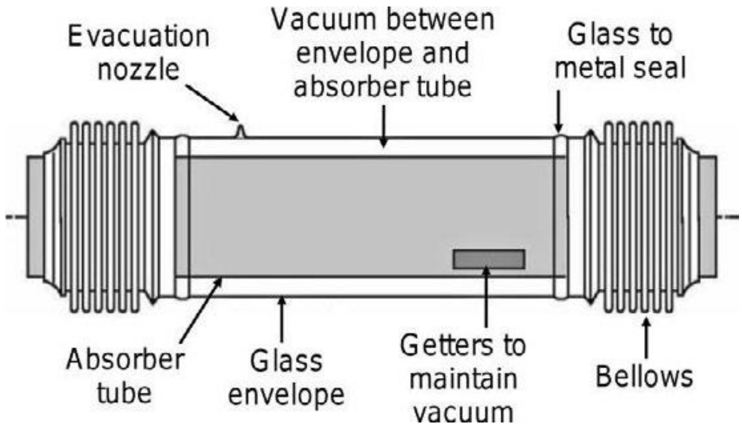


Figure 2. 4 Schematic diagram of ETR.

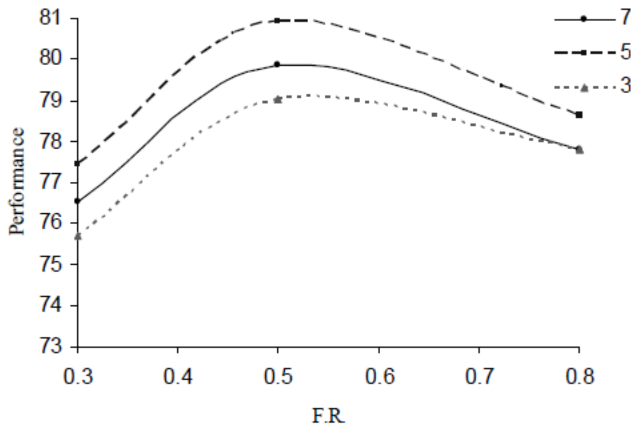
2.5 The Effect of the Input of Heat Flux on the Rate of Thermosyphon

Past researches done have showed the important roles that heat flux by the sun played in affecting the behaviour of thermosyphon. The temperature difference within the operating fluid creates a difference of density that contributes to the working fluid's natural circulation. Several researchers have been done and how various parameters like heat flux intensity, thermal loads, and geometric parameters affect the rate of thermosyphons have been identified. Dehdakhel.et al. [24] performed experimental studies to analyze fill ratio effects on thermosyphon efficiency by varying the heat flux. Successful findings showed how can fill ratio significantly affects the efficiency of a thermosyphon. Another analysis by CFD proclaims the profile of the thermosyphon's temperature closely match with the experimental data.

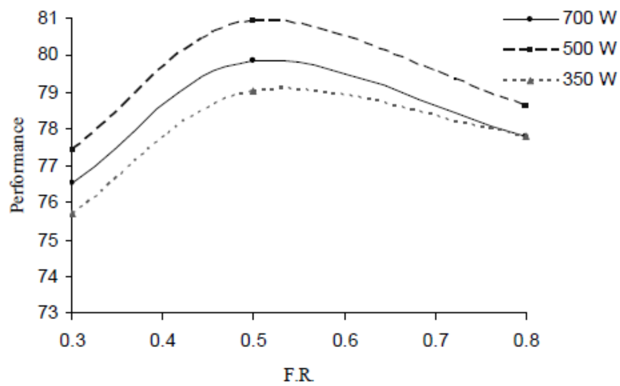
In the process of analysing how various parameter like quantity of riser pipes, the ratio between the size and diameter of the riser pipes, heat flux intensity and collector’s angle of inclination affect the rate of thermosyphon, Freegah et al. conducted numerical studies with no load applied. The research highlights that collector’s angle of inclination tiny effect that can be ignored, but the same thing does not apply to the ratio between the size and diameter of the riser pipes and heat flux intensity as they affect the performance of the thermosyphon greatly. Also, the temperature of operating fluid is raised by increasing the quantity of riser pipes. Theoretical study have been taken by Sato et al.[25] in the process of investigating how the inclination angle of the heat pipe and design specification of the condenser affect the temperature of operating fluid inside the condenser. The findings of the research are the effect inclination angle of the heat pipe is negligibly small and design of conventional solar collector proven to be more optimum in thermosyphon rate.

A study by Mirshahi and Rahimi [26] investigates how the overall performance of a partially vacuumed thermosyphon is the affected by heat flux, cooling water flow rate, fill ratio and extra volume. The thermosyphon was seen to lose its efficiency as the trapped gas fills the entire condenser. The overall study highlights that the heat loads can have significant effects on the rate of thermosyphon due to the existence of trapped air.

Figure 2.5 shows the thermosyphon output at different fill ratios for the three heat loads tested.



a) V_{ex}=0 cm^3, $\dot{V}$ =7 cm^3/s



b) V_{ex}=0 cm^3, $\dot{V}$ =14 cm^3/s

Figure 2. 5 The thermosyphonic efficiency of different heat flux and fill ratio.

Several researchers have identified how can various parameters like intensity of heat flux and type operating fluid used affects the rate of thermosyphons. Experimental experiments were performed in one study to analyze the effects of the fill ratio on a thermosyphon's efficiency under varying heat fluxes. Findings showed that the fill ratio significantly affects the efficiency of a thermosyphon. Future analysis using CFD estimates the profile temperature of the thermosyphon closely match the experimental data. The result obtained from the study indicate that by varying the heat flux, it does significantly affect the velocity of operating fluid and the temperature inside the riser pipe.

CHAPTER 3

METHODOLOGY

3. METHADOLOGY

An open loop solar water heating system for the current investigation is being considered in this section. The purpose of the present study is to evaluate the performance of open loop solar water heating systems by conducting experiments. To predict the outlet water and the absorber tube temperature, a solar water heating system with open loop thermosyphoning was developed. The outcome of the experiment is confirmed by combining the data obtained from the experiments. For a full day experiment from 1000 to 1830 hours, the steady state experiment was performed using the average values of the measured data within half hour period. Experiments were carried out under various climatic conditions of Seri Iskandar, solar radiation, atmospheric temperature, temperature of the inlet water and flow rate. Also discussed are the influence of various external parameters on the thermal efficiency and the temperature of the outlet water.

The solar collector temperature of the outlet water and the absorber tube depends on the flow distribution in the riser tubes. The analyzes were performed based on the following assumptions:

- The thermal and physical property of the absorber tube, riser tube and water are constant during the flow.
- Water is incompressible and continuous.
- Heat loss from the bottom side of the absorber plate and tube is by convection which depends upon the wind speed.

3.1 Developed Evacuated Tube Receiver

The evacuated tube receiver developed for this study consists of brazed riser and header tubing, tube material, glass cover, and insulated case. The assembly of brazed riser and header pipe is shown in Figure 3.1. This is made of one header and two vertical riser tubes. Drilling and brazing had linked the risers to the headers. The absorber tube content is made of copper which has made the absorber surface (90 percent absorbance and 10 percent emittance) capable of optimizing the radiant energy absorption. By creating a vacuum state in a glass cover at the top of the collector, the heat loss due to convection, conduction, and re-radiation was minimized. With glass wool and polyethylene material, the cold water storage tank was fully insulated, and the same was done for header and connector tubing. Using gravity, the cold water was flowed through the pipes from the storage tank. The water flow rate into the storage tank from water supply was controlled using a flow control valve. The detailed specifications of the produced receiver are presented in Table 3.1.

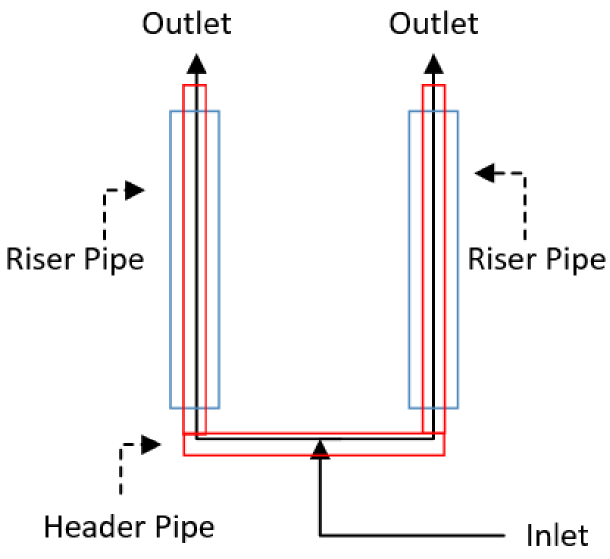


Figure 3. 1 Schematic diagram of riser and header pipe.

Table 3. 1 Detailed specifications fabricated solar collector.

Description	Specification and type
Length of the collector	2 m
Width of the collector	1.5 m
Length of the absorber tube	1.8 m
Width of the absorber tube	1.2 m
Thermal conductivity of the absorber tube	386 W $(m\ K)^{-1}$
Density of the tbe material	8954 kg m^3
Tube thickness	0.0005 m
Diameter of header pipe	0.030 m
Diameter of riser pipe	0.0125 m
Riser and header pipe thickness	0.0007 m
Tube center to center distance	0.1500 m
Number of glass	2
Spacing between glass and absorber tube	0.05 m
Insulating material	Glass wool and polyethylene
Thermal conductivity of insulation material	0.044 W $(m\ K)^{-1}$
Thickness of the insulation material	0.05 m
Density of the insulation material	200 kg m^3
Thickness of glazing material	0.05 m

3.2 Experimental setup

Figure 3.2 shows the experimental configuration of the open loop solar water heating systems used in the present analysis. The cold water storage tank was properly insulated with glass wool and connected to the inlet of the evacuated tube receivers by means of PVC pipes. The 2 evacuated tube receivers used called fixed collector (FCR) and collector variable (VCR). Linked with the measuring cylinders was the outlet from these two evacuated tube receivers. The cold water from the storage tank will flow through the header pipe into the evacuated tube receivers. During circulation, the inlet water gets heated up by the riser, which is then flowed into the measuring cylinder. Figure 3.3 shows the photograph of the open loop solar heating system which indicates the location of different sensors and instruments.

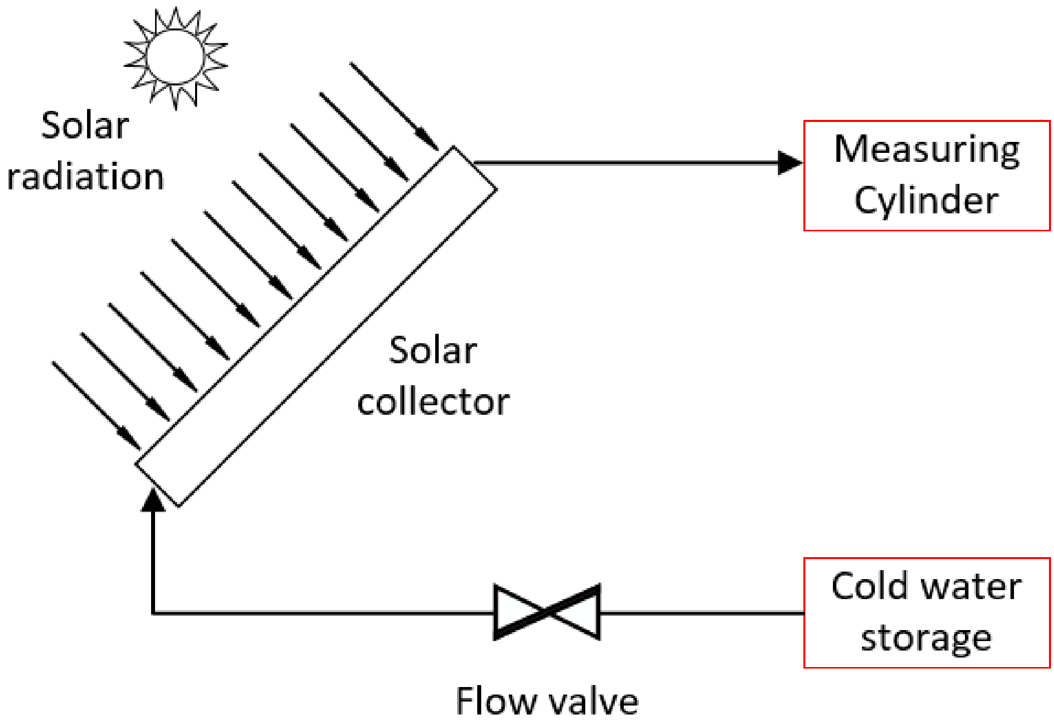


Figure 3. 2 Schematic diagram of the experimental configuration.

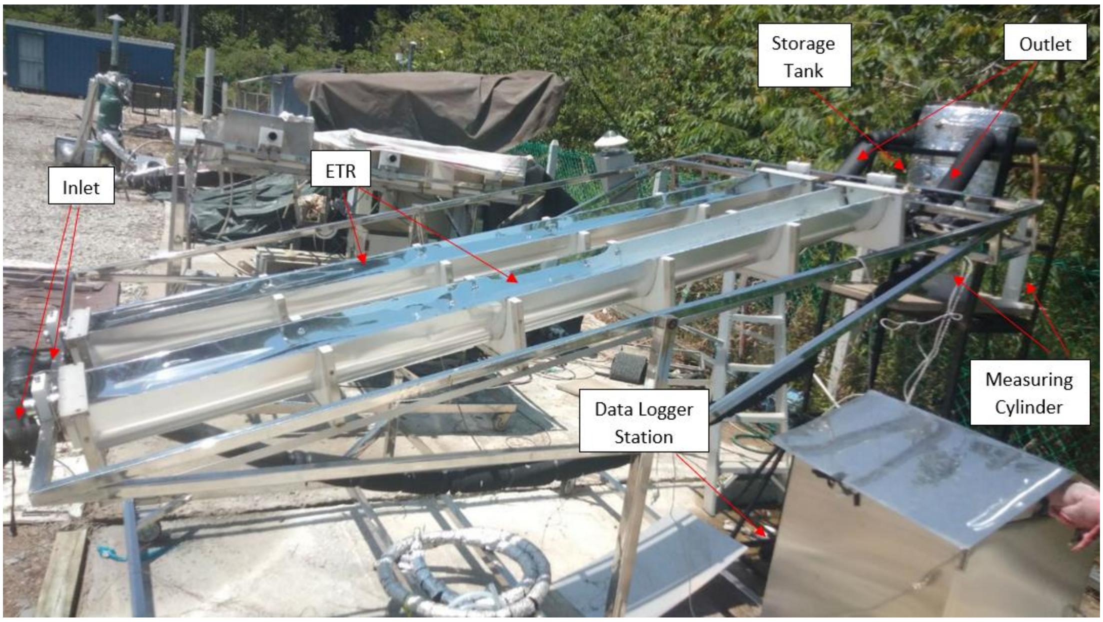


Figure 3. 3 Photograph of the open loop solar heating system.

The collector surface solar radiation was calculated using a pyranometer, while the temperatures of the inlet and outlet water, ambient temperature and ETR's temperature were calculated using thermocouples of type K. During the experiment, the complete data was collected at an interval of 1s by a data logger acquisition system. The solar collector had been positioned at 100.97 ° N latitude and 4.38 ° E longitude, position of Seri Iskandar city. The experiment was performed during the period February to March 2020.

3.3 Gantt Chart

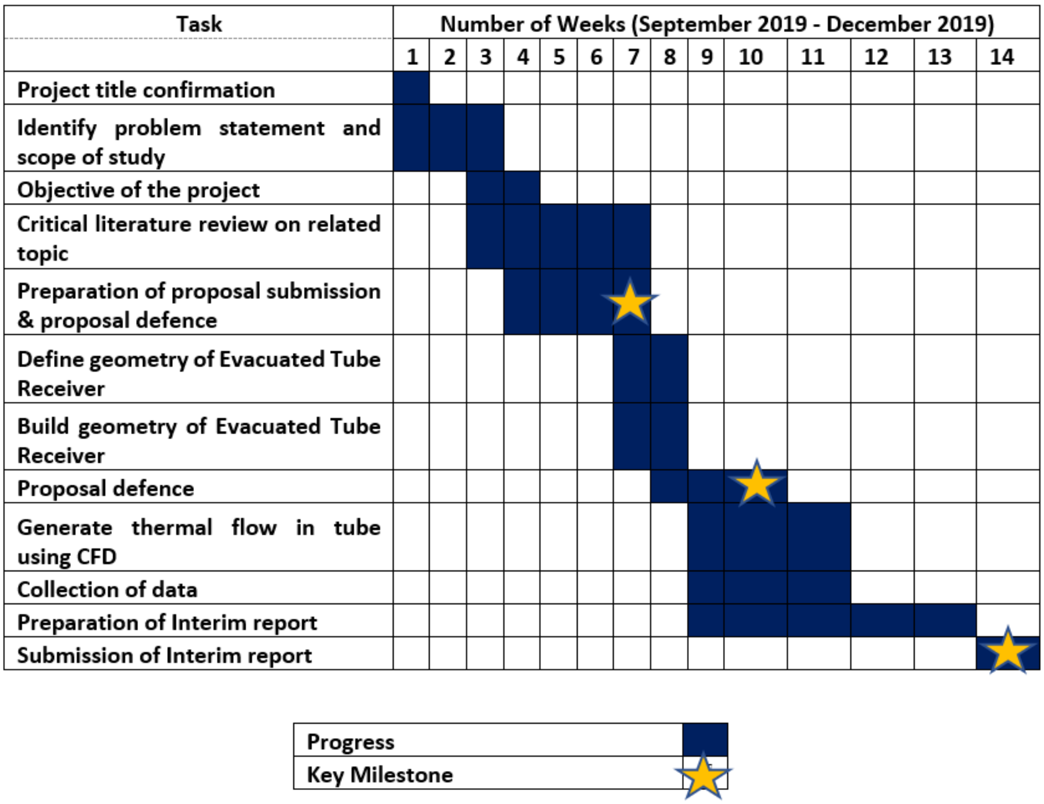


Figure 3. 4 Gantt chart FYP I.

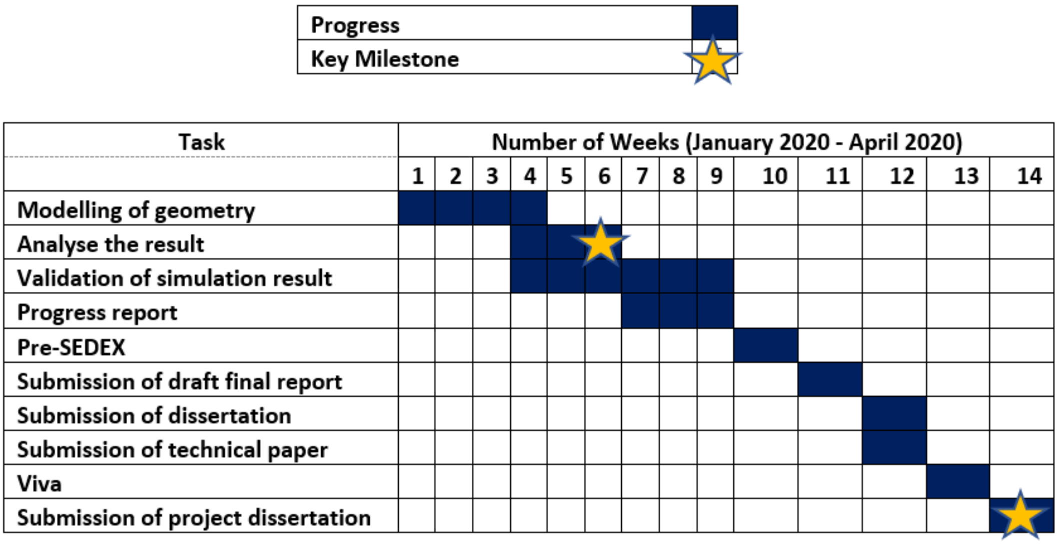


Figure 3. 5 Gantt chart FYP II.

CHAPTER 4

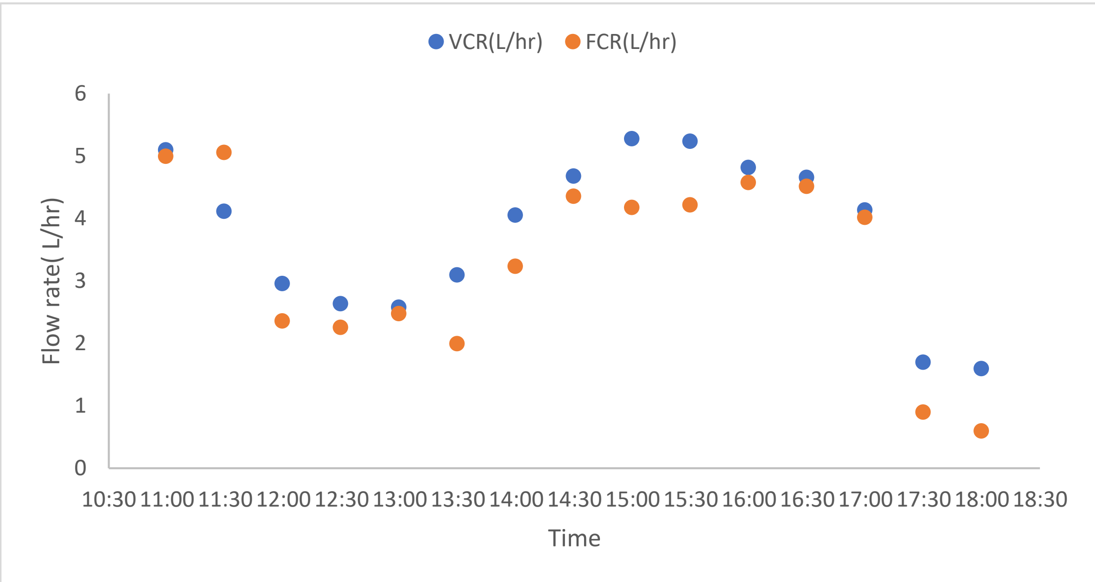
RESULT AND DISCUSSION

4. RESULT AND DISCUSSION

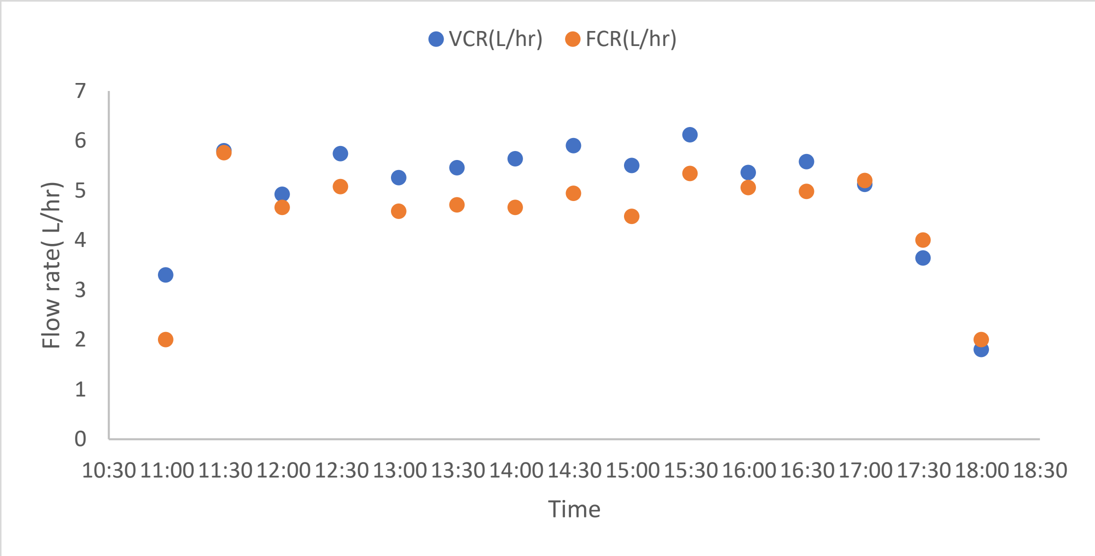
As stated earlier, the aim of this work is to investigate experimentally the output evacuated tube receiver in addition to evaluate the ETR's ability to reduce the electricity consumption used for household water heating. The experiments were performed in 2020 under clear sky conditions from the end of February to the middle of March. The collector frame was tilted with a series of angles equal to 15°, 35° and 45° towards the south direction. The value of these angles reflects various experimental times where it was performed for 15° in late February, 45° in early March and 35° in mid March. At the collector's inlet and outlet, experimental measurements of solar radiation, water mass flow rate, atmospheric temperature, and water temperatures were measured and recorded every 30 min along the daylight hours from 10 AM to 6 PM. In addition, the solar collector was designed and produced according to the dimensions and geometric parameters as shown in Table 3.1.

4.1 Variations of flow rate as a function of daylight hours

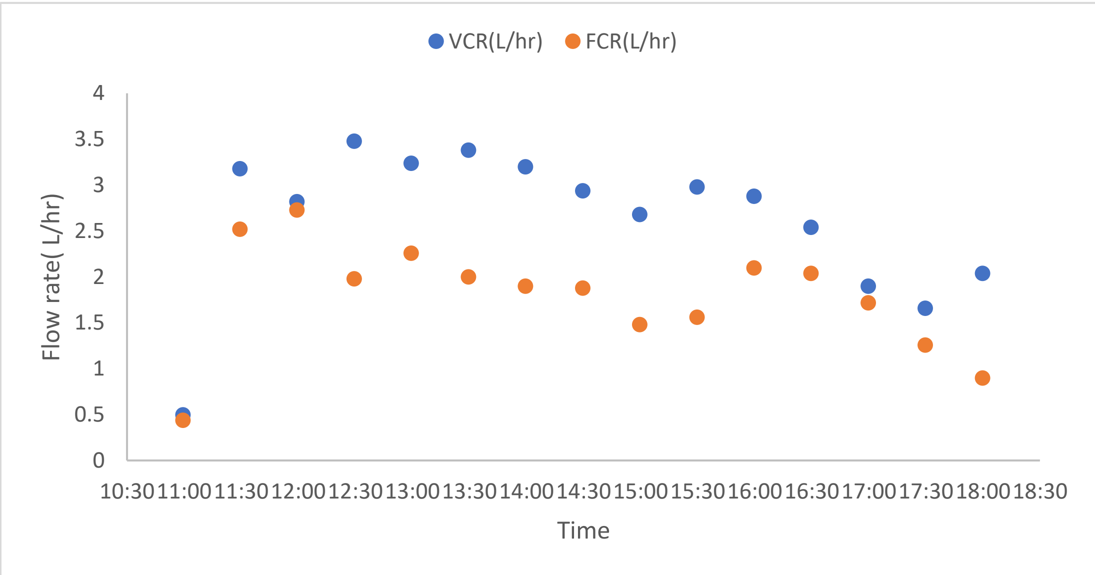
Figure 4.1 shows the flow rate fluctuations as a function of daylight hours for a given day in each of those cycles, where end of February (25, 26 and 27), beginning of March (2nd, 3rd and 4th) and mid-March (10, 12 and 16th) at the same time keeping the cold water level inside the storage tank constant with the flow valve. Those three phases were chosen with different angles of inclination as follows: 15° for the end of February, 45° for the beginning of March and 35 ° for the middle of March. It is evident from Figure 4.1, 4.2 and 4.3 that the maximum flow rate was observed at the end of February for angle 15°. That can be explained by the fact that this period's sunrise across Seri Iskandar's sky is higher than the other two cycles. Additionally, it can be found that there is a small difference between these three cycles in the flow rate values. During the day the flow rate ranges from 0 l/hr (at night) to a maximum value from 11 AM to 4 PM. The average flow rate for these times was found to be equivalent to 6.12 l/hr (at 15° angle), 4.58 l/hr (at 45° angle) and 5.5 l/hr (at 35° angle). At the beginning (10 AM) and ending (6 PM) test times, it is obvious that the flow rate value at 15° angle (at the end of February) is also higher than 45° (at the beginning of March) and 35° (at the end of March) due to earlier sunrise and later sunset at the end of February, respectively, in comparison with these two angles.



(a) at 25th February

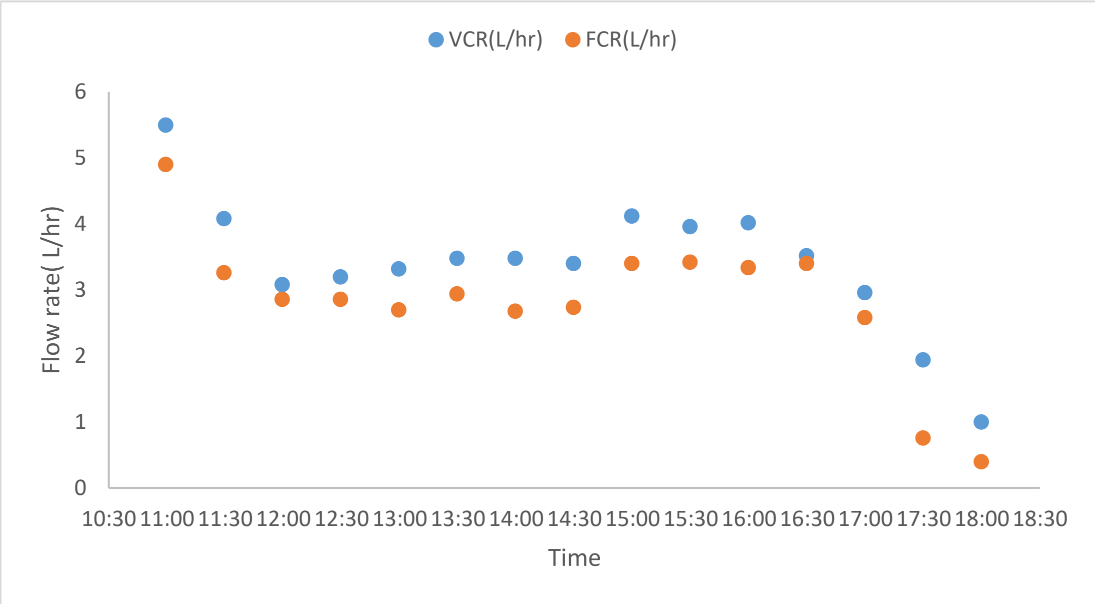


(b) at 26th February

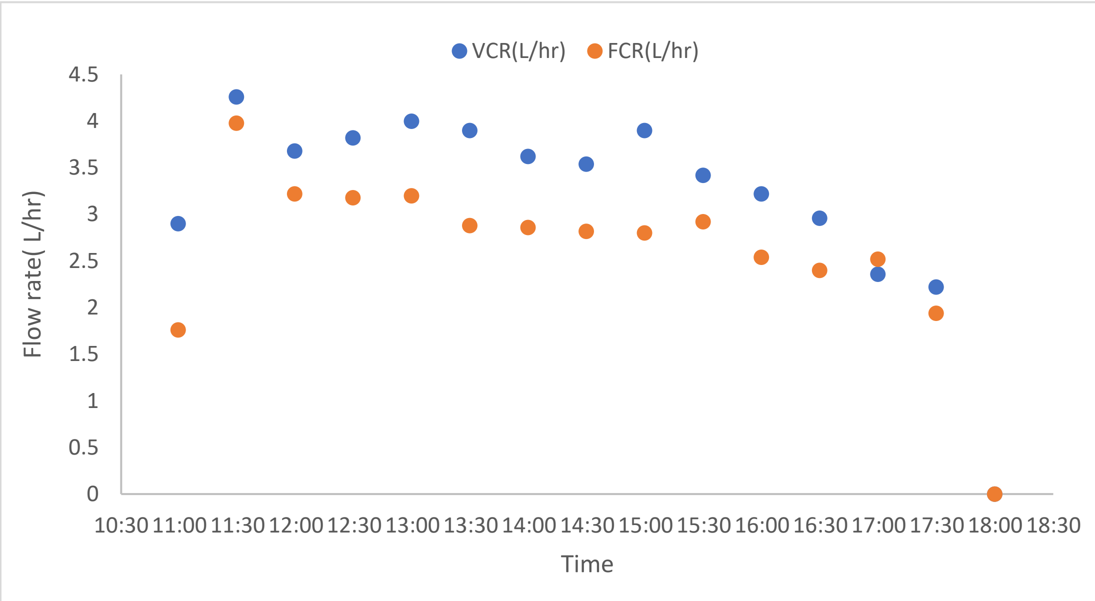


(c) at 27th February

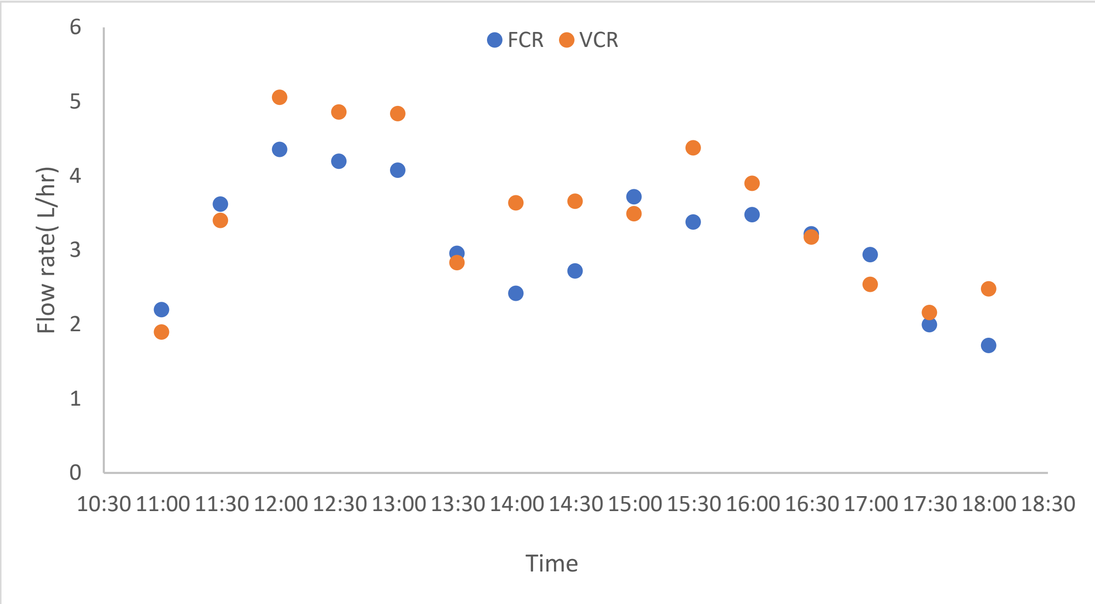
Figure 4. 1 Variations of flow rate as a function of daylight hours for angle 15° at (a) 25th February, (b) 26th February and (c) 27th February.



(a) at 2nd March

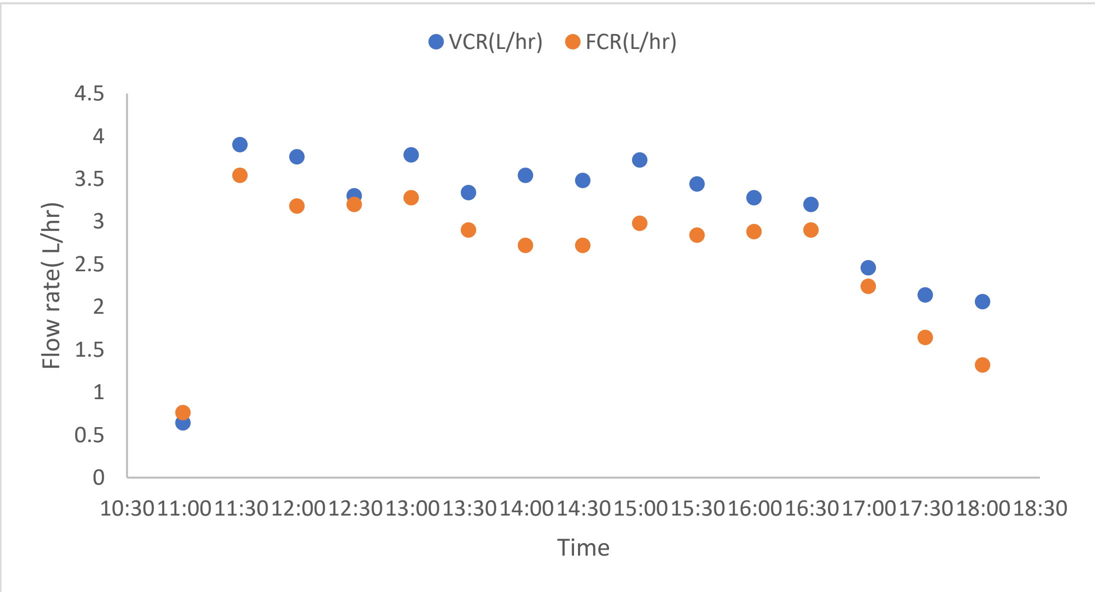


(b) at 3rd March

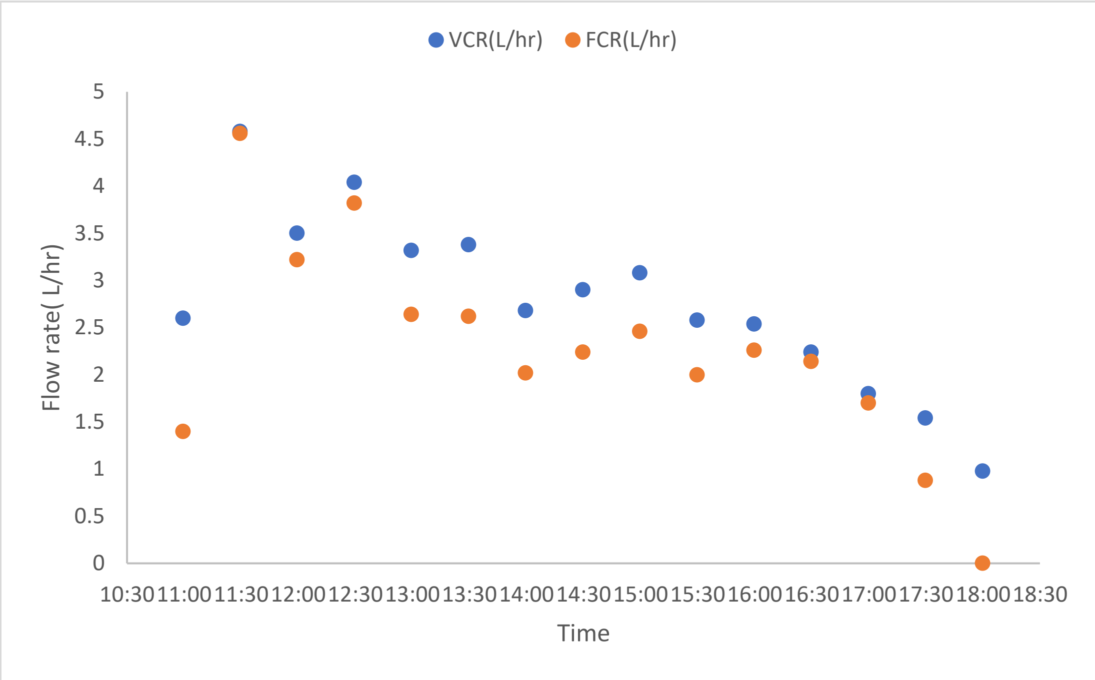


(c) at 4th March

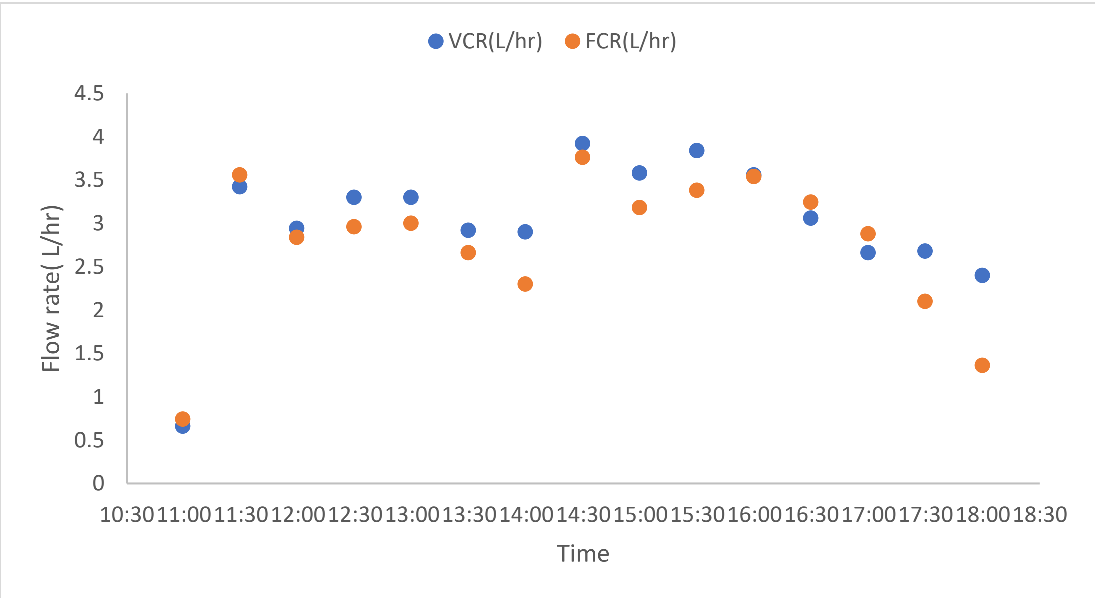
Figure 4. 2 Variations of flow rate as a function of daylight hours for angle 45° at (a) 2nd March, (b) 3rd March and (c) 4th March



(a) at 10th March



(b) at 12th March

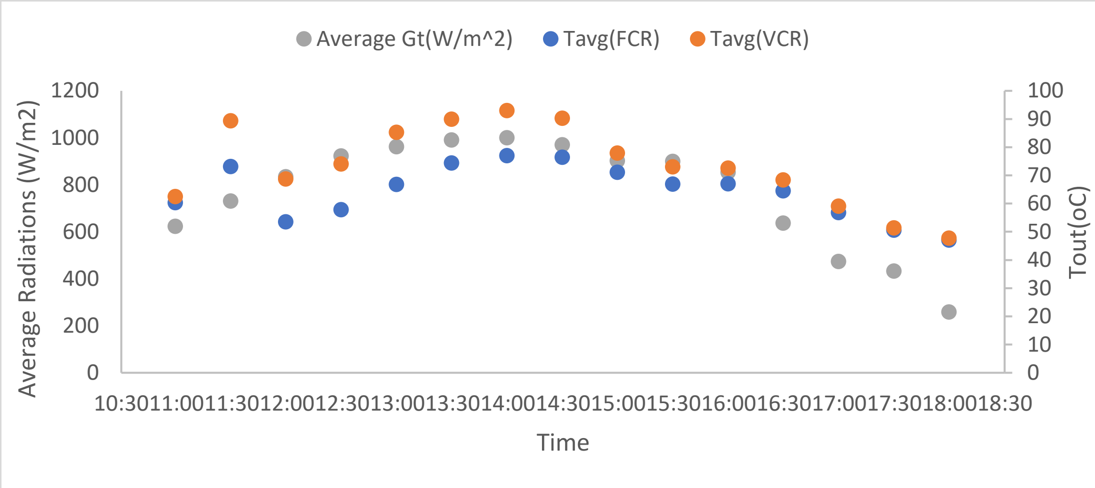


(c) at 16th March

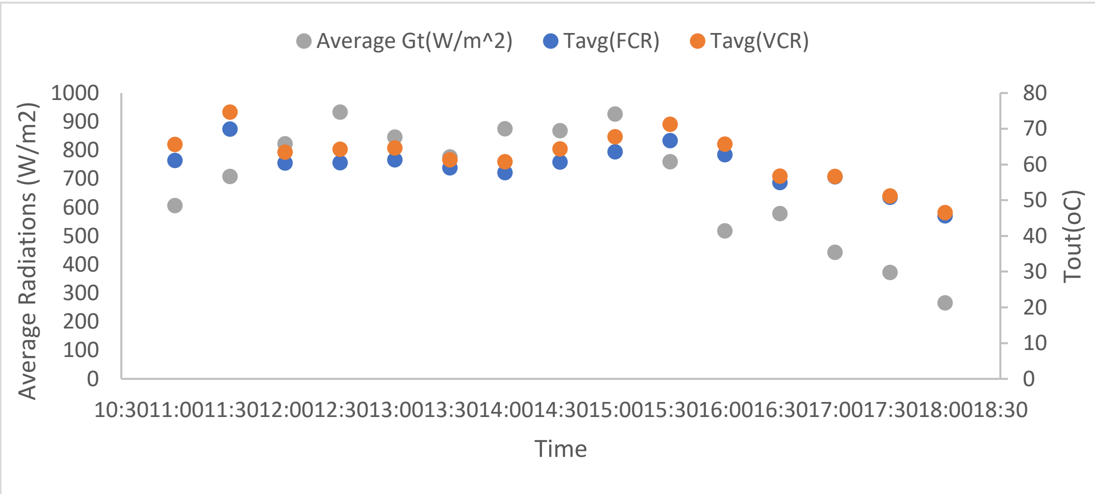
Figure 4. 3 Variations of flow rate as a function of daylight hours for angle 35° at (a) 10th March, (b) 12th March and (c) 16th March

4.2 Variations of radiation, G_t and outlet temperature, T_{out} as a function of daylight hours

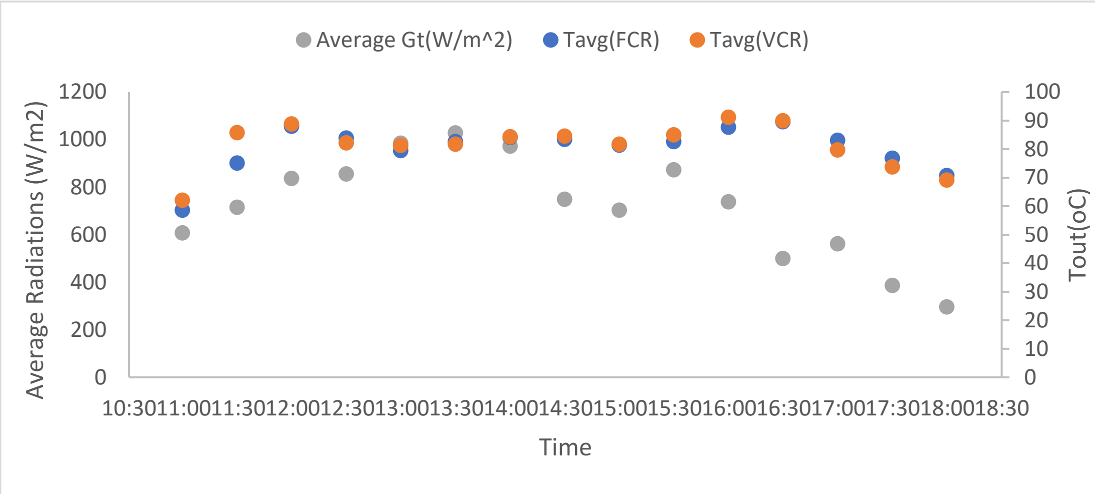
The radiation and outlet temperature fluctuations are illustrated in Figure 4.4, 4.5 and 4.6 as a function of daylight hours from 10 AM to 6 PM. The findings in these figures (4.4,4.5 and 4.6) were reported under the same operating conditions and testing periods in Figure 4.1, 4.2 and 4.3 respectively. From Figure 4.4, 4.5 and 4.6 it can be found that the temperature of the outlet water varies throughout the day and is able to reach the highest value between 2 PM and 4 PM. As expected, the temperature of the outlet water is higher at the end of February than at the beginning and middle of March. A storage tank pushes the water into the ETR to flow in. The storage tank was fixed to a higher elevation than the ETR's position. The water temperature at the ETR's inlet is close to atmospheric temperature (ambient air temperature) and then as it travels through the collector tubes, the water absorbs heat from the tubes through both convection and radiation. For this analysis, the temperature of the outlet water depends on the flow rate of water mass, the angle of incident solar radiation and the strength of solar radiation. The peak temperature of the outlet water was found to be equivalent to 93.0 °C (15° angle), 85.2 °C (45° angle), and 78.6 °C (45° angle). Increasing the solar radiation leads to an increase in the outlet water temperature for constant water mass flow volume. Consequently, as shown in Figure 4.1, 4.2 and 4.3, the highest temperature was measured at the end of February (at an angle of 15°) because of the highest solar radiation in that time. After 3 PM the sun starts to sunset in the city of Sri Iskandar and therefore the temperature of the outlet water is considerably reduced due to the loss of its intensity by the solar radiation. In addition, the temperature of the outlet water can be found from Figure 4.4, Figure 4.5 and Figure 4.6 has the same pattern in solar radiation profile. In all tested cases the average solar radiation was measured between 11 AM and 4 PM.



(a) at 25th February

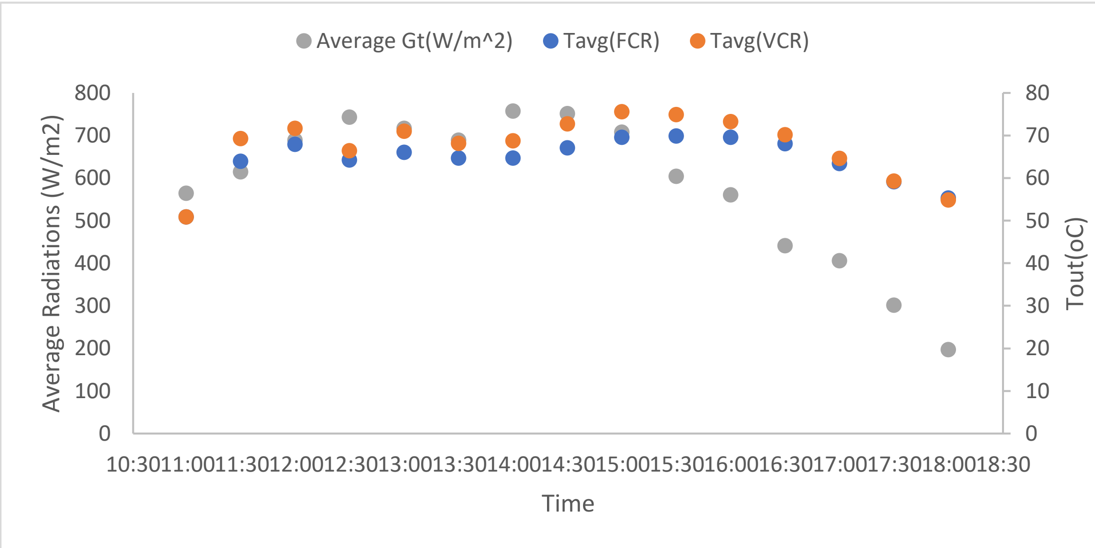


(b) at 26th February

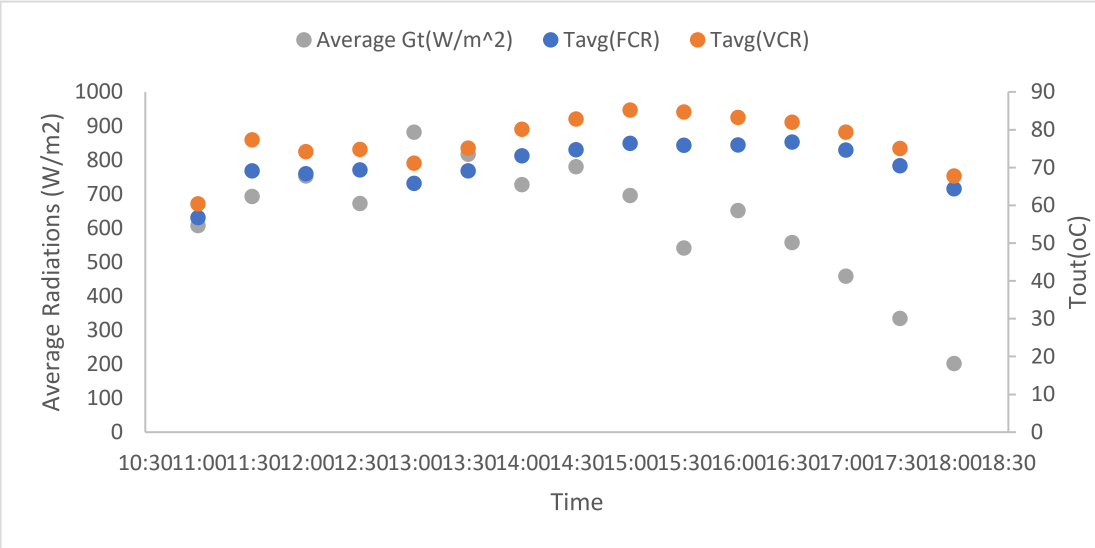


(c) at 27th February

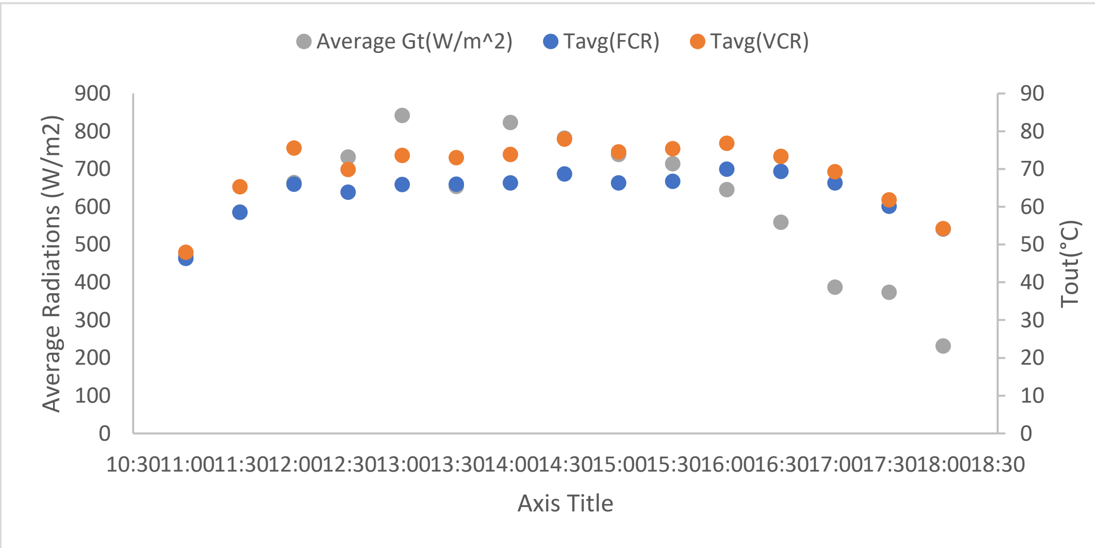
Figure 4. 4 Variations of radiation, Gt and outlet temperature, Tout as a function of daylight hours for angle 15° at (a) 25th February, (b) 26th February and (c) 27th February.



(a) at 2nd March

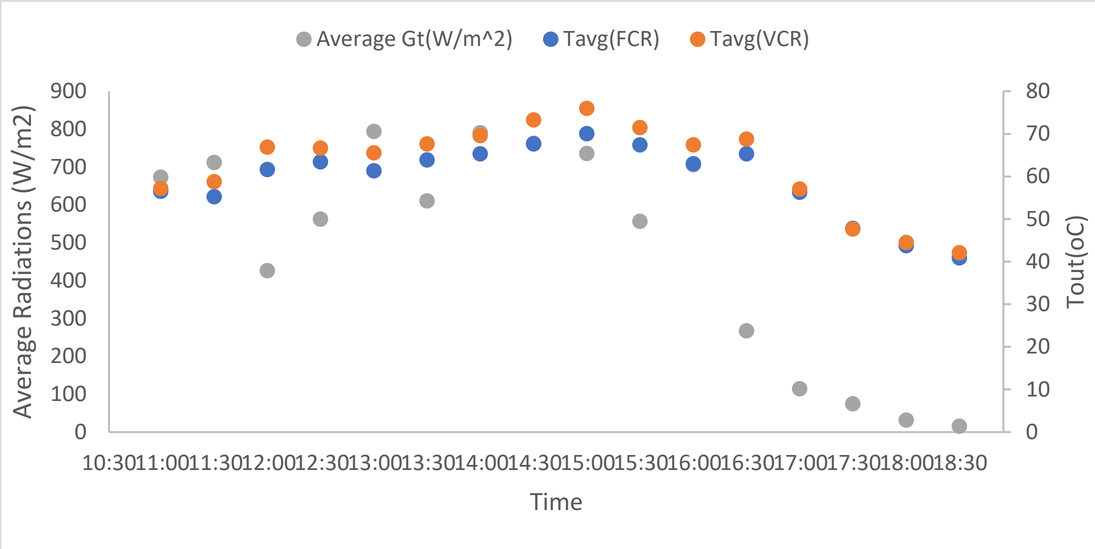


(b) at 3rd March

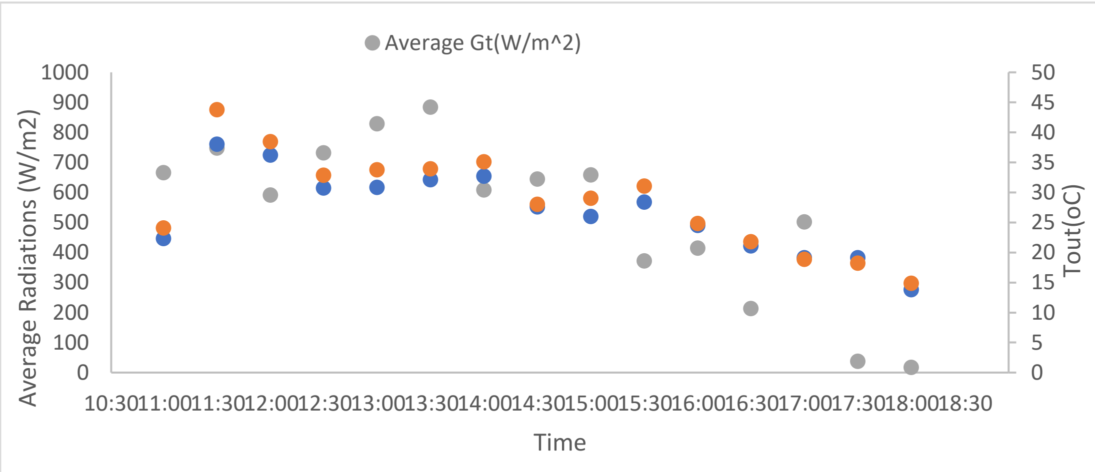


(c) at 4th March

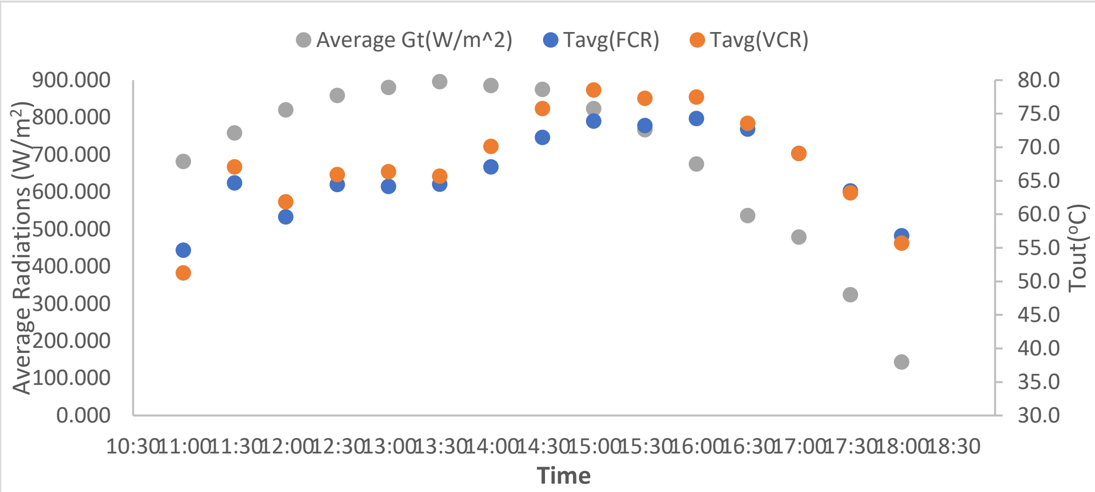
Figure 4. 5 Variations of radiation, Gt and outlet temperature, Tout as a function of daylight hours for angle 45° at (a) 2nd March, (b) 3rd March and (c) 4th March



(a) at 10th March



(b) at 12th March

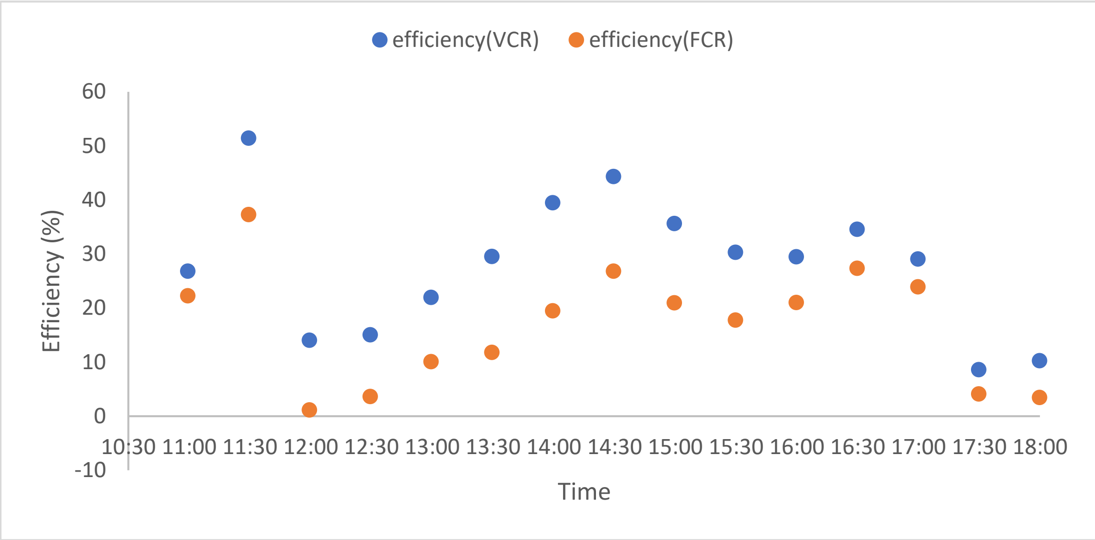


(c) at 16th March

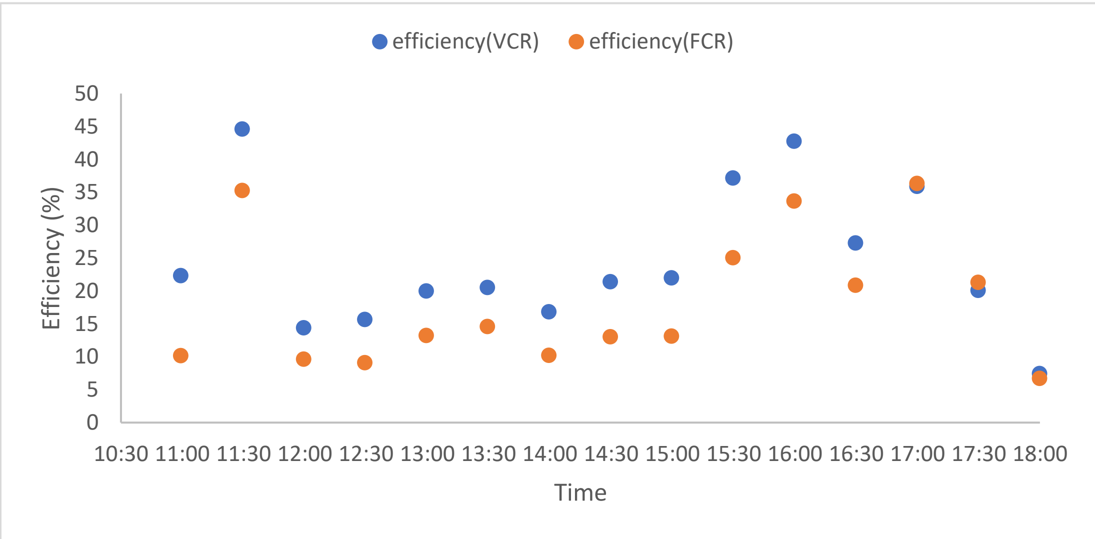
Figure 4. 6 Variations of flow rate as a function of daylight hours for angle 35° at (a) 10th March, (b) 12th March and (c) 16th March

4.3 Variations of efficiency as a function of daylight hours

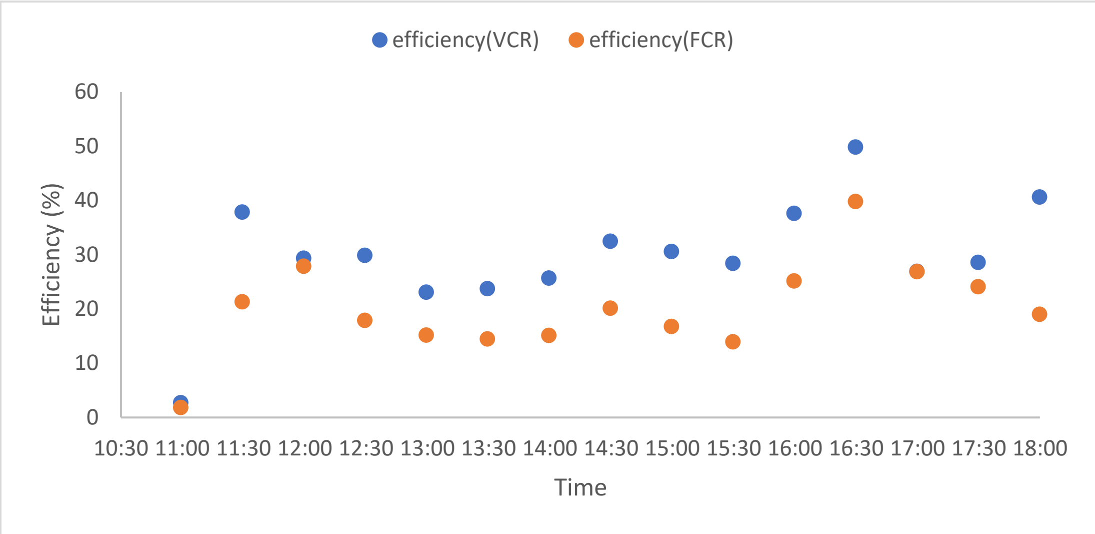
Figure 4.7,4.8 and 4.9 display thermal efficiency of the CPC as a function of daylight hours under the same operating conditions as previous figures (4.1, 4.2, 4.3, 4.4, 4.5 and 4.6). From these figures (4.7,4.8 and 4.9) it is obvious that CPC has a low efficiency particularly at the first running hours between 10 AM and 11 AM due to the low solar radiation at this time leading to a slight difference in temperature between the inlet and outlet water temperature. Here it should be noted that the performance of CPC depends on many variables, such as the inclination angle of the collector, the intensity of solar radiation, the condition of the sky, the rate of water flow and the temperature of the inlet water. It was also observed in Figure 4.7,4.8 and 4.9 that the maximum efficiency for these three days observed to occur between 11 PM and 4 PM due to the highest heat gained values, where the efficiency value can be considered almost constant during this time period. As seen in Figure 4.4, 4.5 and 4.6, at the end of February the maximum solar radiation was collected and this contributes to the biggest difference in outlet water temperature compared to early and mid-March. Therefore, at the end of February the max efficiency was recorded.



(a) at 25th February

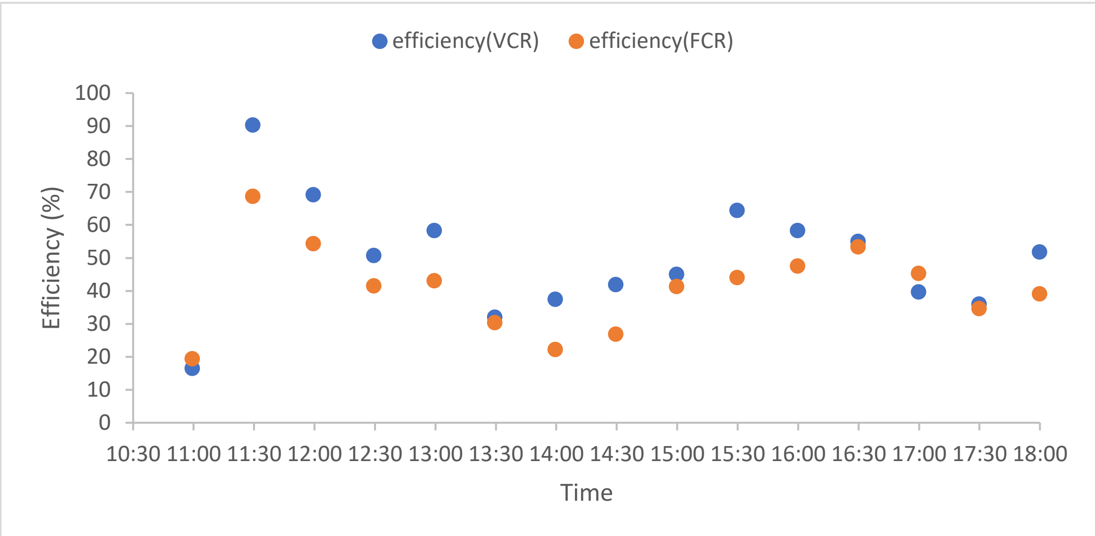


(b) at 26th February

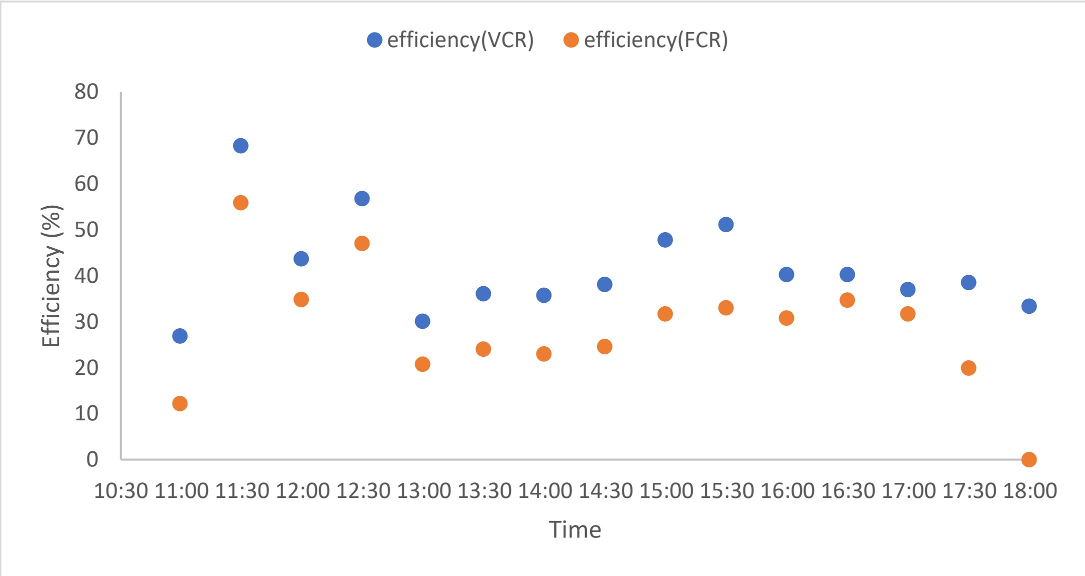


(c) at 27th February

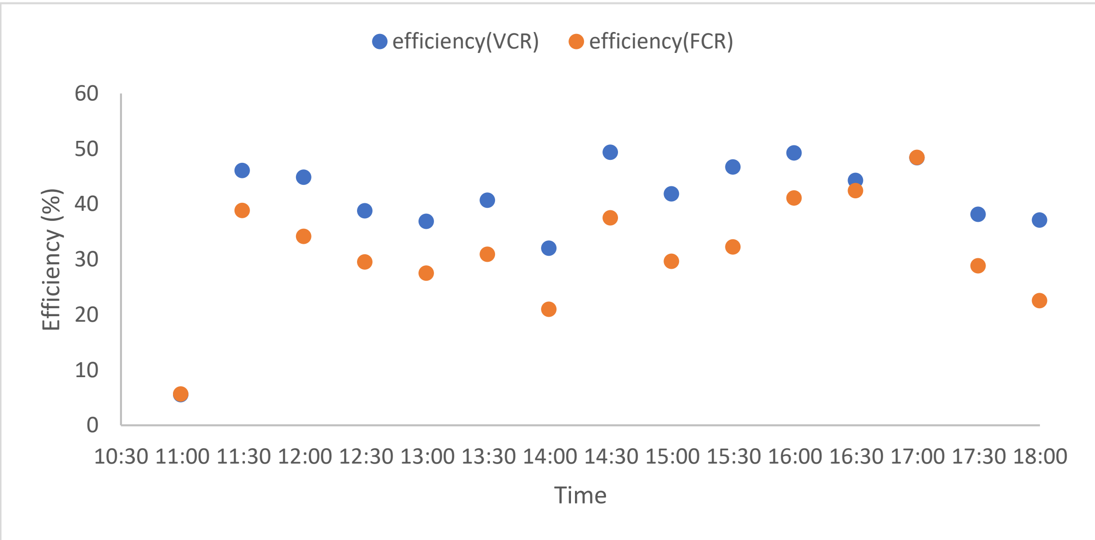
Figure 4. 7 Variations efficieny as a function of daylight hours for angle 15° at (a) 25th February, (b) 26th February and (c) 27th February.



(a) at 2nd March

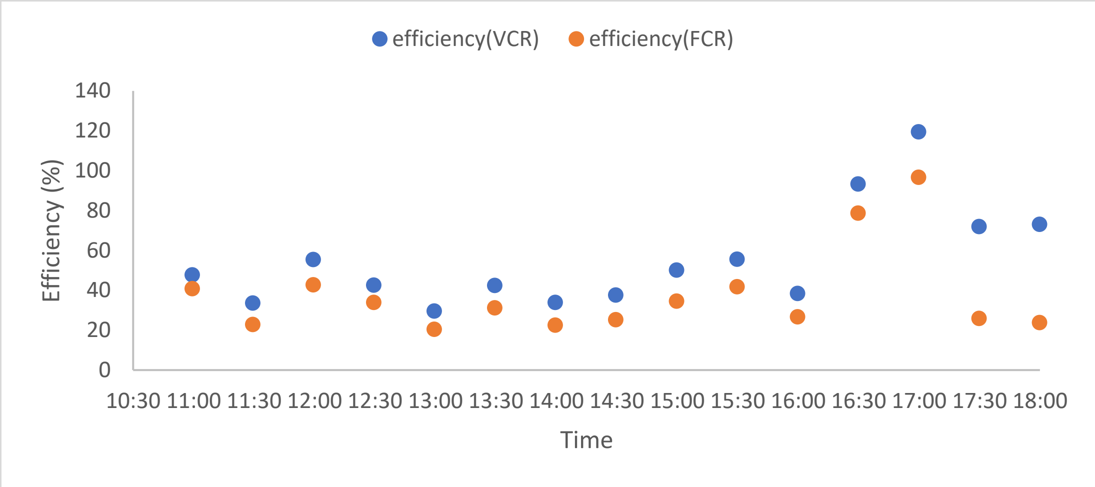


(b) at 3rd March

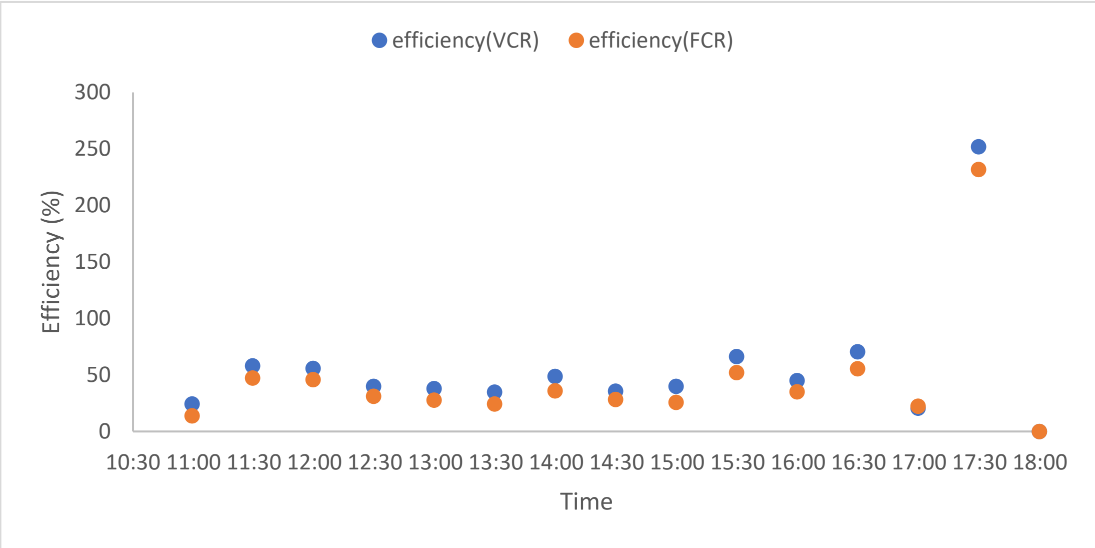


(c) at 4th March

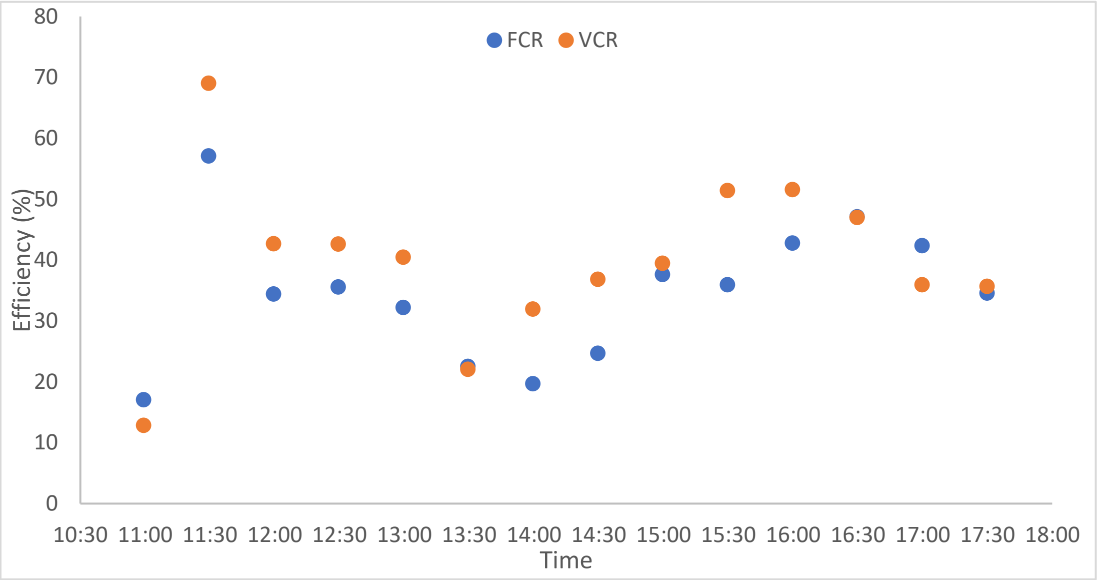
Figure 4. 8 Variations of effiency as a function of daylight hours for angle 45° at (a) 2nd March, (b) 3rd March and (c) 4th March.



(a) at 10th March



(b) at 12th March



(c) at 16th March

Figure 4. 9 Variations of efficiency as a function of daylight hours for angle 35° at (a) 10th March, (b) 12th March and (c) 16th March.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study includes the experimental work of evaluating an evacuated tube receiver's performance in a open loop solar water heating system. The experimental model was developed and created by the present author in the laboratories of Teknologi Petronas University. The collector was measured from 10 AM to 6 PM using Seri Iskandar / Malaysia's solar radiation under the outdoor clear sky conditions. The ETR’s structure was used with CPC, The following important observations are made on the basis of this work:

1. The transition from February to March over the months is found to have a slight effect on the solar radiation. In late February, the maximum solar radiation have been recorded.
2. The experimental findings showed that the temperature of the outlet water at noon has a peak value. The temperature of the outlet water increases with increasing flow rate of water.
3. In mid-March, the maximum efficiency was found. As the mass flow rate increases, the efficiency of the collector is improved due to increasing the amount of heat obtained.
4. Due to the collector's huge water temperature difference, the maximum heat received occurred between 11 AM and 4 PM. Moreover, the heat obtained rises as the flow rate of water increases.

5. The results showed that the difference in temperature between the inlet water and the ambient air temperature is negligible. Nevertheless, due to an increase in the solar radiation level, the inlet water and ambient air temperatures are slowly increased during daylight hours.
6. Most significantly, due to the abundance of solar energy in Seri Iskandar, it is possible to benefit from this energy by using ETR with CPC as an effective alternative and a sustainable solution for low-heat applications, such as household water preheating and with further innovation, for industrial heating.

5.2 Recommendation

The varying heat flux plays an important role for thermosyphon output as a last remark and different inclination angle on different period can give different radiation. Therefore, the variance of testing period and inclination angle can be included in order to enhance the present experimental research. This problem will be dealt with later in the future. Additionally, prospective research will involve a further experimental analysis on traditional solar collector efficiency under the same operating conditions as this report. The new experimental research is needed to compare the present results and to confirm the improvement in thermodynamic efficiency while using ETR. In addition, the theoretical analysis is also needed for evaluating the performance of the present ETR model in order to confirm the experimental results as well as to obtain more realistic results. Thus, it will be taken up in a separate analysis in the future.

REFERENCES

[1] A. Nikpour, "The impact of organizational culture on organizational performance: The mediating role of employee's organizational commitment," *Int. J. Organ. Leadersh.*, vol. 6, no. 1, pp. 65–72, 2017.

[2] A. M. El-nashar, "SA NE M SC PL O E – C EO AP LS TE S M SC PL O E – C EO," vol. II, 1981.

[3] H. Zheng, G. Wu, J. Dai, and Y. Ma, "Design and Testing of a Shell-Encapsulated Solar Collector with the Compound Surface Concentrators," *Int. J. Photoenergy*, vol. 2015, 2015.

[4] Chandraprabu Venkatachalam and Gedlu Solomon, "Evacuated tube solar collector with U-tube Evacuated tube collector receiver consists of a copper U-tube inside a glass vacuumed tube," *Int. J. Sci. Eng. Res.*, vol. 6, no. 12, pp. 138–141, 2018.

[5] G. L. Morrison, I. Budihardjo, and M. Behnia, "Water-in-glass evacuated tube solar water heaters," *Sol. Energy*, vol. 76, no. 1–3, pp. 135–140, 2004.

[6] B. H. Ali, S. I. Gilani, and H. H. Al-Kayiem, "A three dimensional performance analysis of a developed evacuated tube collector using a CFD fluent solar load model," *MATEC Web Conf.*, vol. 13, no. July, 2014.

[7] Q. Wang, J. Wang, and R. Tang, "Design and optical performance of compound parabolic solar concentrators with evacuated tube as receivers," *Energies*, vol. 9, no. 10, 2016.

[8] A. Rabl, J. O'Gallagher, and R. Winston, "Design and test of non-evacuated solar collectors with compound parabolic concentrators," *Sol. Energy*, 1980.

[9] A. Rabl, "Optical and thermal properties of compound parabolic concentrators," *Sol. Energy*, 1976.

[10] G. H. Derrick, D. . Mills, and I. . Bassett, "Relative cost-effectiveness of CPC reflector designs suitable for evacuated absorber tube solar collectors," *Sol. Energy*, 2006.

[11] R. Oommen and S. Jayaraman, “Development and performance analysis of compound parabolic solar concentrators with reduced gap losses - Oversized reflector,” *Energy Convers. Manag.*, 2001.

[12] B. Okafor, “Thermo Siphon Solar Water Heater,” vol. 3, no. 3, pp. 313–316, 2013.

[13] C. L. Gupta and H. P. Garg, “System design in solar water heaters with natural circulation,” *Sol. Energy*, 1968.

[14] A. M. Shariah and G. O. G. Löf, “The Optimization of Tank-Volume-to-Collector-Area Ratio for a Thermosyphon Solar Water Heater,” *Renew. Energy*, 1996.

[15] F. Shahraki and S. abdollah Shojaie, “A review of single-phase closed loop thermosyphon and simulating with ANSYS CFX,” no. figure 1, pp. 25–28, 2010.

[16] D. N. Basu, S. Bhattacharyya, and P. K. Das, “A review of modern advances in analyses and applications of single-phase natural circulation loop in nuclear thermal hydraulics,” *Nuclear Engineering and Design*. 2015.

[17] P. K. Vijayan, “Experimental observations on the general trends of the steady state and stability behaviour of single-phase natural circulation loops,” *Nucl. Eng. Des.*, 2002.

[18] D. S. Pilkhwal, W. Ambrosini, N. Forgione, P. K. Vijayan, D. Saha, and J. C. Ferreri, “Analysis of the unstable behaviour of a single-phase natural circulation loop with one-dimensional and computational fluid-dynamic models,” *Ann. Nucl. Energy*, 2007.

[19] N. M. Rao, B. Maiti, and P. K. Das, “Dynamic performance of a natural circulation loop with end heat exchangers under different excitations,” *Int. J. Heat Mass Transf.*, 2005.

[20] R. Saha, S. Sen, S. Mookherjee, K. Ghosh, A. Mukhopadhyay, and D. Sanyal, “Experimental and Numerical Investigation of a Single-Phase Square Natural Circulation Loop,” *J. Heat Transfer*, 2015.

[21] M. Misale, “Experimental study on the influence of power steps on the thermohydraulic behavior of a natural circulation loop,” *International Journal of Heat and Mass Transfer*. 2016.

[23] M. H. Ahmadi *et al.*, "Solar power technology for electricity generation: A critical review," *Energy Sci. Eng.*, vol. 6, no. 5, pp. 340–361, 2018.

[24] A. Alizadehdakhel, M. Rahimi, and A. A. Alsairafi, "CFD modeling of flow and heat transfer in a thermosyphon," *Int. Commun. Heat Mass Transf.*, 2010.

[25] A. I. Sato, V. L. Scalon, and A. Padilha, "Numerical analysis of a modified evacuated tubes solar collector," *Renew. Energy Power Qual. J.*, 2012.