Performance of the Single and Double Pass V-Groove Solar Collector

By

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Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Khairul Habib)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2012

CERTIFICATION OF ORIGINALITY

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

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RAJA MOHAMED RIZAL B RAJA MOHAMED ABDUL SHAINI

ABSTRACT

The project is about the performance of single and double pass V-groove solar collector. A solar collector will trap heat energy from sun and transfer the heat to the working fluid to be used in any heating application. However, some of the heat is loss to surrounding by radiation and natural convection. Through this project, the author will simulate the performance of single and double pass V-groove solar collector by using computer software. The effect of four different parameter that are the mass flow rate of working fluid, the length of solar collector, the groove height and the groove angle to the efficiency of the solar collector will be presented in this paper.

In order to make the simulation, some formulas and model is used by the author. The details of the formula and model will be explained in the Methodology part of this paper. Four graphs are made to represent the effect of four parameters to the efficiency of V-groove solar collector. Based on the result, efficiency of V-groove solar collector will increase when mass flow rate of working fluid increase and decrease when the length of solar collector, the groove height and groove angle increase. Further discussion about the findings will be discussed in the Result part of this paper.

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First and foremost, all praises The Almighty as for His blessing and guidance and also giving opportunity and strength to the author to get through and completing the research and study about this project.

Author wants to take this opportunity to express his gratitude and deep regards to his supervisor, Dr Khairul Habib for his guidance, monitoring and constant encouragement throughout this project. All the help and guidance given by him time to time shall carry me a long way in the journey of life on which I am about to embark.

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Lastly, the author would like to thank parents, brother and sister for their moral supports and encouragement. Although they do not directly involve in the completion of this project, their support give strength to the author to continue and work hard in order to finish the project.

LIST OF FIGURES

NOMENCLATURE

q_u	Useful energy
C_p	Specific heat of air (J/kg$\dot{m}$K)
$\dot{m}_f$	Fluid mass flow rate (kg/m^2.s)
T_I	Inlet temperature
T_O	Outlet temperature
η	Solar collector efficiency
A_c	Area of solar collector
S	Solar radiation incident on the collector
θ	Angle of groove
Nu	Nusselt number
Re	Reynold number
H_g	Height of v-grooves
ρ	Density of air
ν	Kinematic viscosity of air
μ	Dynamic viscosity of air
K	Thermal conductivity
D_h	Hydraulic diameter
α	Absorption coefficient
ε	Emission coefficient
T_c	Glass cover temperature
T_{ap}	Absorber plate temperature
T_f	Working fluid temperature
T_{bp}	Insulation temperature
$h_{r,c-s}$	Radiation heat transfer coefficient between glass cover and sky
h_w	Heat transfer coefficient through wind

h_b	Conduction heat transfer coefficient of insulation
$h_{c,ap-c}$	Convection heat transfer coefficient between absorber plate and glass cover
$h_{r,ap-c}$	Radiation heat transfer coefficient between absorber plate and glass cover
$h_{c,ap-f}$	Convection heat transfer coefficient between absorber plate and working fluid
$h_{r,ap-f}$	Radiation heat transfer coefficient between absorber plate and working fluid
$h_{c,f-bp}$	Convection heat transfer coefficient between fluid and insulation
$h_{r,ap-bp}$	Radiation heat transfer coefficient between absorber plate and insulation

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Final year project (FYP) is a program required to be taken by all final year students in Universiti Teknologi Petronas (UTP). This program is divided into two sections that are Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2). In this program, students are required to handle a project based on research, design and development or both. The objective of this project is to gives opportunity for students to apply tools and techniques that they gain during their studies in UTP and practical company in order to solve the problems they may encountered while completing their project. Every student will be place under one supervisor. Students will work under the guidance of supervisor. This will shape the direction of what they want to be in the future. Teamwork values will be included with the development of good and professional relationship with their supervisor and colleagues.

The author has chosen “Performance of the Single and Double Pass V-Groove Solar Collector” as his Final Year Project. This project will be focusing on the design and simulating the performance of solar collector. The difference between the single and double pass solar collector will be measured and simulated by using specific computer software.

A solar collector is one component of heating system. It is equipment that collecting heat energy from the sun. A solar collector usually used together with other equipment such and pump and heat exchanger. However, this project will be focusing on the solar collector only.

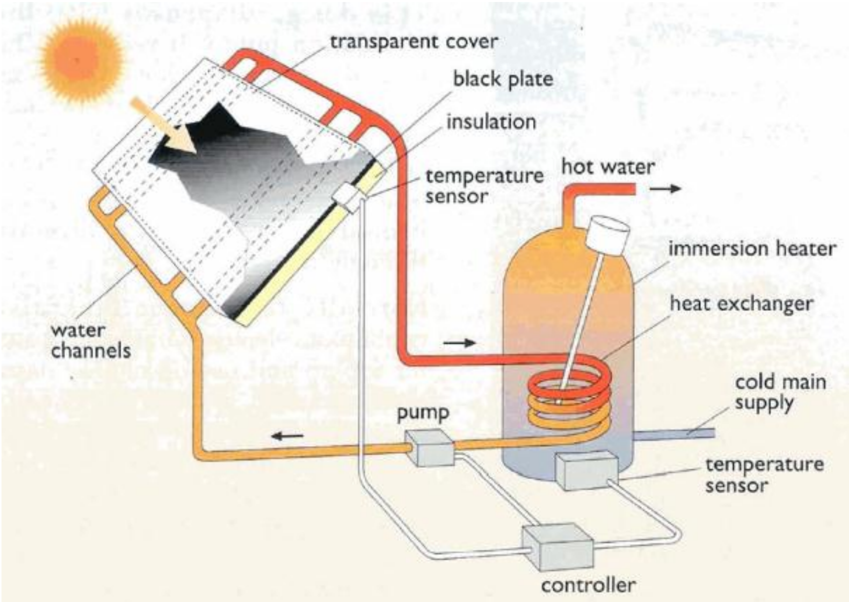

Figure 1.1: Solar Heating System.... [1]

A medium will be allowed to flow between the absorber plate and the glazing. This medium is called working fluid. It will absorb the heat energy collected by the absorber plate. The heat energy will be carried by the working fluid as it flow through the solar collector and will be used in many type of applications. The common working fluids that being used with solar collector is air or water. Various applications that involve solar collector are solar water heating, solar space heating, solar refrigeration and food drying. This project will be focusing air as the working fluid. All the analysis and calculations will be based on the properties of air.

1.2 Problem Statement

Heat energy is absorbed by solar collector. The heat then will be transferred to the working fluid usually water or air. However, the amount of heat transferred to the working fluid will be less than the total heat energy absorbed by the solar collector. The losses may be because the environmental effects such as heat transfer coefficient and also the properties of the solar collector. This phenomenon affects the performance of the solar collector. This project is to design and simulate the performance of the solar collector.

1.3 Objective and Scope of Study

The objective of this project is to design and simulate the performance of single and double pass solar collector. The performance different between the present result will be compared with the previous work.

The effect of four different parameters to the efficiency of v-groove solar collector will be simulated. The four parameters are:

- Mass flow rate of working fluid.
- Length of solar collector.
- Groove height.
- Groove angle.

Recommendation on the best V-groove solar collector will be made based on the result of the simulation at the end of this paper.

The scope of this project is about the V-groove solar collector with air as the working fluid.

CHAPTER 2
LITERATURE REVIEW

2.1 Solar Collector Fundamental

A solar collector is a combination of several parts namely glazing, absorber plate, insulation and box. Each of the components has its specific function [2]. The absorber plate will absorb the heat from the sun and transfer the heat to working fluid. Glazing is a transparent cover that allowed sun radiation to reach the absorber plate. Glazing helps to reduce the heat loss from collector to sky through radiation. A box made from a material with low conduction heat transfer coefficient act as a base for the absorber plate and glazing to be placed. Insulation is placed at the bottom and side of the collector to reduce the heat loss by conduction.

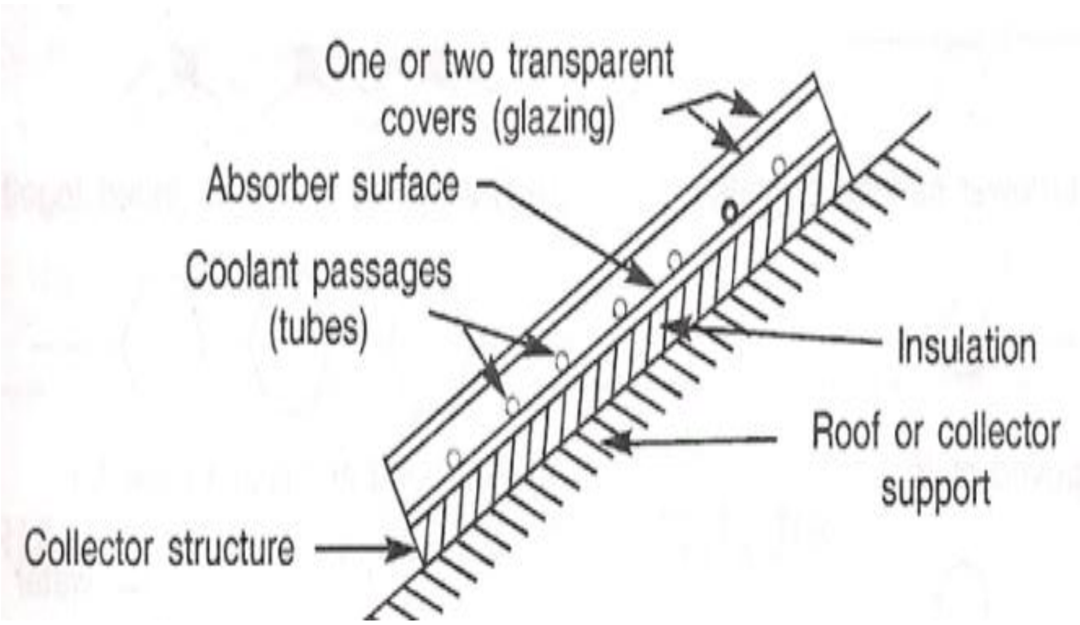

Figure 2.1: Solar Collector Components… [2]

In order to improve the performance of solar collector some researchers had invented solar collector that has more than one pass. It is called the single and double pass solar collector.

2.1.1 Single Pass Solar Collector

Single pass solar collector is the simplest design for solar collector. It has one air flow channel. The air will flow between the cover and absorber plate. The air will only pass flowing through the solar collector once before it leaves the solar collector [3].

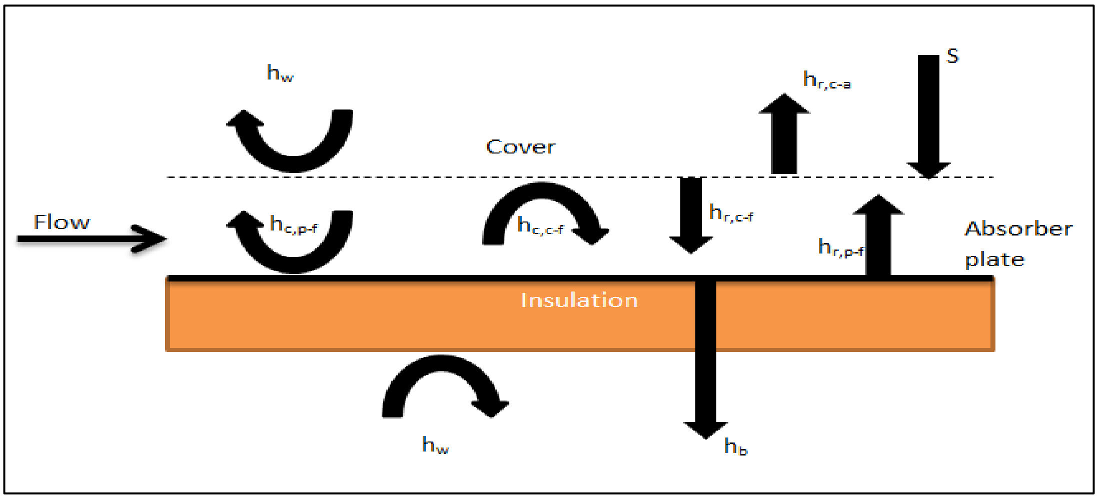

Figure 2.2: Single Pass Solar Collector

2.1.2 Double Pass Solar Collector

The idea of double pass solar collector was generated by Satcunanathan and Deonarine [4]. Double pass solar collector has two air flow channel. The air will flow between the cover and the absorber plate and between the absorber plate and the bottom plate. The air will flow twice through the solar collector before it leaves it. Air will flow through the top channel before it turn back and flow through the bottom channel before it leaves. Thus, it give the air opportunity to absorbed more heat energy compare to the single pass solar collector.

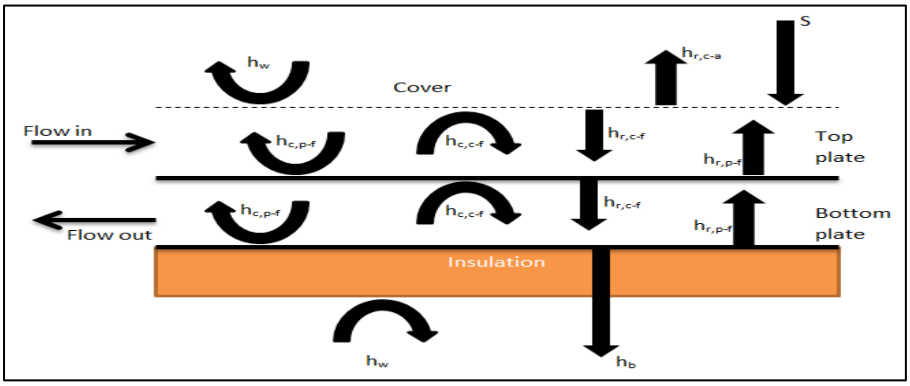

Figure 2.3: Double Pass Solar Collector

2.1.3 V-Groove solar collector

There are many modification has been made to the existing solar collector in order to increase the performance of the solar collector. Examples of modification that already made by Rene Tchinda [3] researchers is shown below. One of the modifications is the v-groove solar collector.

The v-groove solar collector has no different with the other type of solar collector. It has the same basic components and also same function. However, the absorber plate is made in v-groove shape. The figure of v-groove solar collector is shown in figure 2.4. Similar with other type of solar collector, v-groove solar collector also can be divided into single pass and double pass. The different between single pass v-groove solar collector and double pass v-groove solar collector is same as explained in section 2.1.1 and section 2.1.2.

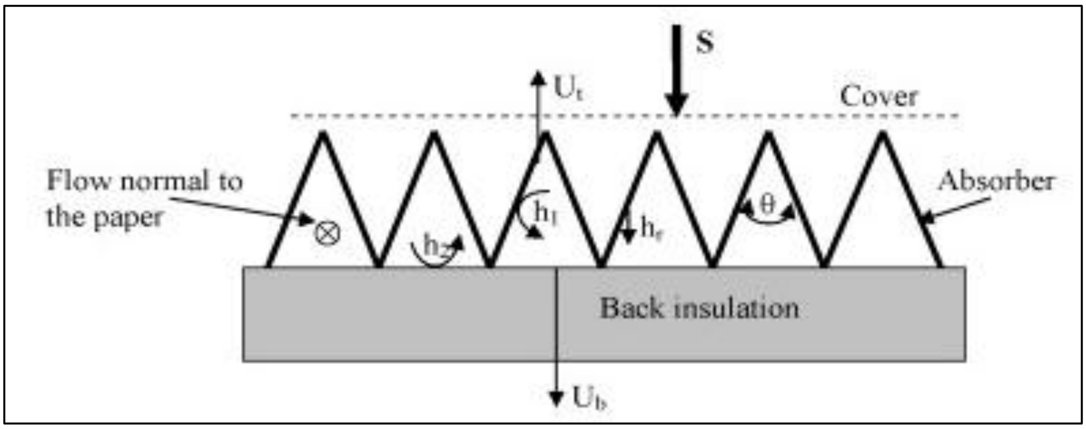

Figure 2.4: Single Pass V-Groove Solar Collector… [3]

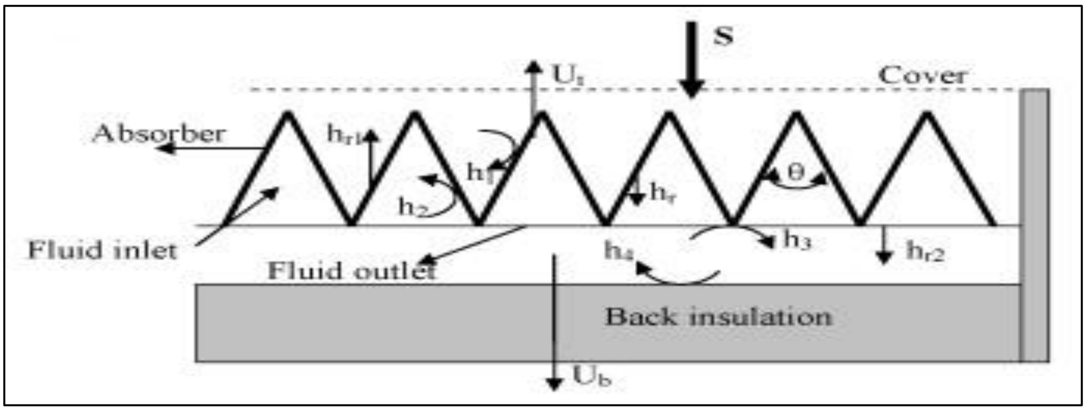

Figure 2.5: Double Pass V-Groove Solar Collector… [3]

2.2 Theory

From a study, the amount of energy that sun supply to the earth is 170 trillion kW [5], [6]. However, earth did not get all the energy supply by the sun. 30% of the energy is reflected to the space, 47% are radiated back to space, and 23% of the power is used to power evaporation cycle of biosphere. People and plant on the earth only receive less than 0.5% of the energy.

The efficiency of a solar collector can be calculated by knowing the energy absorbed by the absorber plate and the useful energy. Useful energy is the energy transferred from absorber plate to the working fluid. According to Liu et al [7], the useful energy can be calculated by using mathematical formula.

$$q_u = C_p \dot{m}_f (T_O - T_I) \quad (2.1)$$

where q_u is the useful energy (J/s), C_p is the specific heat of air (J/kg$\dot{m}$K), $\dot{m}_f$ is the fluid mass flow rate (kg/m^2.s) and T_O and T_I is the outlet temperature and inlet temperature respectively. According to K. Sopian [5], the thermal performance of a solar collector can be determined by the formula below:

$$\eta = \frac{Q_u}{A_c S} \quad (2.2)$$

where A_c is the area of the collector and S is the solar radiation incident on the collector.

From formula (2.2), we can see that we can increase the solar collector performance by increasing the useful energy. In order to increase the useful energy we have to increase the difference between the inlet and outlet temperature. It can be shown by formula (2.1), the difference between the inlet and outlet temperature can be increase if we improve the heat transfer between the absorber plate and the working fluid. The above formula can be applied to any type of solar collector including V-groove solar collector.

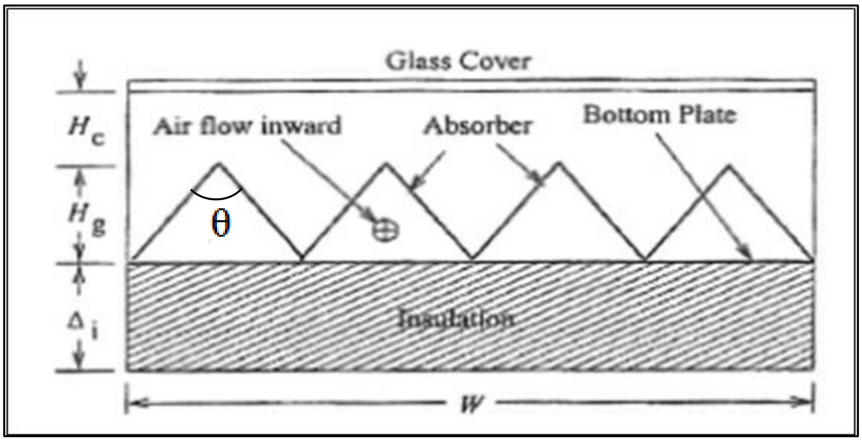

Figure 2.6: V-Groove Solar Collector [7]

Several researches about the performance of v-groove solar collector have been made. A paper made by A.E Kabeel and K. Mecarik (1997) had given a different formula to calculate the useful energy. According to them, useful energy can be calculated by knowing the value of convection heat transfer, area of the collector, inlet temperature and outlet temperature [8].

$$q_u = h_c A_c (T_o - T_i) \quad (2.3)$$

Besides that, they also found that the angle of v-groove affect to the value of useful energy. This is because the angle affects both the value of convection heat transfer coefficient and the area of the collector that being used to calculated the value of useful energy. The mathematical model for this explanation had been generated by assuming constant temperature different:

$$q_u = c_1 \frac{(cos\theta)^{n-1}}{1+cos\theta}\left(\frac{L}{cos\theta}\right)\Delta T \quad (2.4)$$

$$q_u = c_2 \frac{(\cos\theta)^{n-2}}{(1+\cos\theta)^{n-1}} \quad (2.5)$$

where $$c_2 = K\left(\frac{\rho V}{\mu}\right)^n \left(2H_g\right)^{n-1} L\Delta T \quad (2.6)$$

The value of useful energy then will affect the efficiency of the solar collector because from the formula (2.2), efficiency is directly proportional to the useful energy. Thus, according to them, the v-groove angle will affect the performance of the solar collector.

A research made by Luo et al [7], propose that the height of the v-groove absorber (H_g) will decrease the performance of the solar collector. However, the temperature of glass cover, absorber plate and bottom plate increase with the increase of H_g. In this report, they conclude that the convection heat transfer coefficient between the absorber plate and fluid decrease while the radiation heat transfer coefficient between the absorber plate and the bottom plate increase with the increase of $H_{g.}$. This factor not just affect the performance of v-groove solar collector, it will also affect the performance of other type of solar collector such as flat-plate solar collector.
Some other method to increase the v-groove solar collector is by combining the v-groove solar collector with other type of solar collector. Niko Aris Sudiyanto [9] have made and experimental study about the performance of v-groove solar collector with honeycomb. The purpose is to increase the contact area between the plate and the air so that more heat can be transferred from the absorber plate to the air. From Niko Aris Sudiyanto experiment, the v-groove solar collector with additional honeycomb gives a higher efficiency.

Another study made by Bashira et al [10], to compare the performance of single pass v-groove solar collector, double pass v-groove solar collector and double pass v-grove solar collector with porous media. The result of his study shows that single pass v-groove solar collector has the lowest efficiency. The second is double pass v-groove solar collector by efficiency different of 4-7% more. The highest efficiency is the double pass v-groove solar collector with porous media by efficiency different of 7% with single mode and 2-3% more than the double pass v-groove solar collector without porous media. However, by increasing the number of pass and additional of porous media will increase the pressure drop. Thus, we need more power to blow the air through the collector.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The research for this project has been done by reading the previous studies and experiment made by researchers. The sources are collected through the internet and some energy book about solar radiation. Some information that might be useful for this project such as the efficiency equations of solar collector are extracted and being documented in this proposal. The suitable model and equations are selected and used for the purpose of simulation. The reference articles are listed in the Reference section.

3.2 Project Activities

The first step in this project is data collection. It starts after the title selection. During this step, all available data, formulas and model are gathered from various reference sources. The list of references is placed at the end of this paper. The project continues by selecting the most suitable model and formula for the simulation. All the selected formulas and data are then being used in programming the simulation. In order to make the programming, specific computer software called MATLAB is used.

After finishing the programming, the result is tested by simulating the program. The result is then being compared with the result of previous research. If the result that the author gets is different as the previous research result, the formula and the model of the programming will be review to find out any mistake done during the programming. On the hand, if the result is same as the previous research result, the author will continue with the discussion and conclusion. The final step in this project is to prepare and submit the final report.

The flow chart of the activities is shown in the figure below:

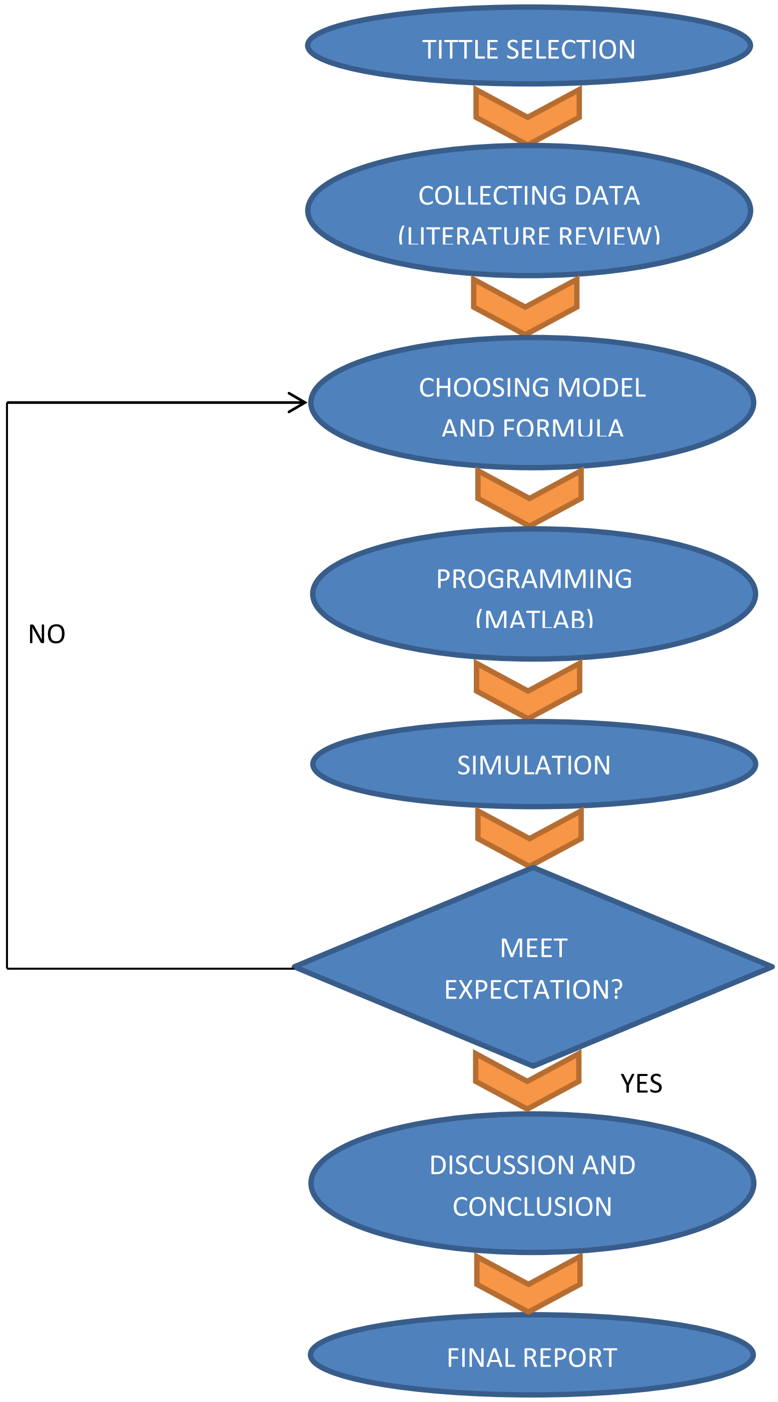

Figure 3.1: Project Activities Flow Chart

3.3 Gantt Chart

3.3.1 FYP 1

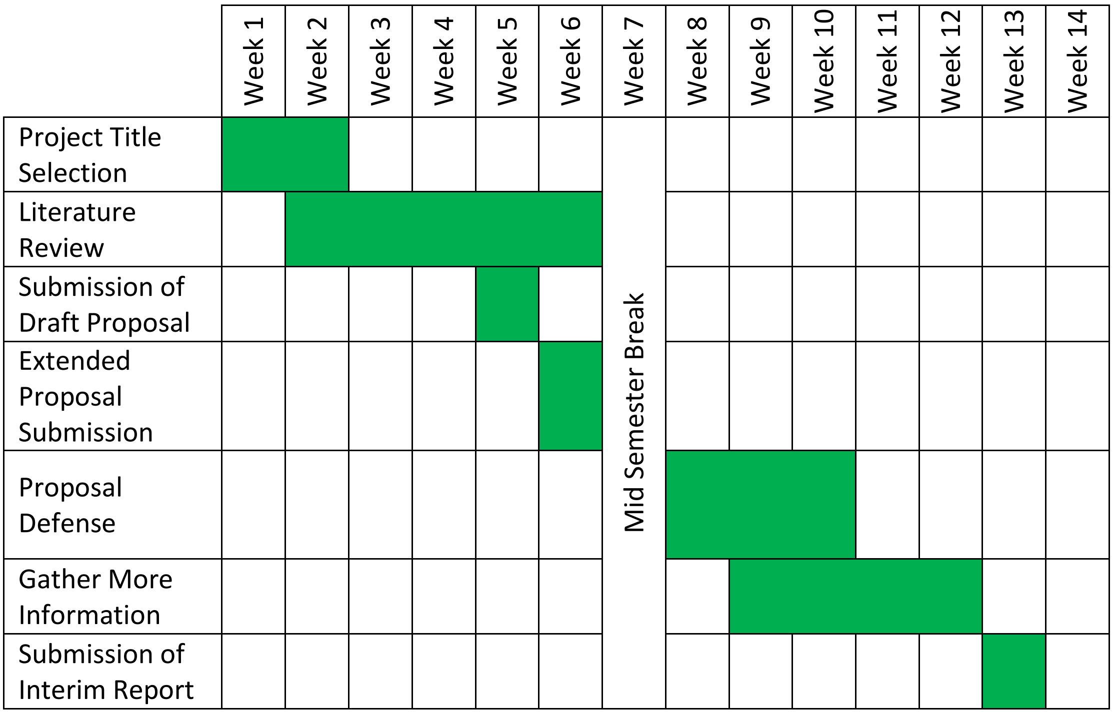

Figure 3.2: FYP 1 Project Gantt Chart

The Gantt chart shows the activities that already done during FYP 1. In FYP 1, there are 3 major activities that already done by the author. The activities are submission of extended proposal, proposal defense and submission of interim report. The extended proposal was submitted on week 6. The proposal defense was done during week 10 and interim report is submitted on week 13. Apart from the major activities, some gathering activities are done during FYP 1 for preparation for FYP 2. Information about the project topic and also the suitable software are gathered through internet and previous research.

3.3.2 FYP 2

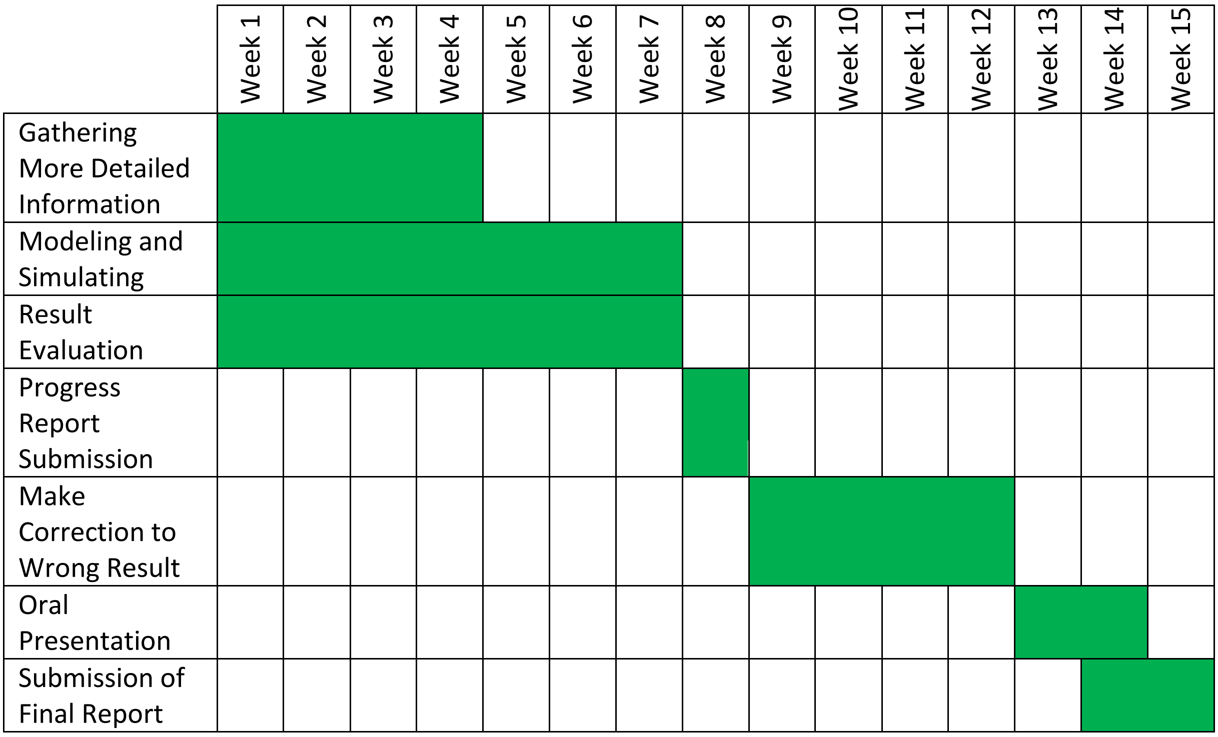

Figure 3.3: FYP 2 Project Gant Chart

These are the activities during FYP 2. The modeling and simulation will be start at the start of FYP 2. The result will be evaluated and verified. Progress report will be submitted at the end of week 8. Any modification on the simulation result will be done after the progress report before the oral presentation and Final Report submission. The oral presentation will be done on week 13 to week 14 and the final report will be submitted on week 14 and week 14.

3.4 Tools and Software

This project will require the author to use computer simulation software. The simulating software that will be used in this project is MATLAB. Apart from that, Microsoft Word and Microsoft Excel will be used if necessary.

3.4.1 MATLAB

MATLAB or in the full name Matrix Laboratory is a computer software with numerical computing environment and fourth-generation programming language. MATLAB software has the capabilities to manipulate matrix, plotting functions and data, implement algorithm, create user interface, and interfacing with programs written in other languages. MATLAB also offer powerful simulation capabilities.

3.4.2 Microsoft Word and Microsoft Excel

Microsoft Word and Microsoft Excel is the common computer software that being used for documentation. Microsoft Word will be used to prepare the reports during FYP 1 and FYP 2. Microsoft Excel is act as supporting software for MATLAB in order to do the simulation. Some simple calculations can be calculated by using Microsoft Excel before it is used in MATLAB for modeling and simulation.

3.5 Model and Formula

In order to simulate the performance of V-groove solar collector, a model made by T. Liu and W. Lin is use. The model is shown in the figure below.

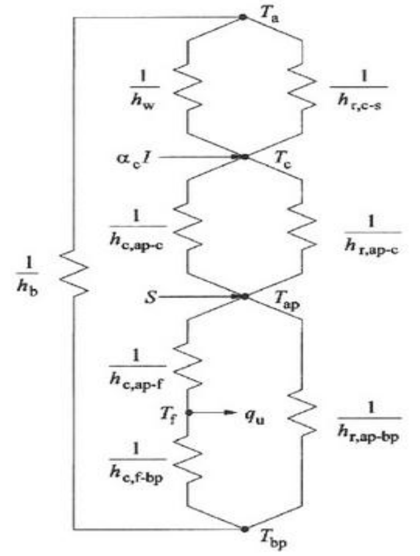

Figure 3.4: Single Pass V-Groove Solar Collector Model

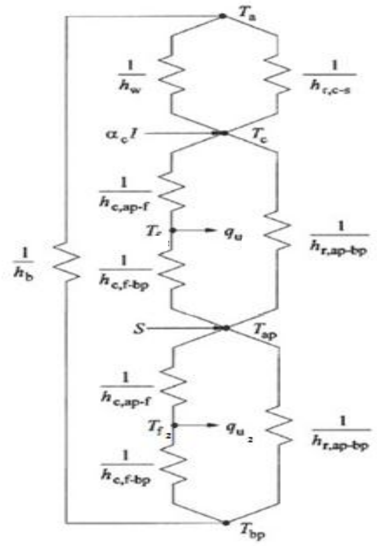

Figure 3.5: Double Pass V-Groove Solar Collector Model

From this model, a solar collector is divided into four main points. Those points are glass cover (c), absorber plate (ap), working fluid (f) and insulator (bp). From these four components, four different energy balance equations have been made. The first energy balance equation is at the glass cover. At this point, the glass cover absorbed from the absorber plate through conduction ($h_{c,ap-c}$) and radiation ($h_{r,ap-c}$) and sun ($\alpha_c I$). However, the equal amount of heat absorbed by the glass cover is loss to the surrounding (h_w) and also to the sky ($h_{r,c-s}$)

$$\alpha_c I + (h_{c,ap-c} + h_{r,ap-c})(T_{ap} - T_c) = (h_w + h_{r,c-s})(T_c - T_a) \quad (3.1)$$

At the absorber plate, the energy balance equation can be written as:

$$S = (h_{c,ap-c} + h_{r,ap-c})(T_{ap} - T_c) + h_{r,ap-bp}(T_{ap} - T_{bp}) + h_{c,ap-f}(T_{ap} - T_f) \quad (3.2)$$

where S is the energy absorbed by absorber plate from the sun. From the equation, the energy absorbed by the absorber plate is equal to the energy lass to the cover plate, insulator and also the working fluid. S can be calculated by using formula:

$$S = 0.97\tau_c\alpha_{ap}I \quad (3.3)$$

At the working fluid, the energy balance equation can be written as:

$$h_{c,ap-f}(T_{ap} - T_f) = q_u + h_{c,f-bp}(T_f - T_{bp}) \quad (3.4)$$

From the above equation, some heat energy that the working fluid gain from the absorber plate will be loss to the insulator and the remaining will be used as useful energy.

Last but not least, the energy balance equation at the insulator can be written as:

$$h_{r,ap-bp}(T_{ap} - T_{bp}) + h_{c,f-bp}(T_f - T_{bp}) = h_b(T_{bp} - T_a) \quad (3.5)$$

from this equation, it is shown that the total heat energy the insulator gain from working fluid and absorber plate will be loss to the surroundings.

For double pass V-groove solar collector, there two different for working fluid, working fluid 1 (T_{f1}) and working fluid 2 (T_{f2}). The energy balance equation for working fluid 1 is similar with the equation 3.4, however at working fluid 2 the energy absorbed from the absorber plate is equal to the summation of energy loss to the insulation and useable energy. The energy balance equation can be written as:

$$h_{c,ap-f2}(T_{ap} - T_{f2}) = q_{u2} + h_{c;ap-f2}(T_{f2} - T_{ap}) \quad (3.6)$$

From equation (3.1),

$$T_c = \frac{\alpha_c I + \left(h_{c,ap-c} + h_{r,ap-c}\right)T_{ap} + (h_w + h_{r,c-s})T_a}{h_{c,ap-c} + h_{c,ap-c} + h_w + h_{r,c-s}} \quad (3.7)$$

From equation (3.2),

$$T_{ap} = \frac{S + \left(h_{c,ap-c} + h_{r,ap-c}\right)T_c + h_{r,ap-bp}\,T_{bp} + h_{c,ap-f}T_f}{h_{c,ap-c} + h_{r,ap-c} + h_{r,ap-bp} + h_{c,ap-f}} \quad (3.8)$$

From equation (3.4),

$$T_f = \frac{h_{c,ap-f}\left(T_{ap} + T_{bp}\right) + q_u}{h_{c,ap-f} + h_{c,f-bp}} \quad (3.9)$$

Because q_u can be replace with $2C_p\dot{m}_f(T_f - T_{fi})$, thus,

$$T_f = \frac{h_{c,ap-f}\left(T_{ap} + T_{bp}\right) + 2c_p\dot{m}_f T_{fi}}{h_{c,ap-f} + 2c_p\dot{m}_f} \quad (3.10)$$

From equation (3.5),

$$T_{bp} = \frac{h_b T_a + h_{r,ap-bp}T_{ap} + h_{c,ap-f}T_f}{h_b + h_{r,ap-bp} + h_{c,ap-f}} \quad (3.11)$$

From equation (3.6),

$$T_{f2} = \frac{h_{c,ap-f2}\left(T_{ap} + T_{bp}\right) + 2C_p\dot{m}T_{f1}}{2h_{c,ap-f2} + 2C_p\dot{m}} \quad (3.12)$$

The value of h_w and h_b is then calculated by using formula recommended by McAdams s[11]:

$$h_w = 5.7 + 3.8V_w \quad (3.13)$$

$$h_b = \frac{K_i}{\Delta_i} \quad (3.14)$$

where V_w is the air velocity, K_i is the heat transfer coefficient of the insulator and Δ_i is the thickness of the insulator.

The radiation heat transfer coefficient between glass cover and surrounding can be calculated by using formula:

$$h_{r,c\text{-}s} = \frac{\varepsilon_c (constant)(T_c{}^4 - T_a{}^4)}{(T_c - T_a)} \quad (3.15)$$

The radiation heat transfer coefficient between the absorber plate and glass cover and radiation heat transfer coefficient between absorber plate and insulator can be calculated by:

$$h_{r,ap\text{-}c} = \frac{(constant)(T_{ap}{}^4 - T_c{}^4)}{(T_{ap} - T_c)(\frac{1}{\varepsilon_{ap}} + \frac{1}{\varepsilon_c} - 1)} \quad (3.16)$$

$$h_{r,ap\text{-}bp} = \frac{(constant)(T_{ap}{}^4 - T_{bp}{}^4)}{(T_{ap} - T_{bp})(\frac{1}{\varepsilon_{ap}} + \frac{1}{\varepsilon_{bp}} - 1)} \quad (3.17)$$

The natural convection heat transfer coefficient between the absorber plate and glass cover can be calculated by knowing the Rayleigh number and Nusselt number is known:

$$Ra = \frac{g\beta(T_{ap} - T_c)\left(\frac{A_c}{p}\right)Pr}{\nu^2} \quad (3.18)$$

$$Nu_{ap\text{-}c} = 1 + 1.44(1 - \frac{1708}{Ra}) + [(\frac{Ra}{5830})^{1/3} - 1] \quad (3.19)$$

$$h_{c,ap\text{-}c} = Nu_{ap\text{-}c}\frac{k}{H_c} \quad (3.20)$$

where Ra is Rayleigh number, Nu is Nusselt number A_c is collector area, p is collector perimeter, Pr is Prantle number, ν is the viscosity of air and H_c is the distance between the absorber plate and glass cover.

The value for force convectional heat transfer coefficient between absorber plate and working fluid can be calculated given that the hydraulic diameter and Reynold number is known:

$$D_h = \frac{2H_g cos\theta}{1+cos\theta} \quad (3.21)$$

$$Re = \frac{V_w D_h}{\nu} \quad (3.22)$$

$$Nu_{ap\text{-}f} = 2.821+0.126Re\frac{H_g}{L}, \text{ when } Re<2800 \quad (3.23)$$

$$Nu_{ap\text{-}f} = 1.9x10^{-6}Re^{1.79}+225\frac{H_g}{L}, \text{ when } 2800<Re<10^4 \quad (3.24)$$

$$Nu_{ap\text{-}f} = 0.0302Re^{0.74}+0.242Re^{0.74}\frac{H_g}{L}, \text{ when } 10^4<Re<10^5 \quad (3.25)$$

$$h_{c,p\text{-}f} = \frac{Nu_{ap-f}K}{D_h} \quad (3.26)$$

where D_h is the hydraulic diameter and Re is the Reynold number.

The problem of these formulas is the value of T_c, T_{ap}, T_f, and T_{bp} is not known and these values are needed to calculate the heat transfer coefficient and also the efficiency. Thus, the value of these temperatures is assumed first to calculate the value of heat transfer coefficients and then revaluate again by using formula (3.7), (3.8), (3.10), and (3.11). This procedure is repeated until the different between the assumed value and calculated value is 0.01% or lower.

CHAPTER 4

RESULTS AND DISCUSSIONS

All the formula to calculate the efficiency of solar collector is put into MATLAB software as programming. The result of the programming is shown in form of graph. There are four graphs that represent the effect of four different parameters to the efficiency of V-groove solar collector.

4.1 Single Pass V-Groove Solar Collector

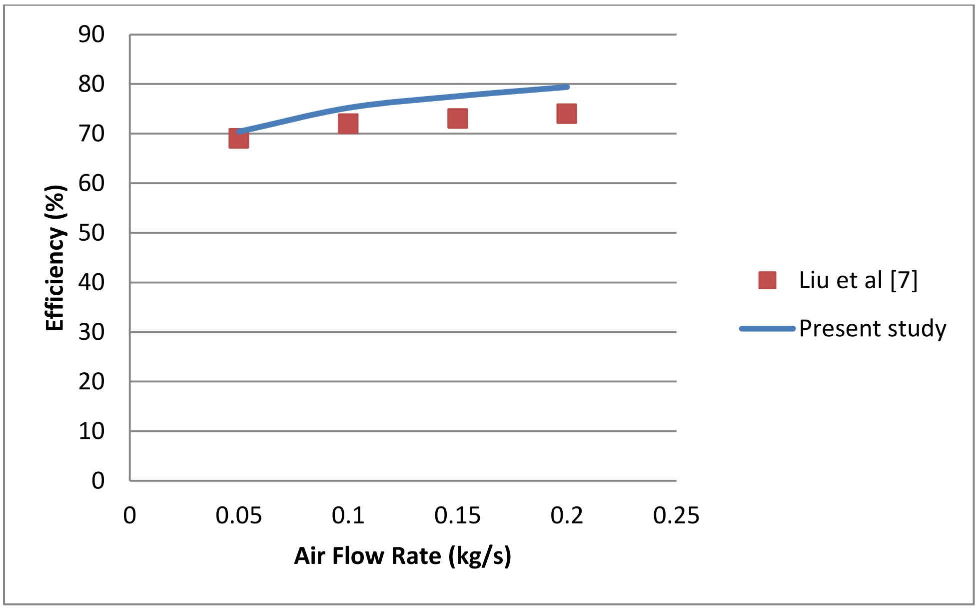

Figure 4.1: Efficiency Vs Air Flow Rate

From figure 4.1, we can say that the efficiency is increasing with the increase of mass flow rate. The useful energy is directly proportional with the mass flow rate, specific heat capacity of the fluid and also the different between the fluid inlet temperature and fluid outlet temperature based on formula (2.1).

Thus it is clear that as the air flow rate ($\dot{m}_f$) increase, the efficiency will increase because the higher the useful energy, the higher the efficiency.

Besides that, air flow rate will increase the rate of heat transfer. Thus it increases the efficiency of the solar collector. The simples' example is a person who just finish 400 meter run will sit in front of fan to help him cool faster. What he did is increase the flow rate of air to increase the heat transfer from his body to the air.

From figure 4.1, the result of the present study is slightly different with the result of found by Liu et al [7]. The average different percentage for every point is calculated to be ±5%. The different is due to the different solar radiation data used. The data used in this study is based on Malaysia environment.

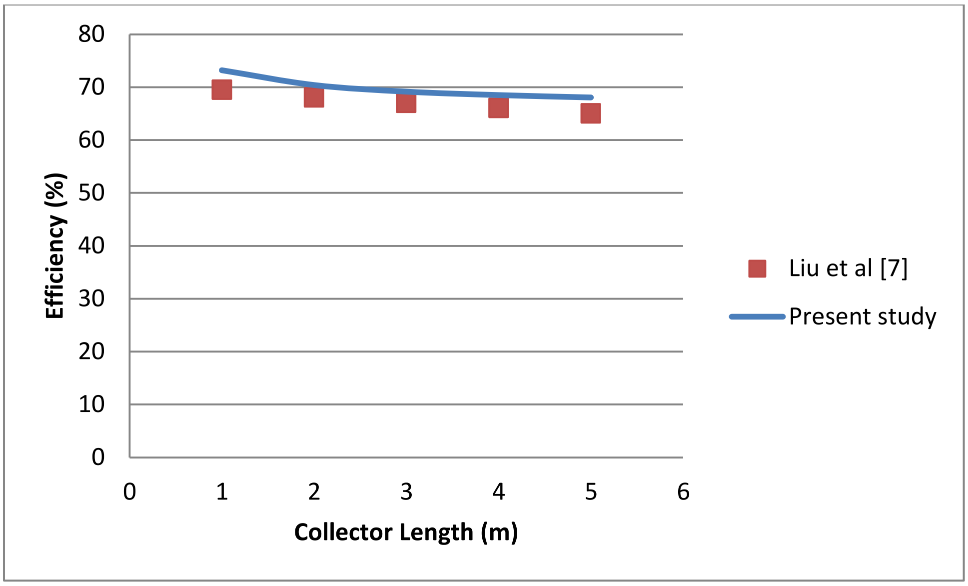

Figure 4.2: Efficiency Vs Collector Length

From the figure 4.2, the result of the present study is slightly different with the result made by Liu et al [7]. The efficiency calculated by Liu et al [7] is slightly higher compared to the efficiency of the present study. The average different percentage for every point is calculated to be ±4%. The different is due to the different information used in this study and study made by Liu et al [7].

Based on figure 4.2, the efficiency of single pass V-groove solar collector will decrease when the length of solar collector increase. Based on Liu et al [7], as the length increase the efficiency will decrease because there will be small reduction in the value of convection heat transfer between absorber plate and working fluid ($h_{c,ap-f}$). The value of $h_{c,ap-f}$ is important because it will affect the heat transfer between the absorber plate to the fluid. The effect of collector length to the convection heat transfer is shown in figure 4.3 below.

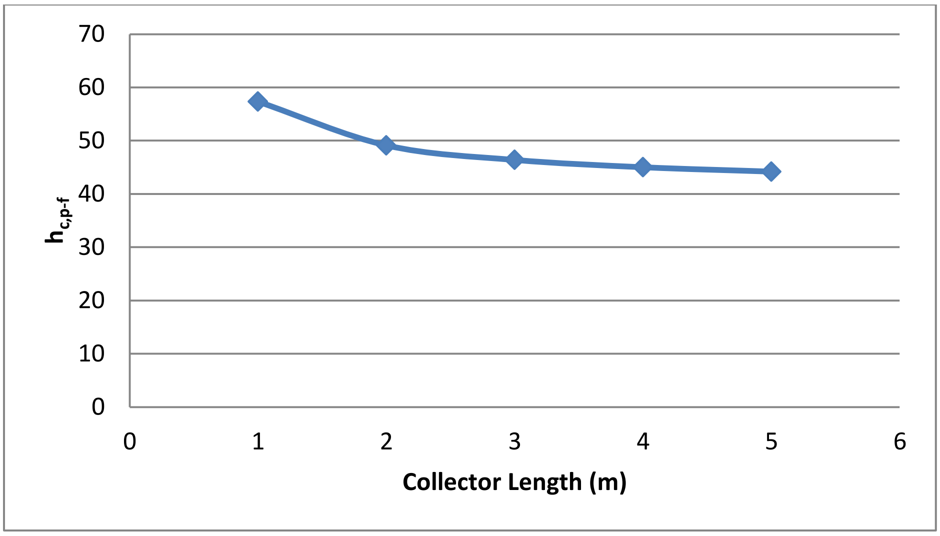

Figure 4.3: Convection Heat Transfer Vs Collector Length Graph

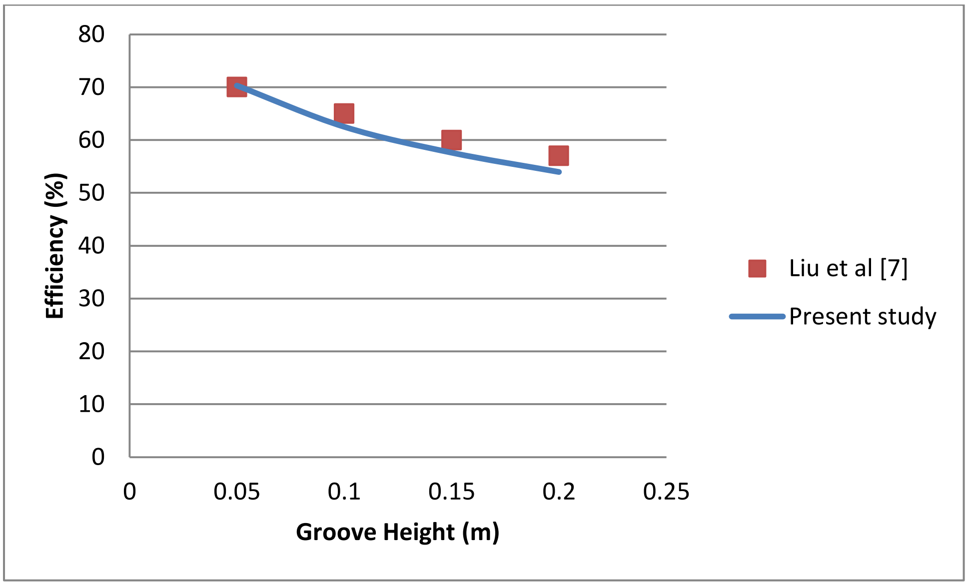

Figure 4.4: Efficiency Vs Groove Height

From the figure 4.4, the result of the present study similar shape with the made by Liu et al [7], however the efficiency of the present study is slightly lower compared to the efficiency found by Liu et al [7]. The average different percentage for every point is calculated to be ±3.4%. The different is might be due to some error in calculation and formula used in the programming.

Figure 4.4 shows that as the groove height increase, the efficiency of single V-groove solar collector will decrease. This is because with the same value of groove angle, the number of groove will decrease. Figure 4.5 explains the effect of groove height to the number of groove.

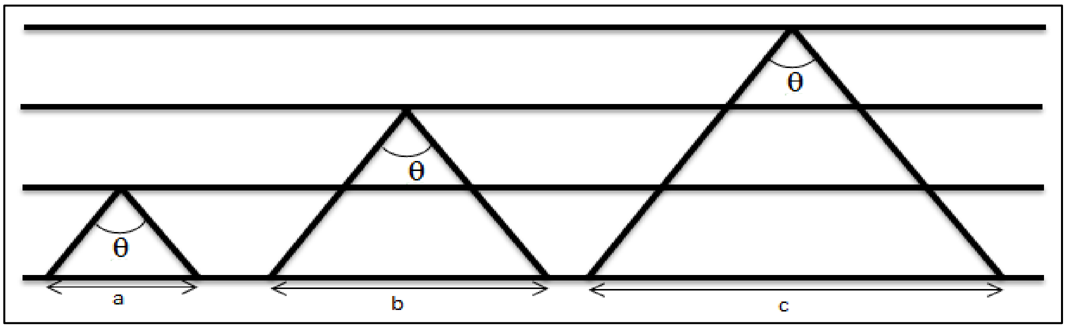

Figure 4.5: Effect of Groove Height to the Number of Groove

As the height of groove increase, the wide of the groove will also increase to maintain the same angle. The value of *c* is more than *b* and value *b* is more than *a*. Thus, with the fix width of solar collector, the number of groove will decrease.

Besides that the values of convection heat transfer between absorber plate and working fluid decrease as the collector length increase. Figure 4.6 show the result of MATLAB simulation. From the figure, it is proof that the convection heat transfer decrease when the collector length increases.

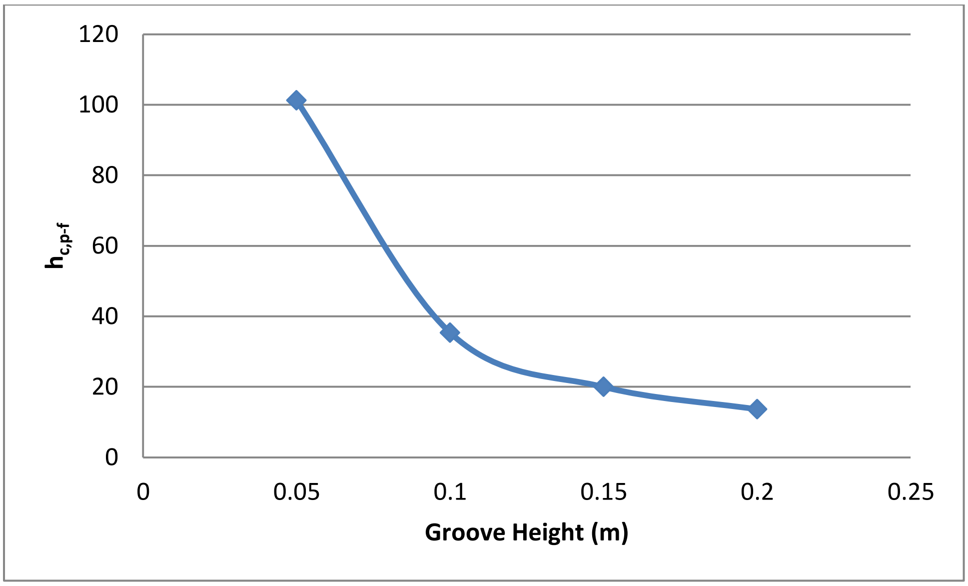

Figure 4.6: Convection Heat Transfer Vs Groove Height Graph

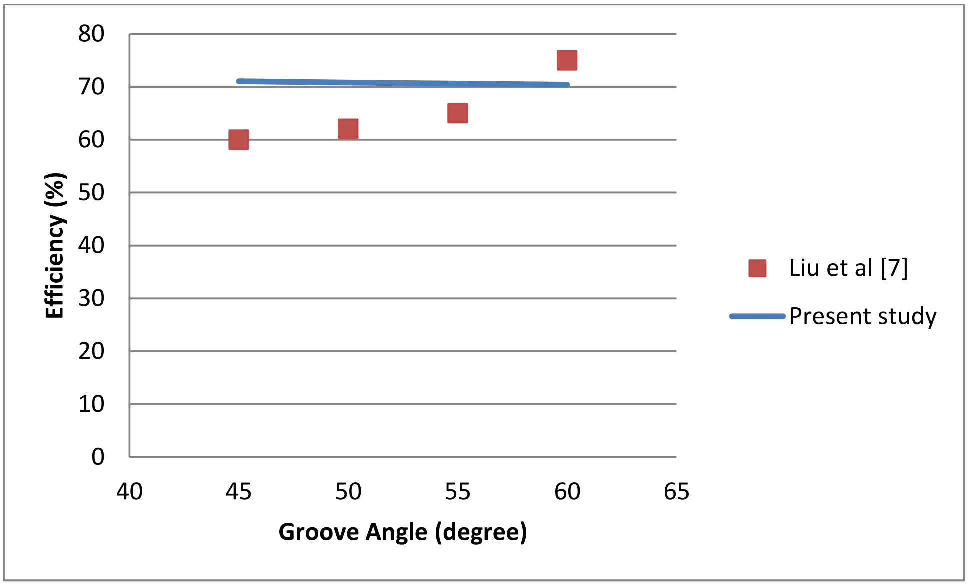

Figure 4.7: Efficiency Vs Groove Angle

Based on figure 4.7, the efficiency increase when the groove angle increase. However, from the present study that has been made by the author, the efficiency decrease slightly when the groove angle increase. The difference might be because some major different in formula and model that being used by the author. The average different percentage for every point is calculated to be ±11.8%.

From figure 4.7, it shows that the efficiency of single and double pass V-groove solar collector decrease when the groove angle increases. This is because as the groove increase, the V-groove solar collector will be more like flat plate solar collector. Figure 4.8 show the effect of increasing the groove angle to the shape of absorber plate.

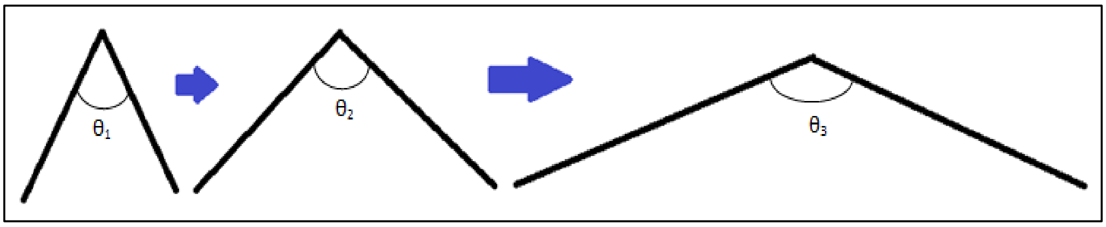

Figure 4.8: The effect of groove angle to the shape of absorber plate

From figure 4.8, the value of θ_3 is larger than value of θ_2 and value of θ_2 is larger than value of θ_1. As the value of angle increase, the shape of the absorber plate is changing from V shape to flat shape. To Liu et al [7], the efficiency of flat plate solar collector is less than V-groove solar collector.

In addition, the value of convective heat transfer between the absorber plate and the working fluid is decreasing when the groove angle increase. The convective heat transfer will affect the heat transfer rate between absorber plate and working fluid. Thus, low convective heat transfer will result low heat transfer rate and reduce the efficiency of the solar collector. The effect of groove angle to the convective heat transfer is shown in figure 4.9 below.

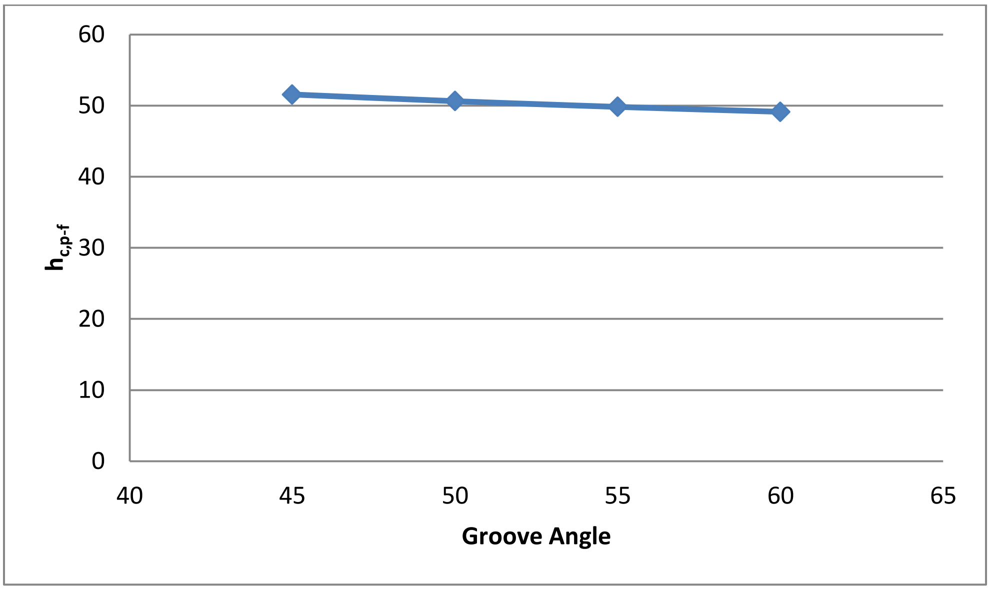

Figure 4.9: Convection Heat Transfer Vs Groove Angle Graph

4.2 Double Pass V-Groove Solar Collector

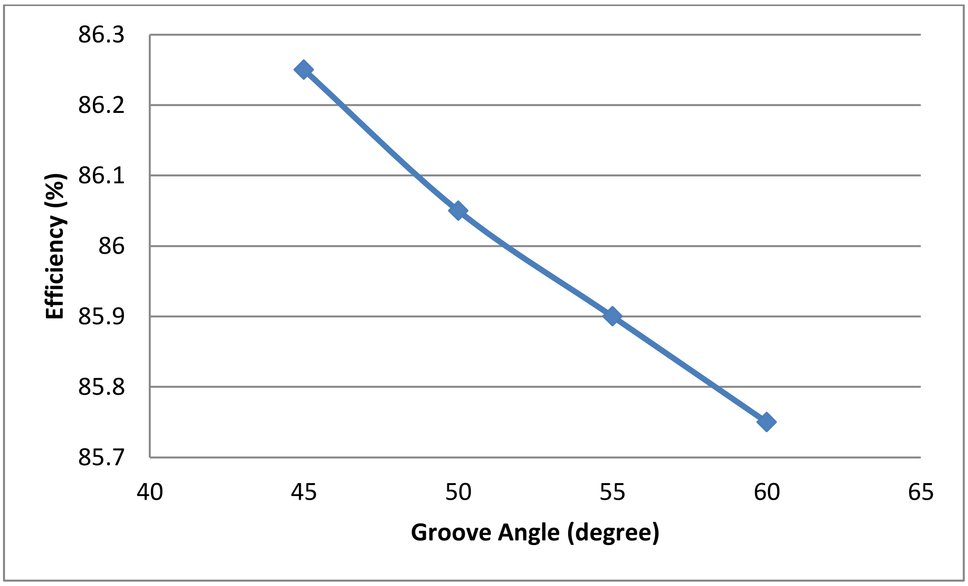

Figure 4.10: Efficiency Vs Groove Angle Graph

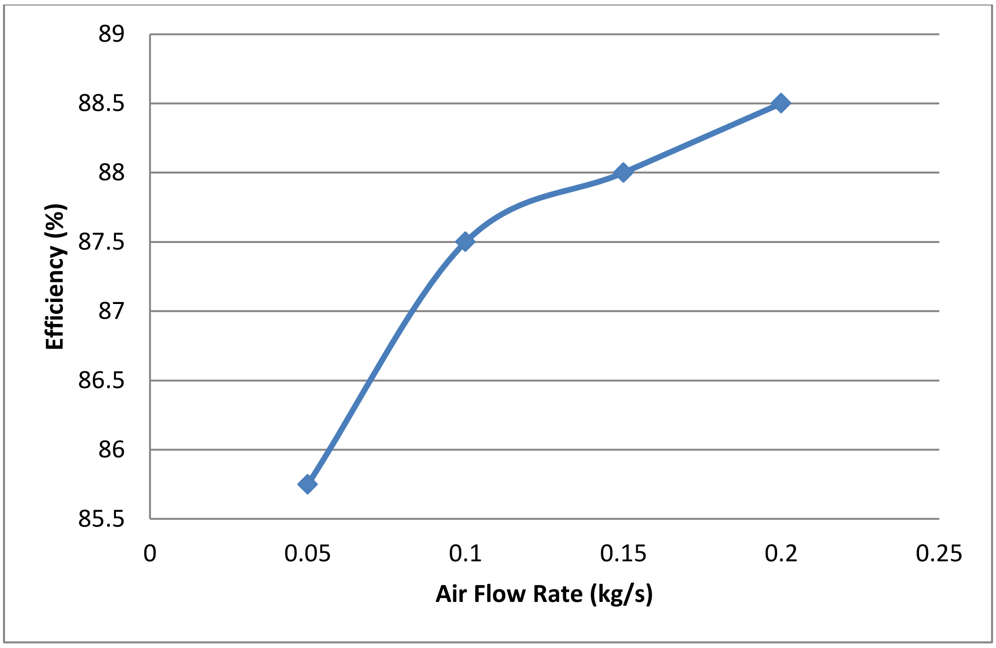

Figure 4.11: Efficiency Vs Air Mass Flow Rate

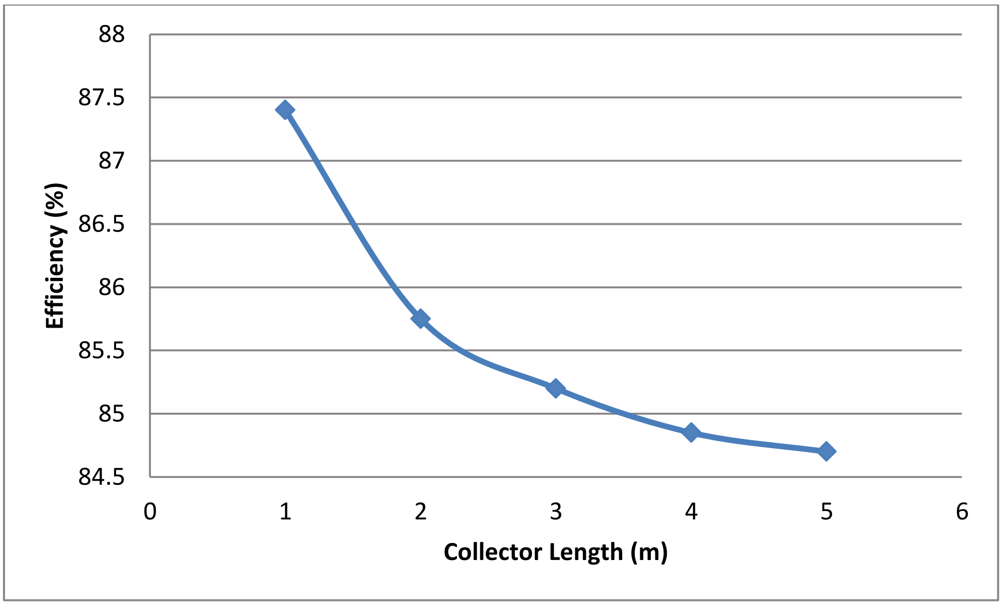

Figure 4.12: Efficiency Vs Solar Collector Length

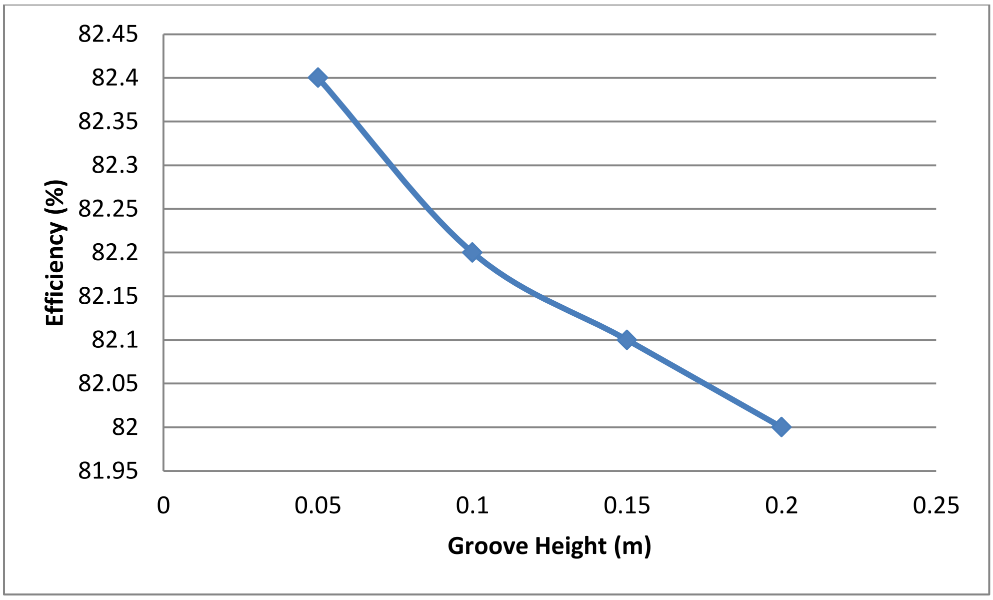

Figure 4.13: Efficiency Vs Groove Height

Figures 4.10 until figure 4.13 are the result of double pass v-groove solar collector. The efficiency of double pass V-groove solar collector increases when the air flow rate increases. On the other hand, the efficiency decreases when the groove angle, the collector length and groove height increase. However, the efficiency is higher compared with the single pass V-groove solar collector. This is reasonable because working fluid flow twice in the solar collector. This will allow more heat to be transferred from the absorber plate to the working fluid. From figures 4.10 until figure 4.13, double pass V-groove solar collector has 10% efficiency higher compared to single pass solar collector.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

From the result of the present study, it can be conclude that the efficiency of V-groove solar collector increase when air flow rate increase and decrease when groove height, groove angle and collector length increase. The result for single and double pass V-groove solar collector is same. Thus, the effects of the four different parameters are same for single and double pass V-groove solar collector. However, the efficiency of double pass V-groove solar collector is more than the efficiency of single pass solar collector. Efficiency of double pass V-groove solar collector is around 10% more than single pass V-groove solar collector. This is because the air flowing twice in the solar collector before the air out from the double pass solar collector while air only flow once before it out from single pass solar collector. Thus, double pass V-groove solar collector is better than single pass V-groove solar collector.

As recommendation more study should be made in order to further improve the efficiency of V-groove solar. There are other parameters that might affect the efficiency of V-groove solar collector. Combination of V-groove solar collector with another type of solar collector also can be considered in order to increase the performance of the solar collector.

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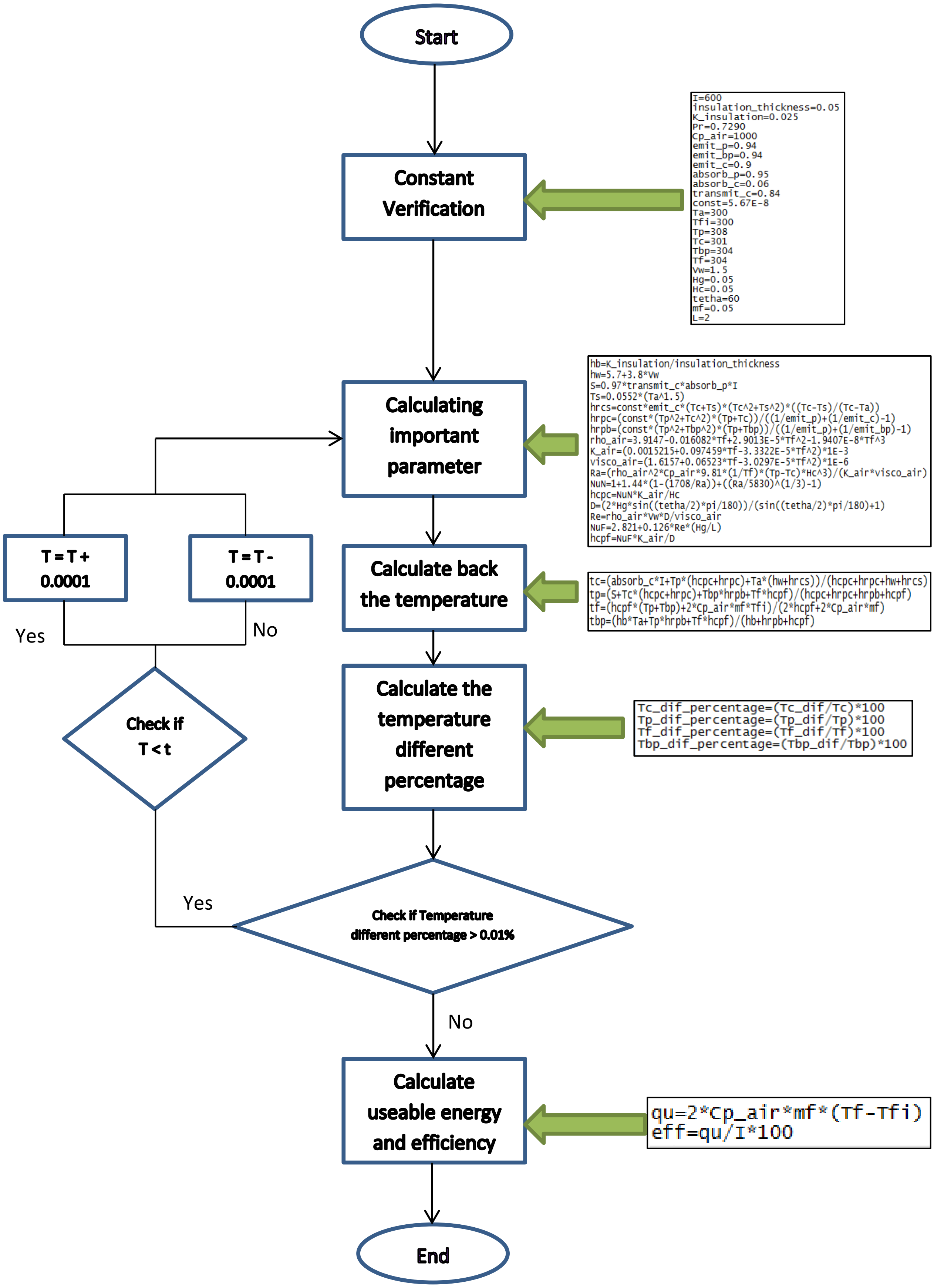
APPENDIX



Start
Constant Verification
I=600
insulation_thickness=0.05
K_insulation=0.025
Pr=0.7290
Cp_air=1000
emit_p=0.94
emit_bp=0.94
emit_c=0.9
absorb_p=0.95
absorb_c=0.06
transmit_c=0.84
const=5.67E-8
Ta=300
Tfi=300
Tp=308
Tc=301
Tbp=304
Tf=304
Vw=1.5
Hg=0.05
Hc=0.05
tetha=60
mf=0.05
L=2
Calculating important parameter
hb=K_insulation/insulation_thickness
hw=5.7+3.8*Vw
S=0.97*transmit_c*absorb_p*I
Ts=0.0552*(Ta^1.5)
hrcs=const*emit_c*(Tc+Ts)*(Tc^2+Ts^2)*((Tc-Ts)/(Tc-Ta))
hrpc=(const*(Tp^2+Tc^2)*(Tp+Tc))/((1/emit_p)+(1/emit_c)-1)
hrpb=(const*(Tp^2+Tbp^2)*(Tp+Tbp))/((1/emit_p)+(1/emit_bp)-1)
rho_air=3.9147-0.016082*Tf+2.9013E-5*Tf^2-1.9407E-8*Tf^3
K_air=(0.0015215+0.097459*Tf-3.3322E-5*Tf^2)*1E-3
visco_air=(1.6157+0.06523*Tf-3.0297E-5*Tf^2)*1E-6
Ra=(rho_air^2*Cp_air*9.81*(1/Tf)*(Tp-Tc)*Hc^3)/(K_air*visco_air)
NuN=1+1.44*(1-(1708/Ra))+((Ra/5830)^(1/3)-1)
hcpc=NuN*K_air/Hc
D=(2*Hg*sin((tetha/2)*pi/180))/(sin((tetha/2)*pi/180)+1)
Re=rho_air*Vw*D/visco_air
NuF=2.821+0.126*Re*(Hg/L)
hcpf=NuF*K_air/D
T = T + 0.0001
T = T - 0.0001
Yes
No
Calculate back the temperature
tc=(absorb_c*I+Tp*(hcpc+hrpc)+Ta*(hw+hrcs))/(hcpc+hrpc+hw+hrcs)
tp=(S+Tc*(hcpc+hrpc)+Tbp*hrpb+Tf*hcpf)/(hcpc+hrpc+hrpb+hcpf)
tf=(hcpf*(Tp+Tbp)+2*Cp_air*mf*Tfi)/(2*hcpf+2*Cp_air*mf)
tbp=(hb*Ta+Tp*hrpb+Tf*hcpf)/(hb+hrpb+hcpf)
Check if T < t
Calculate the temperature different percentage
Tc_dif_percentage=(Tc_dif/Tc)*100
Tp_dif_percentage=(Tp_dif/Tp)*100
Tf_dif_percentage=(Tf_dif/Tf)*100
Tbp_dif_percentage=(Tbp_dif/Tbp)*100
Yes
Check if Temperature different percentage > 0.01%
No
Calculate useable energy and efficiency
qu=2*Cp_air*mf*(Tf-Tfi)
eff=qu/I*100
End