INVESTIGATION OF A HEAT PIPE EVACUATED TUBE SOLAR COLLECTOR PERFORMANCE UNDER THAILAND CLIMATIC CONDITIONS

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การตรวจสอบหาประสิทธิภาพของเครื่องกักเก็บพลังงานแสงอาทิตย์แบบหลอดแก้วสุญญากาศภายใต้สภาพภูมิอากาศของประเทศไทย

ณัชชา พุ่มศรีสวัสดิ์

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Title	Investigation of a Heat Pipe Evacuated Tube Solar Collector Performance under Thailand Climatic Conditions
By	Miss Nutcha Phumsrisawat
Field of Study	Petrochemical Engineering
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Abstract

This thesis focusses on the possibility to use a 20 heat pipe evacuated tube solar collector to collect solar thermal energy. The experiment was performed under the Bangkok, Thailand's climatic condition in march, 2018. To find the optimum condition, the independent variables are types of heating media and mass flowrate. The temperature was recorded by K-type thermocouples at the inlet, outlet of the solar collector and storage tank. The results were analyzed in terms of total energy collected in a day. In this work, water and propylene glycol were chosen as heating medias. At the similar flowrate, temperature of propylene glycol at the outlet was higher than that of water since its boiling point is greater. The maximum outlet temperature recorded was 119 ˚C which occurred during 1:00- 2:00 p.m. on 21st Mar 2018 with the mass flowrate of 50 kg/h. The maximum daily solar intensity was 908 W/m^2 on the clear sky day.

เรื่อง การตรวจสอบหาประสิทธิภาพของเครื่องกักเก็บพลังงานแสงอาทิตย์แบบหลอดแก้วสุญญากาศภายใต้สภาพภูมิอากาศของประเทศไทย

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บทคัดย่อ

ปริญญานิพนธ์ฉบับนี้จัดทำขึ้นเพื่อทดสอบประสิทธิภาพของเครื่องกักเก็บพลังงานแสงอาทิตย์ชนิดหลอดแก้วสุญญากาศจำนวน 20 หลอด โดยทำการทดลองภายใต้สภาพอากาศของกรุงเทพมหานครฯ ประเทศไทย ระยะเวลาที่ทำการทดลองคือช่วงเดือนมีนาคมและเมษายน ตัวแปรที่สนใจศึกษาคือชนิดของของเหลวที่เป็นตัวกลางในการรับความร้อนจากเครื่องกักเก็บพลังงานแสงอาและอัตราการไหลเชิงมวล ในการเก็บค่าอุณหภูมิของระบบจะใช้เทอร์โมคัพเปิลชนิด K โดยจะวัดค่าอุณหภูมิของของเหลวที่บริเวณทางเข้าและทางออกของเครื่อง รวมถึงอุณหภูมิภายในของถังเก็บของเหลว ในการหาประสิทธิภาพของเครื่องจะแสดงในรูปของอุณหภูมิขาออกของของเหลวและพลังงานที่เก็บได้ในแต่ละชั่วโมงภายในหนึ่งวัน ในการทดลองนี้จะใช้ของเหลวเป็นน้ำและโพรพิลีนไกลคอล ซึ่งจากผลการทดลองจะพบว่าอุณภูมิขาออกสูงสุดของโพรพิลีนไกลคอลนั้นสูงกว่าน้ำ เนื่องจากคุณสมบัติต่าง ๆ ของสารที่แตกต่างกัน เช่น จุดเดือด ความหนืด และค่าความจุความร้อนจำเพาะ จากผลการทดลองอุณหภูมิขาออกที่สูงที่สุดที่วัดได้เท่ากับ 119 องศาเซลเซียส ซึ่งเกิดขึ้นวันที่21 มีนาคม 2561ในช่วงเวลา 13:00 น.- 14:00 น.วัดความเข้มแสง ณ ช่วงเวลานั้นได้เท่ากับ 908 วัตต์ต่อตารางเมตรและมีอัตราการไหลเชิงมวลเท่ากับ 50 กิโลกรัมต่อชั่วโมง

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NOMENCLATURE

Symbols	Parameters
$Q_{thermal}$	Thermal energy (W)
$\dot{m}$	Mass flow rate (kg/s)
C_p	Working fluid specific heat capacity (kJ/kg·°C)
$\eta_{collector}$	Collector efficiency
A_{SSA}	Solar selective absorption area (m^2)
I	Solar radiation intensity (W/m^2)
T_{in}	Inlet fluid temperature (°C)
T_{out}	Outlet fluid temperature (°C)

CHAPTER I
INTRODUCTION

1.1 Background

In daily life of human activity, electricity is needed. Over a period of several years passed, energy sources used to produce electricity in Thailand are natural and coal Continuous increasing demand of electricity using makes non-renewable energy resources like fossil fuels decreased. In addition, the prices of these fuels are also depending on the situation of economies and politics of the world. This leads to the need of alternative energy. Sunlight or solar energy will not run out and it is also a source of clean energy without polluting the environment. Thailand is located near the equator and in the tropics, that means this area can get the solar irradiance constant and steady throughout the year. Because the amount of solar radiation that hits the earth's surface in each location that are not equal, it is important to know the solar thermal energy quantity obtained in each area in order to be able to evaluate whether those areas are suitable to provide efficient solar energy or not. Solar thermal energy quantity depends on direct variation with the amount of irradiation hit that area. Solar power can be converted to other energy forms such as electrical, chemical, or thermal energies for household or industrial uses.

Thailand, average solar intensity throughout a year is 18.2 $MJ/m^2 \cdot d$ (5.05 $kWh/m^2 \cdot d$) and maximum solar intensity is about 20-24 $MJ/m^2 \cdot d$. It is evident that Thailand has the light intensity relatively high compared with other countries. Therefore, it is suitable to use solar energy to facilitate daily life. Figure 1.1 shows solar intensity distribution in Thailand.

In the case of thermal energy usages, solar energy can be directly collected in the form of thermal energy without any energy conversion process needed. To be able to use solar energy, solar collector is a thermal energy storage system that is used in worldwide. Solar collectors can be divided into 3 types; 1. Flat plate solar collector 2. Evacuated tube solar collector 3. Concentrating solar collector. [2] Type of solar collector both for study and for real application depends on the suitability local, season and purpose of their experiment. When solar radiation is transmitted to earth, it spreads to different locations, therefore different areas will get the different solar radiation intensity. Moreover, types of evacuate tube solar collectors can be categorized into three types; one is water-in-glass, u-tube and heat pipe evacuated tube solar collectors. Heat pipe evacuated tubes solar collectors was investigated in this study to reach a high-fluid temperature outlet for application of steam production (Temperature of fluid > 100°C)

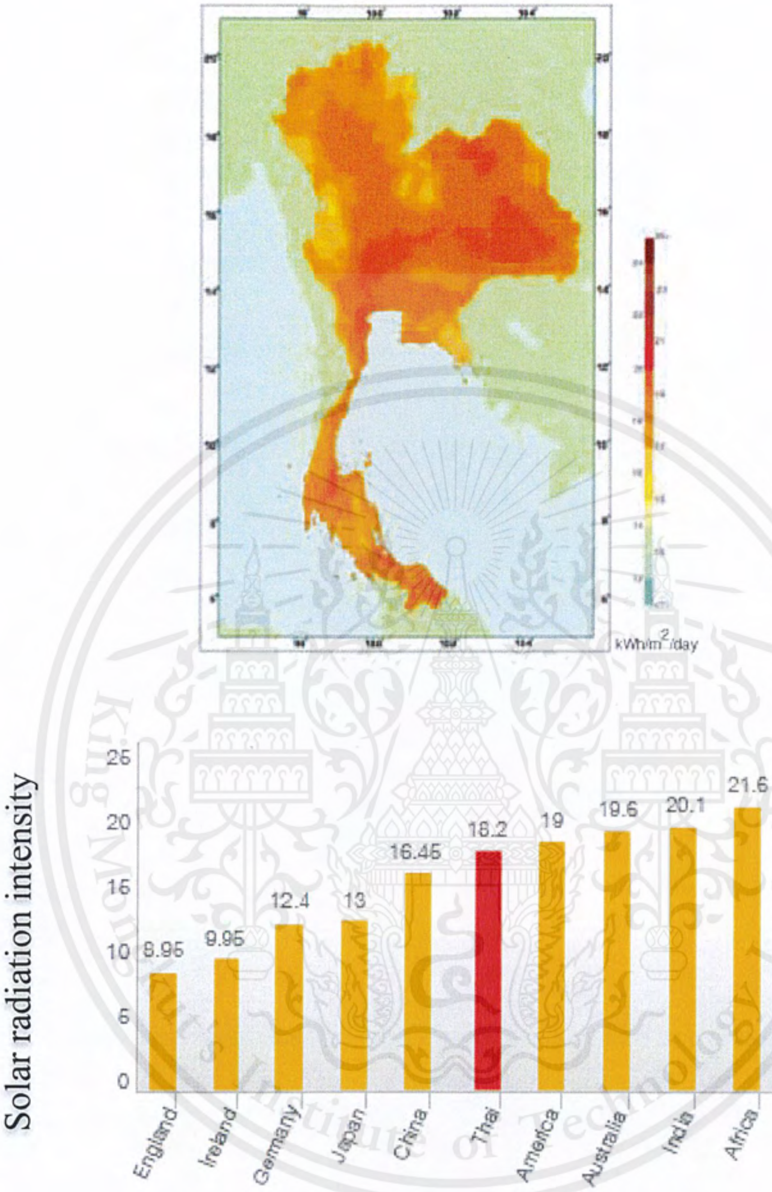


Figure 1.1 Solar intensity distribution in Thailand [1]

In the present study focus on the heat pipe evacuated tube solar collector for transporting heat to solar water heating system. The heat collected from the solar thermal collector will be observed in terms of water outlet temperature at different times during the day. In addition, the effect of water flow rate on the heat transfer rate will be studied.

1.2 Objectives

1.2.1 To study the working principle of heat pipe evacuated tube solar collectors
1.2.2 To observe the effects of outlet temperature and irradiance on heat transfer characteristic of a solar collector.

1.2.3 To investigate the effect of transfer fluid flow rate on the solar collector efficiency.

1.3 Scopes of Work

1.3.1 Measure the temperature at various points in the system to find the efficiency
1.3.2. Adjust the water flow rate of inlet and outlet of the collector to find the appropriate value.

1.4 Expected Outputs

1.4.1 Can be identify the working of the heat pipe evacuated tube solar collector

1.4.2 Get the optimal flow rate for this water heating system

CHAPTER II
THEORY AND LITERATURE REVIEW

2.1 Theory

Types of Solar Collectors [2]

Solar collectors can be divided into 3 types that are flat plate collector, evacuated tube collector and concentrating collector.

Flat plate solar collectors are absorber plates usually made from copper or aluminum because of a high thermal conductivity. Flat plate solar collectors are classified as a non-tracking solar collector that is not rotated with the solar irradiance. It is suitable for the hot water system that does not require very high temperatures such as a water heater in the bathroom, or reactor preheater in the industrial. Advantages of this collector are easy installation, easy to maintenance and low equipment costs. However, it has many disadvantages such as high heat loss due to the difference between collector temperature and ambient temperature, requiring larger installation space than the vacuum tubes, not suitable for high temperature application such as steam production. Figure2.1 show the characteristics of flat plate solar collectors.

Figure 2.1 Flat plate collector [3]

Heat pipe was invented the first time 50 years ago. In 1964, Grover and Erickson developed heat pipe design and applications. Evacuated tube collectors were designed to reduce the defect of heat loss term. The heat pipe is covered by a vacuum glass tube that acts as an absorber plate for absorb solar irradiance which is coated with a material that absorbs sunlight. Vacuum between inner glass tube and outer glass tube is intended for eliminating the convection loss and increasing thermal insulation. It has high performance, even under low solar radiation. The materials used in the coating should be in black or blue to enhance solar energy absorption.

The evacuated tube solar collector applies the principles of evaporation and condensation for generate heat for solar water heater. The majority of thermal energy from this collector is the latent heat from evaporation of working fluid at heating zone inside the heat pipe. Heat is transferred through the manifold header to heat up water or other transfer fluid. The process of the equipment is as follows this, first the sunlight will radiation to the absorption layer of copper pipe, which has a high abusability and low emissivity, mostly of the coating material in Solar collectors used made of aluminum nitride(absorptance>0.94 and emittance<0.06). Heat will conduct from outer surface of heat pipe to the inner surface of heat pipe, the working fluid was boiled at the heat pipe central and vaporize to the top. When the vapor float to the cold section the vapor will condense and the condensate will turn back to the bottom of the heat pipe and the cycle of heating is repeated. The latent heat from evaporation process will transfer heat energy from internal tube to the head manifold by heat conduction after that the heat will transport to transfer fluid medium to bring the thermal power to the water heating system respectively. Figure 2.2 shows the heat transfer in heat pipe evacuated tube solar collector.

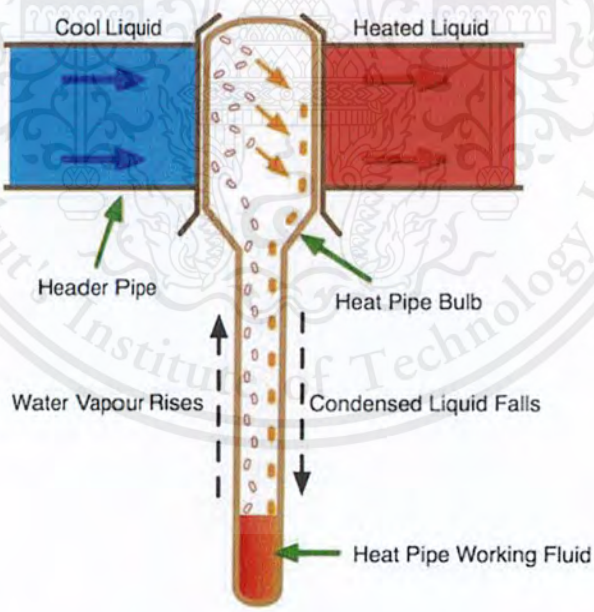


Figure 2.2 Heat transfer in heat pipe evacuated tube solar collector [4]

Although evacuated tube solar collectors can provide heat more than flat plate solar collectors, evacuated tube solar collectors is also a non-tracking solar collector. Table1 Shows the rang of temperature that each solar collector will be provide. Therefore, its efficiency is limited as it cannot be rotated to the direction that the highest irradiance is obtained. Figure 2.3 shows the evacuated tube solar collectors on the roof house.

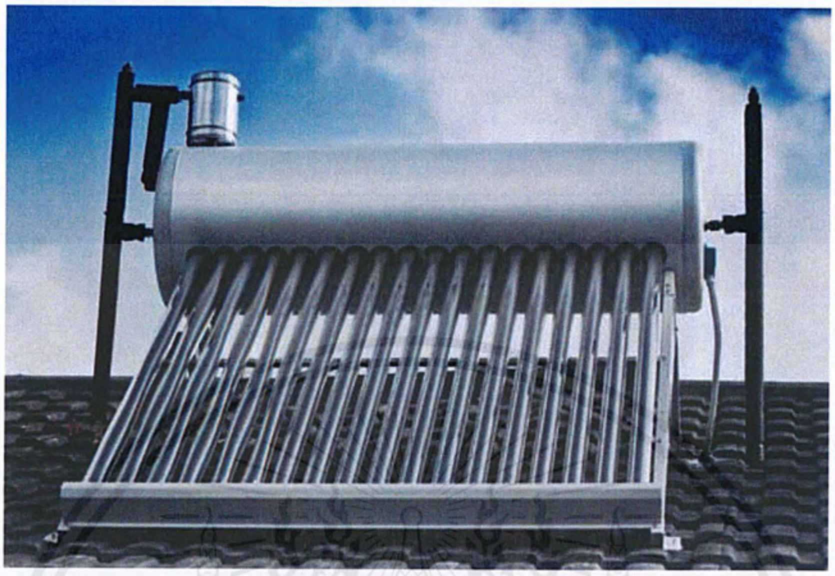


Figure 2.3 Heat pipe evacuated tube solar collector [5]

Concentrating solar collectors are designed to increase the chance that sunlight enters the absorber plate. Its principle is to rotate following the angles of sun irradiance, therefore it will be able to collect the energy of sunlight throughout the day. A common concentrating collectors example is the compound parabolic collector. Figure 2.4 shows the Concentrating collector in field trial.

Figure 2.4 Concentrating collector [6]

Table 2.1 Range of Temperature of each solar collectors [2]

Solar collector types	Temperature Range (°C)
Flat plate	30 – 80
Evacuated tube	50 – 200
Concentrating	60-300

Mostly, researches have been focused on the performance of solar collector they were recorded the result in comparison of the collector efficiency with time or fluid temperature with time.

2.2 Literature reviews

2.2.1 Variables that effect to performance of solar collector

Ismail and Abogderah used a flat-plate solar collector with heat pipes as a heat source for heating up water, and methanol was used as a working fluid. The experiment was performed during winter in Brazil. They compared the efficiency of heat pipe collector with that of conventional collector and found that heat pipes provided higher efficiency than conventional collector. **[7]**

Hayek et al. investigated the performance of solar collector in the eastern coast of the Mediterranean Sea. They studied the effect of collector types by comparing water-in-glass evacuated tube solar collectors with heat pipe evacuated tube solar collectors. The solar water heating system in this study was a closed-loop system which hot water was not drawn off from the tank. Moreover, they investigated the influent of tilt angle by comparing the efficiency of solar collectors with different tilt angles of 30°, 45°, and 55°. The final results showed that the tilt angle did not affect the efficiency of the solar collector in both types. The heat pipe collector provided higher efficiency than the other type. [8]

Ayompe, Duffy investigated the performance of a heat pipe evacuated tube solar collector for household usage. This study measured temperatures from a field trial installation over a year in Dublin, Ireland. They observed that water temperatures out of the solar collector and the bottom storage tank were equal to 70.3 °C and 59.5 °C respectively. The difference of temperature was caused by the influence of thermal loss during water transporting to storage tank. Moreover, they used immersion heater coil for auxiliary supplying heat to water in the tank during the time that the collector had less performance such as intermittent cloud covered day or winter. [9]

The flow rate of transfer fluid is the one of significant variable, which it shows the result in heat transfer rate. Therefore, Gao et al. investigated the effect transfer fluid flow rate in forced-circulation solar water heating system by compared the energy collection efficiency of water-in-glass and U-pipe evacuated-tube solar collectors. The results of this experiment shown that the higher flow rate will reduced energy collection performance of the solar collector. And water-in-glass get the energy storage less than U-pipe evacuated-tube collectors. As a result of the water-in-glass have a large volume of fluid that reduced ability of the transported solar energy to cooling water storage tank. [9]

Hlaing and Myat investigated the heat pipe evacuated tube solar collector. They done the experiment in Mandaly, Myanmar over the year. In this study the researcher used ethylene glycol in water base as a working fluid due to it has high heat transfer capacity, moderate cost, low toxicity, low flammability and low corrosiveness.

Working fluid is one of significant variable that the studies will usually concerned due to it give a strongly effect to solar collector performance, different kinds of working fluid will give different performance of evaporation process inside heat pipe. Copper pipe was covered with black coating to enhance absorption rate of solar radiation. Heat pipe surface was coating of aluminum nitrate to improve the absorptance and reduce the emittance. The obtained results they found that the maximum water temperature is 43°C while the ambient temperature is 21 °C, moreover the maximum collector efficiency is 72% which happened in the December. [4]

2.2.2 Modification of the structure of solar collectors

Abd-Elhady et al. (2016) This study improved structure of heat pipe evacuated tube solar collectors. The experiment was carried out in Beni-Suef city, Egypt, on September 2016. Water was used as a working fluid.

The common structure of heat pipe, the heat pipe and cover glass tubes are bonded together by an aluminum fin to increase the heat transfer rate in term of conduction heat transfer, however there may be some parts that do not close together, resulting in poor performance. To improve the performance of heat pipe evacuated tube solar collectors, the heating capability is the one of variable that should be concerned. Therefor this study was modified a heat pipe structure by adding oil to fill a gap of air between heat pipe and a cover glass tube which it makes the conduction heat transfer will be increase. The comparison of three types of heat pipe evacuated solar collectors including 1st finned surface 2nd finned surface and oil 3rd Foamed copper and oil. Figure 2.5 shows the cross section of three cases of evacuated tube heat pipe. [11]

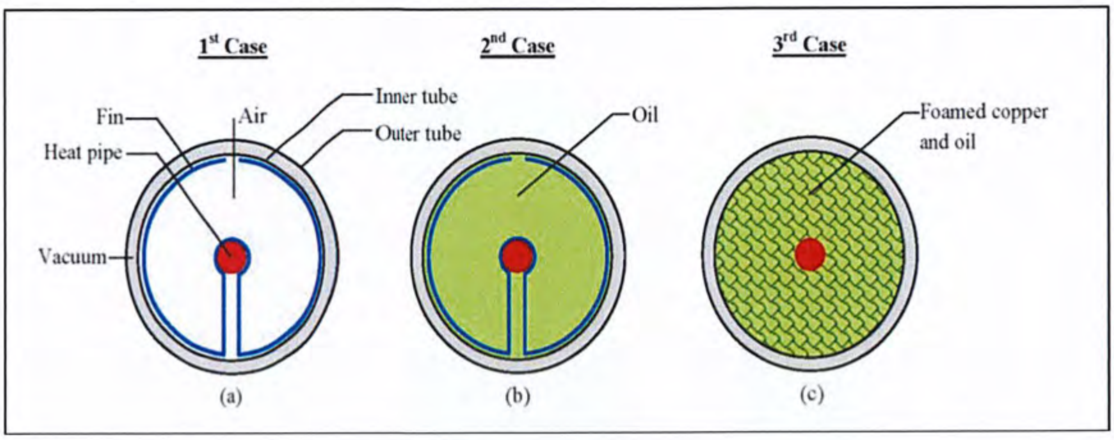


Figure 2.5 Cross section of the evacuated tube heat pipe in case of inserting (a) finned surface (b) finned surface and oil and (c) foamed copper and oil. [11]

The results show that, the heat pipe evacuated tube collector with copper foamed and oil had a higher efficiency more than other cases as a result in transmission of heat consists of conduction and convection instead of only conduction. Foamed copper is better contact between the inner glass tube and heat pipe than aluminum finned surface. The air gap was filled by a good heat transfer medium, that made the heat transfer rate increase.

Sakhrieh and Al-Ghandoor compared the performance of five types of solar collectors: 1. Black coating selective copper thermosyphon solar water heater 2. Blue coating selective copper collectors 3. Copper solar collector 4. Aluminum solar collectors 5. Evacuated tube collector with water as a working fluid. Solar water heating systems are used to test the performance of the solar collector. Jordan is location experiment and the solar radiation intensities are equal to 154.0-1004.33 W/m^2 happened in 8.00 a.m. to 4.00 p.m. the outside temperature was about 18-16 degree Celsius. [12]

When comparing the performance of different types of solar collectors, the evacuated tube collector has a maximum temperature and maximum efficiency. And when measuring the temperature of outgoing water after the solar collector, the water is the hottest in April and occurs at about 1:00 p.m. - 3:00 p.m., the result show that black coating selective copper thermosyphon solar water heater, Blue coating selective copper collectors, Copper solar collector and evacuated tube collector are suitable for medium scale application because they have long life, high efficiency and easy to maintenance. And aluminum collector is suitable for small application such as household.

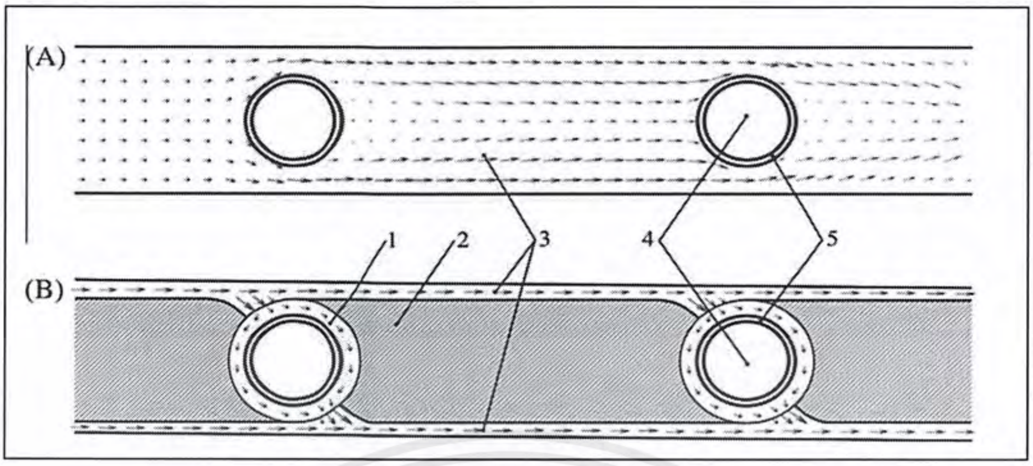


Figure 2.6 Difference between flow canals in standard manifold header (A) and modified manifold header (B) with depicted flow vectors and inner parts (1 – metal foam heat exchange chamber, 2 – foam glass pillar, 3 – flow channels, 4 – heat pipe condenser, 5 – condenser casing) [13]

Rybar et al. improved the model structure of header manifold section by added the metal foam to increase the surface area for better conduction heat transfer than old structure. And they found that, the optimum number of heat pipe is equal to 15 pipes and the maximum water in storage tank temperature is 64 °C which happened around 3.00-4.00 pm. Figure 2.6 shows the flow characteristics of water through conventional manifold and modified manifold. They indicated that the modified manifold header provided a better performance than the conventional manifold header. [13]

Daghigh and Shafieian created a heat pipe evacuated from copper pipe and designed the solar water heating system with heat pipe evacuated tube solar collector. Water was used as a working fluid. The heater coil was installed at the middle of cold water tank for heated up water when the time that the collector cannot provide a hot water such at the early morning or night. Environment characteristics that they concern for calculation including of angel of solar radiation, ambient temperature and wind speed, the results of this study are shown that, they found that its temperature will increase as the number of pipes increases until number of het pipes were equal to 15 the temperatures will begin to change only small after that it will constant. The maximum temperature of outlet water is 64 degrees Celsius which collect at 3:00-4:00 pm. The effect of mass flow rate of water after trough the collector is less when the morning and end of day because at that time collector has low performance. [14]

Sobhansarbandi et al. modified the evacuated tube solar collectors by used the dry drawable Carbon Nanotube (CNT) sheet to coated heat pipe instead of aluminum nitrate to improve the solar radiation absorption efficiency of the collector. They compared the heating rate of Carbon Nanotube sheet at different layers. Moreover, they used the Phase Change Material (PCM) as a heat accumulator to increase the potential of the system, and Octadecane Paraffin is a selected Phase Change Material. The results of combination of CNT and PCM shown that, the heat pipe with CNT coatings had higher solar absorption efficiency identical to black body material. The CNT will provide increasing of the spectral absorption for improving the performance of solar water heating system and accumulated the thermal energy for longer time. [15]

2.2.3 Mathematical analysis

Hlaing and Myat , Daghigh and Shafieian estimated the efficiency of heat pipe evacuated tube solar collector. Mathematic model was used for calculation.

Heat loss is a strongly effect to the collector efficiency. The previous study had a different cause of heat loss which depended on their assumptions such as heat loss from radiation forced convection by wind and heat loss from the difference of temperature at surface collector and the ambient temperature.

Thermal energy balance was shows in the equation (2.1): [4], [14]

$$Q_{thermal} = Q_{absorb} = Q_{en} - Q_{loss} \tag{2.1}$$

Where

$Q_{thermal}$ is the thermal power received by heat pipe evacuated tube solar collector

Q_{en} is the solar radiation that pass the vacuum glass tube and it was absorbed by heat pipe surface.

Q_{loss} is the loss energy

$$Q_{en} = IA_{SSA} \tag{2.2}$$

$$Q_{collector} = \dot{m}C_p\Delta T \tag{2.3}$$

$Q_{collector}$ is the energy collected (kJ/h)

$\dot{m}$ is the mass flow rate of fluid (kg/h)

C_p is the heat capacity of fluid (kJ/(kg·°C)

ΔT is difference of fluid outlet temperature and fluid inlet temperature (°C)

Efficiency of heat pipe evacuated tube solar collector:

$$\eta = \frac{Q_{total}}{(I \times A_{SSA})} \quad (2.4)$$

η is solar collector efficiency

I is solar intensity (W/m^2)

A_{SSA} is solar selective absorption area

$$A_{SSA} = \pi DL \quad (2.5)$$

D is diameter of heat pipe (m)

L is length of heat pipe (m)

CHAPTER III
RESEARCH METHODOLOGY

3.1 Experimental Set up

Figure 3.1 shows the diagram of experimental set up of fluid heating media system and the position of each devices. The heat pipe evacuated tube solar collector is consisting of 20 heat pipes. The collector connects with 50 liters water tank for heat generating. Pump and valve are installed for controlling the water flowrate. Thermocouples are installed at the storage tank, inlet water and outlet water for measuring the temperatures. Moreover, the climate conditions (wind speed, ambient temperature and global solar irradiance) are measured by anemometer and pyranometer. Figure 3.2 shows the circulating of working fluid inside the heat pipe. Ethylene glycol in water base is used as a working fluid.

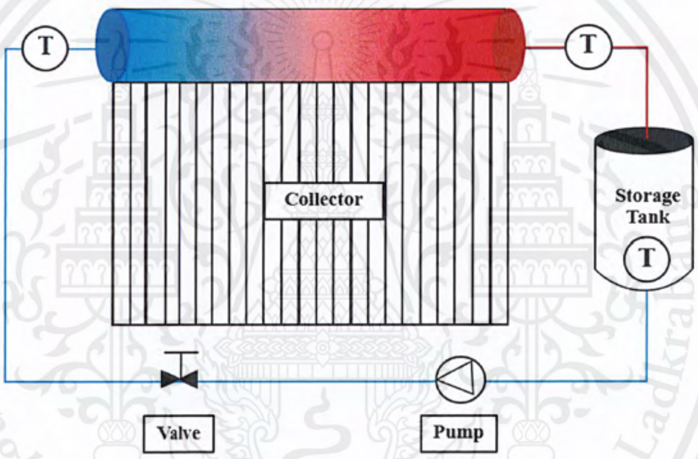


Figure 3.1 Fluid heating media system with heat pipe evacuated tube solar collector

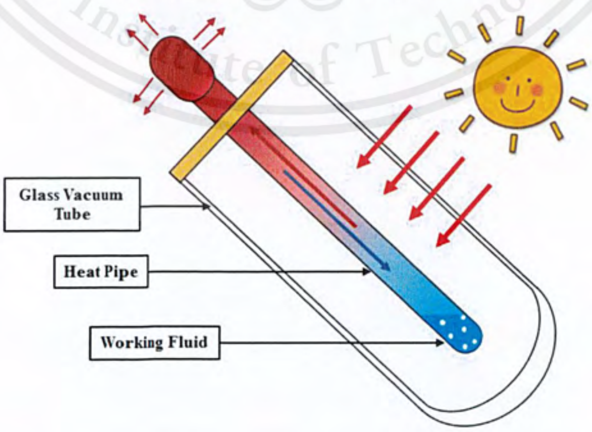


Figure 3.2 Working fluid circulation in heat pipe evacuated tube solar collector

Figure 3.3 illustrates the setup of solar thermal collecting system which consists of 20-pipe evacuated tube solar collector connected with fluid heating medium system.

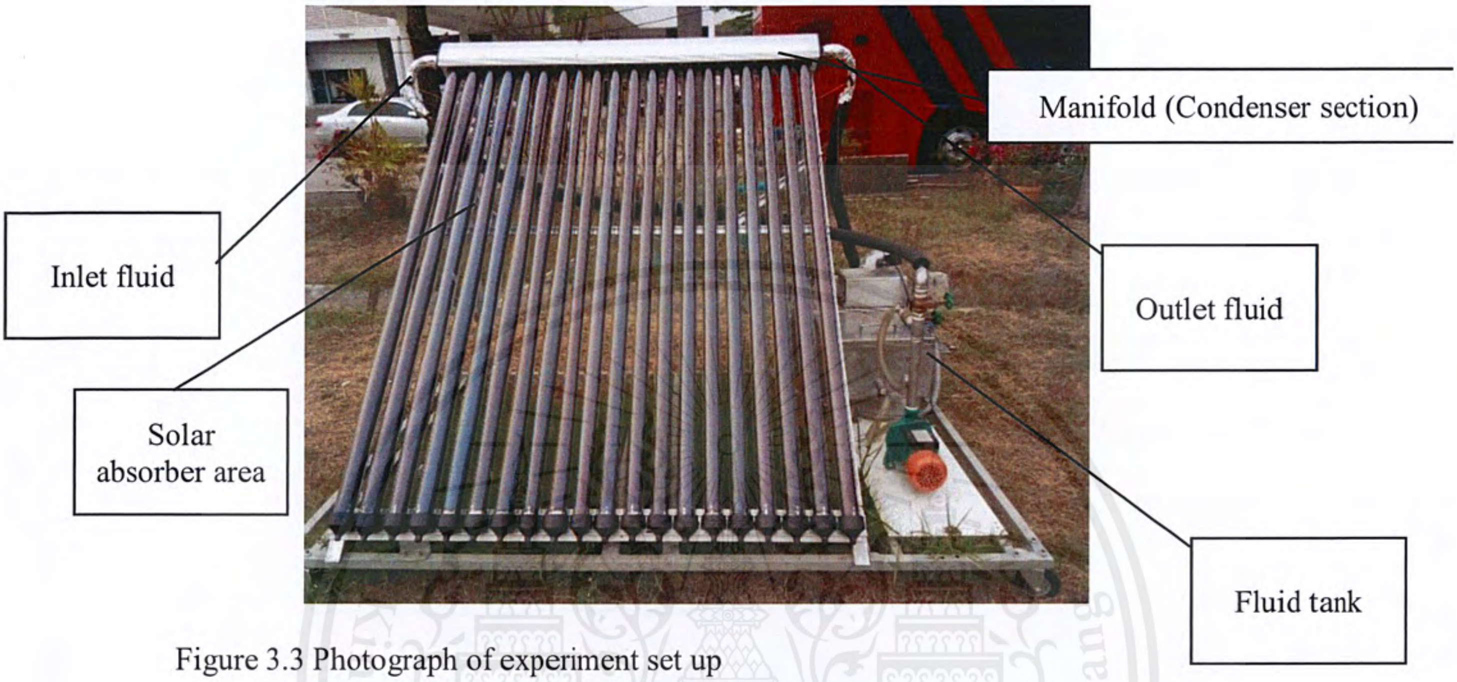


Figure 3.3 Photograph of experiment set up

Figure 3.4 describes the various components within single evacuated tube consisting of heat pipe installed inside vacuum glass tube coated by Aluminum-Nitride.

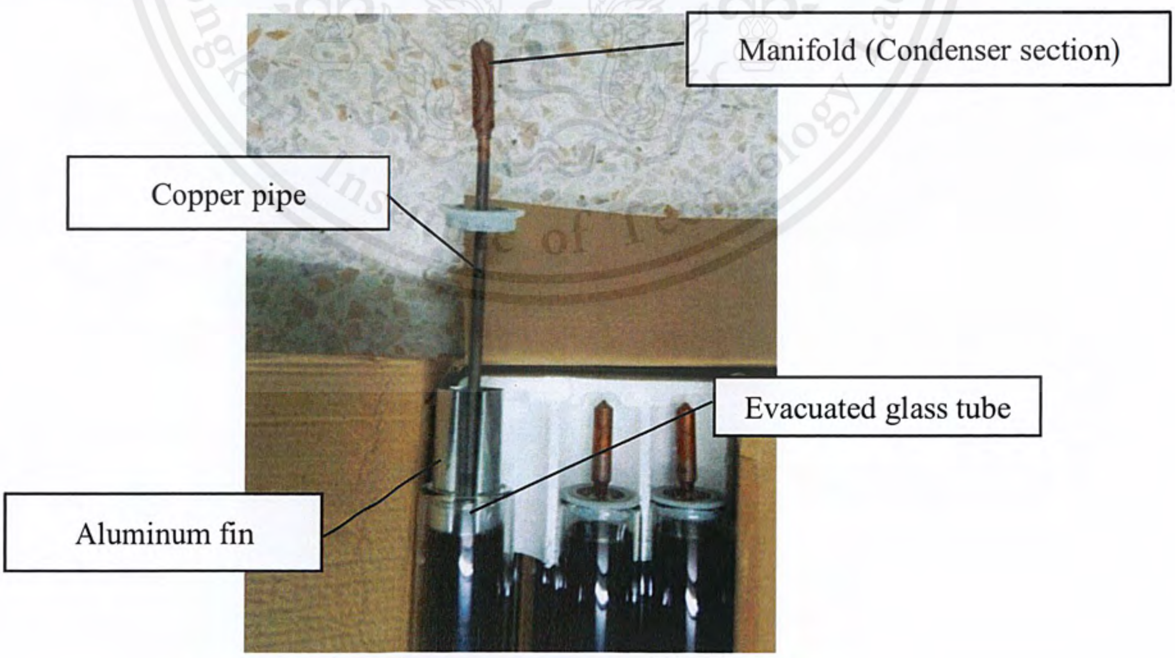


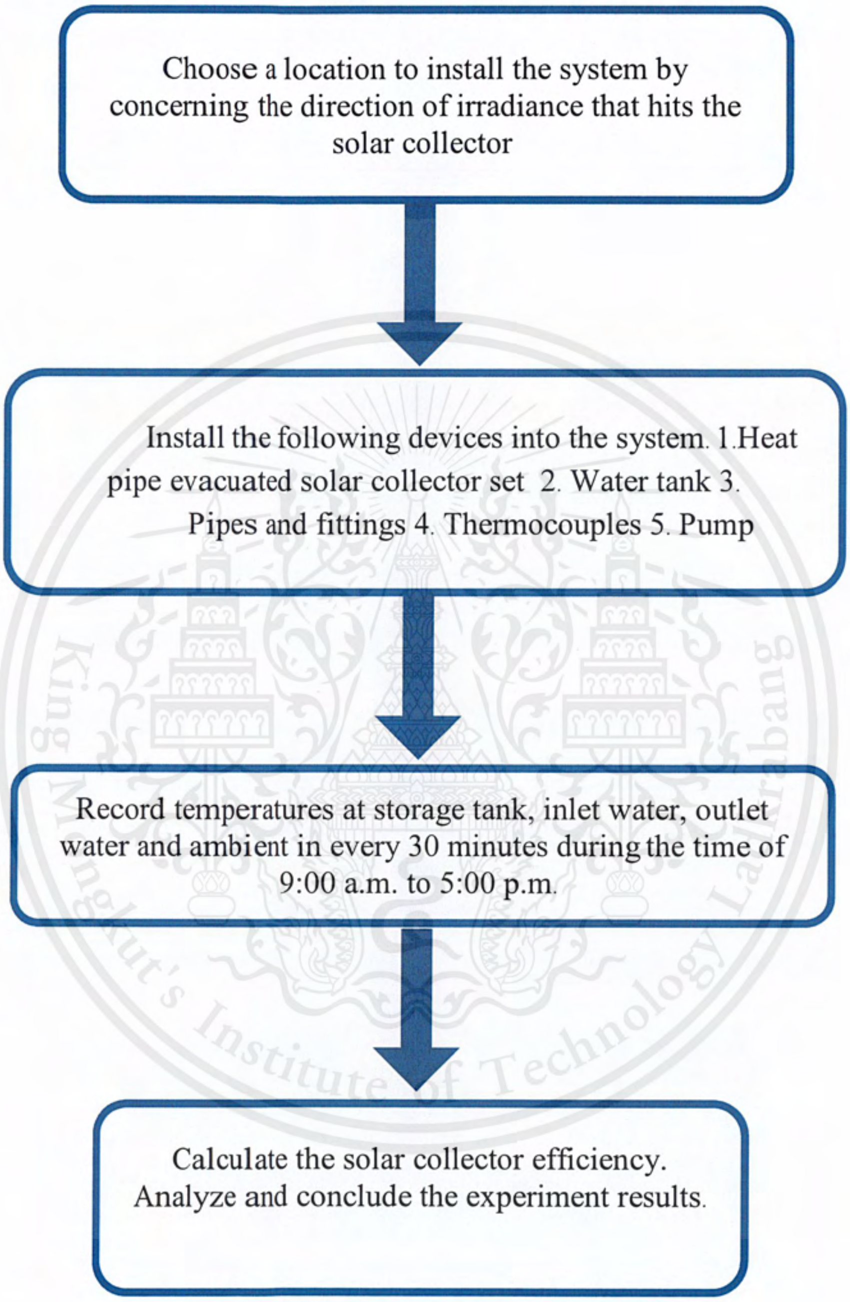
Figure 3.4 Schematic of evacuated tube

The vacuum glass tube acts to save heat loss from natural convection from wind and the loss energy from the absorbers to ambient, due to temperature difference. Aluminum fin or outer tube that covers the heat pipe is responsible for absorbing solar energy by increasing absorption area. Table3.1 shows the physical characteristic of collector.

Table 3.1 Physical characteristic of collector

Collector	Absorber area (m^2)	1.13
	Manifold length (m)	1.8
	Tilt angle	45°
	Number of tube	20
Evacuated glass tube	Glass thickness(m)	0.004
	Material	Borosilicate glass
	Inside coating material	Aluminum nitride
Heat pipe	Material	copper
	Length (m)	1.8
	Diameter (m)	0.01
	Vacuum	50mmHg
Outer tube (Finned tube)	Material	Aluminum
	Diameter(m)	0.55

3.2 Experimental Procedure



CHAPTER IV
RESULTS AND DISCUSSION

4.1 The effect of environmental condition on outlet temperature

Four days representative of clear sky day conditions in Bangkok, Thailand were used to analyze the performance of heat pipe evacuated tube solar collector. Bangkok, Thailand is located at Thailand country in the Cities place category with the gps coordinates of 13° 44' 12.1812" N and 100° 31' 23.4696" E. Figure 4.1 shows the plot of global solar intensity on the collector surface during 4 days at the date of experiment (March – April 2018). During these 4 days, the experiments were carried out using water (WT) and propylene glycol (PG) at 3 different flow rates as fluid heating media. It can be seen that the patterns of solar intensity were similar. The maximum global solar intensity was 908 W/m^2 which happened at 1:00 pm of 21/03/18.

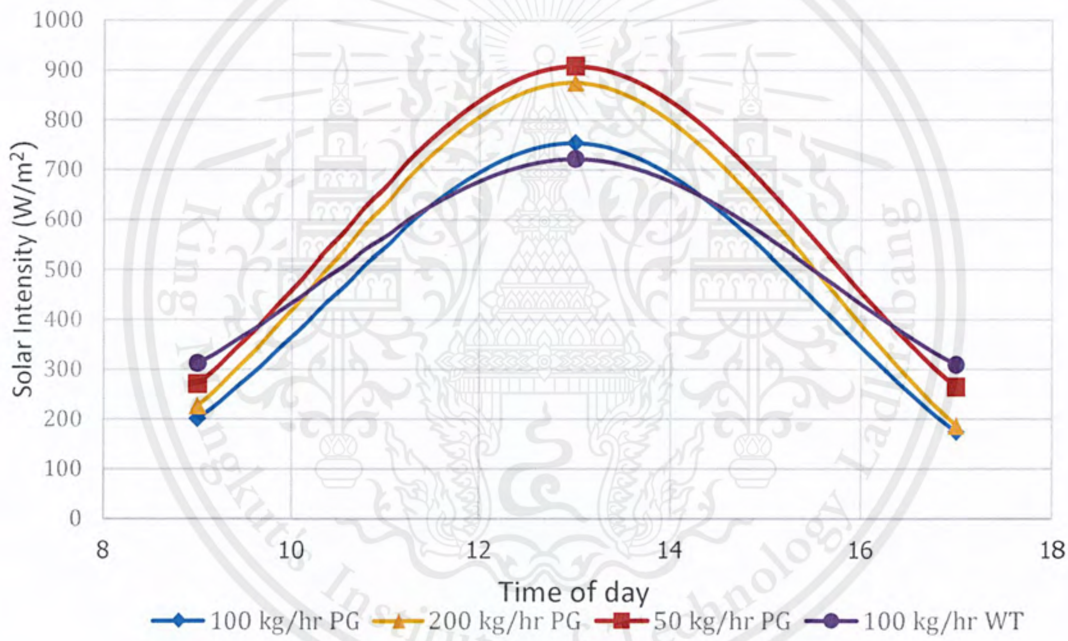


Figure 4.1 Global solar intensity on the collector surface during 4 days at the date of experiment

Figures 4.2 – 4.5 show the comparison of solar intensity, ambient temperature and the fluid outlet temperature for the experiments conducted using different flow rates and types of fluid heating media.

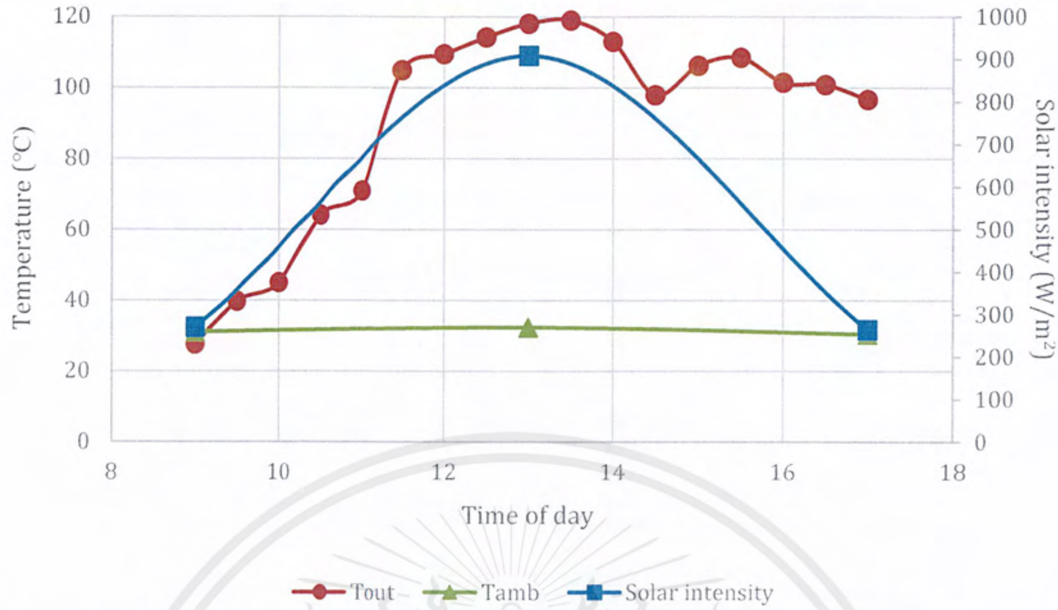


Figure 4.2 Comparison of solar intensity, ambient temperature and fluid outlet temperature at mass flow rate 50 kg/h of propylene glycol

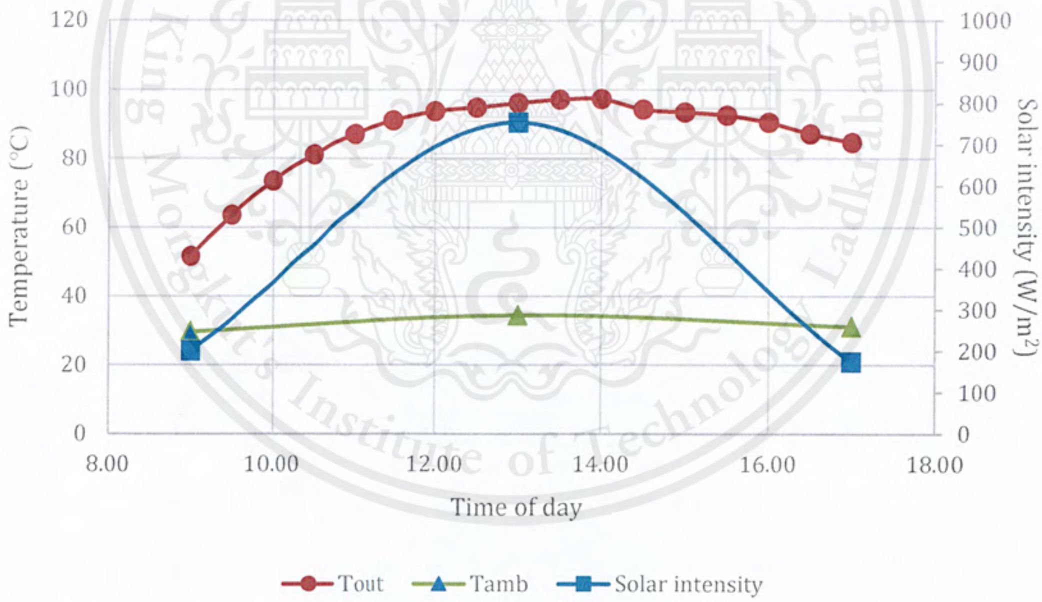


Figure 4.3 Comparison of solar intensity, ambient temperature and fluid outlet temperature at mass flow rate 100 kg/h of propylene glycol

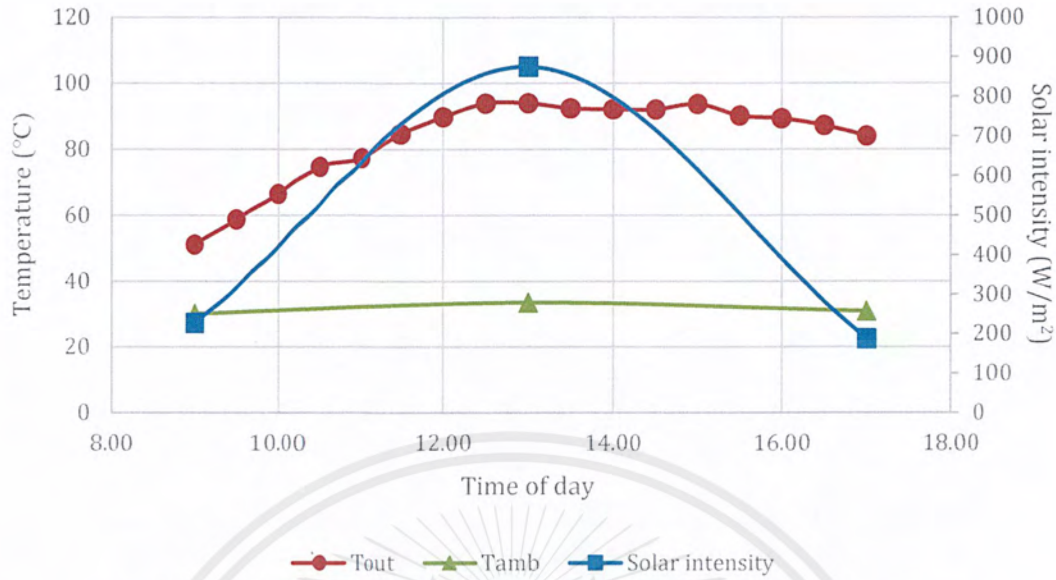


Figure 4.4 Comparison of solar intensity, ambient temperature and fluid outlet temperature at mass flow rate 200 kg/h of propylene glycol

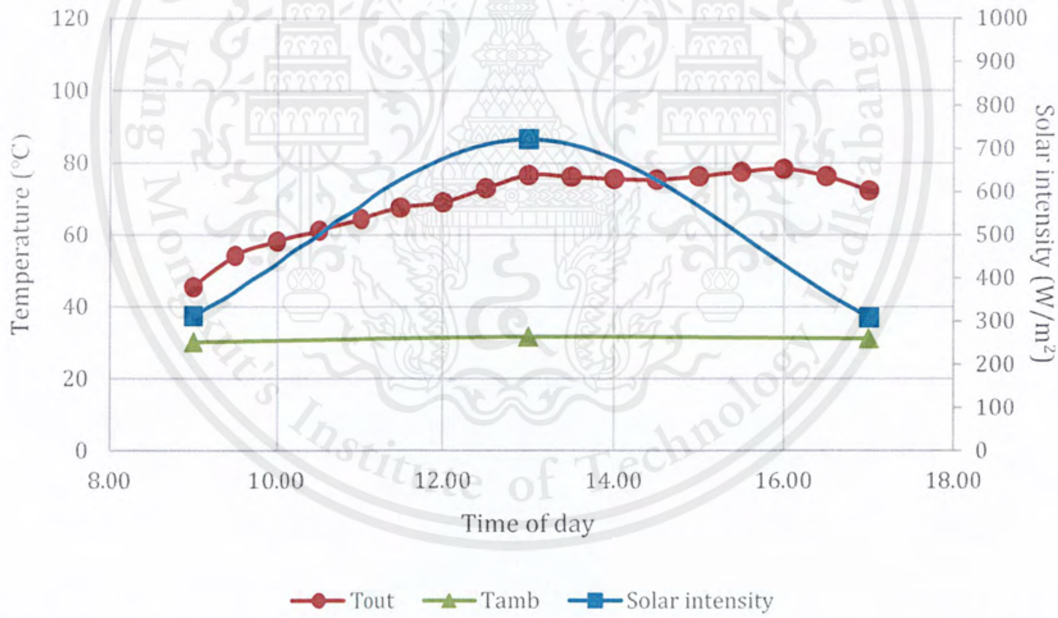


Figure 4.5 Comparison of solar intensity, ambient temperature and fluid outlet temperature at mass flow rate 100 kg/h of water

Figures 4.6 – 4.9 show the comparison of wind velocity, ambient temperature and the fluid outlet temperature for the experiments conducted using different flow rates and types of fluid heating media. It can be seen that the maximum wind speed was 0.8 m/s and the maximum ambient temperature was 34.5 °C.

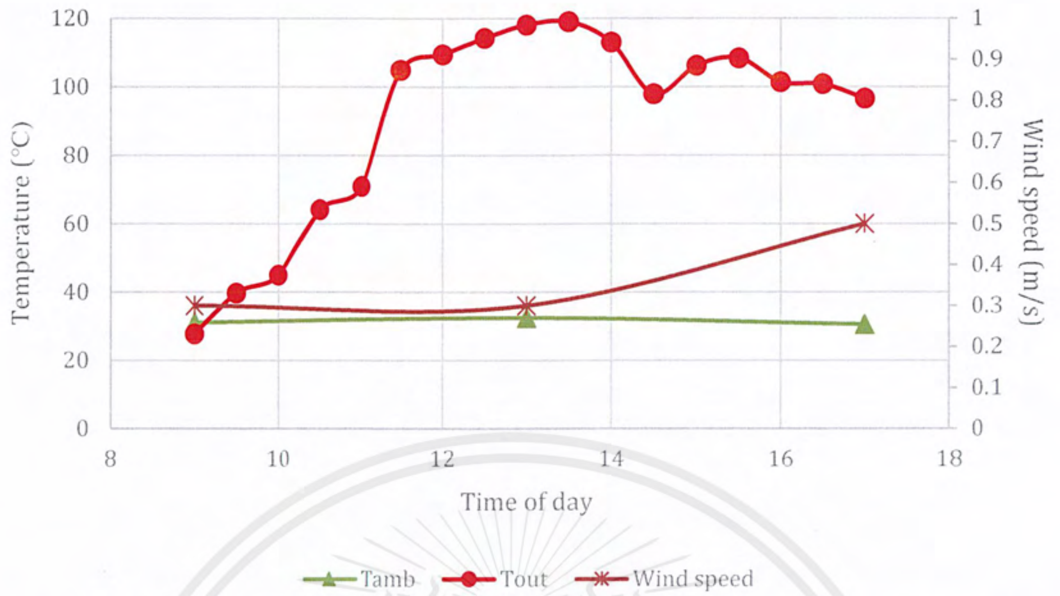


Figure 4.6 Comparison of wind velocity, ambient temperature and fluid outlet temperature at mass flow rate 50 kg/h of propylene glycol

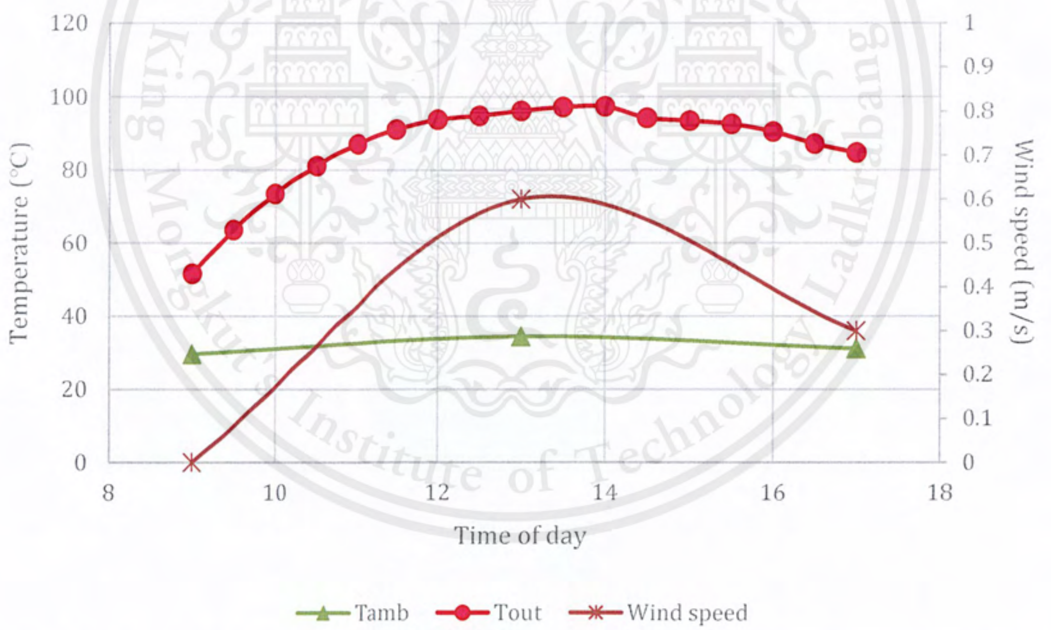


Figure 4.7 Comparison of wind velocity, ambient temperature and fluid outlet temperature at mass flow rate 100 kg/h of propylene glycol

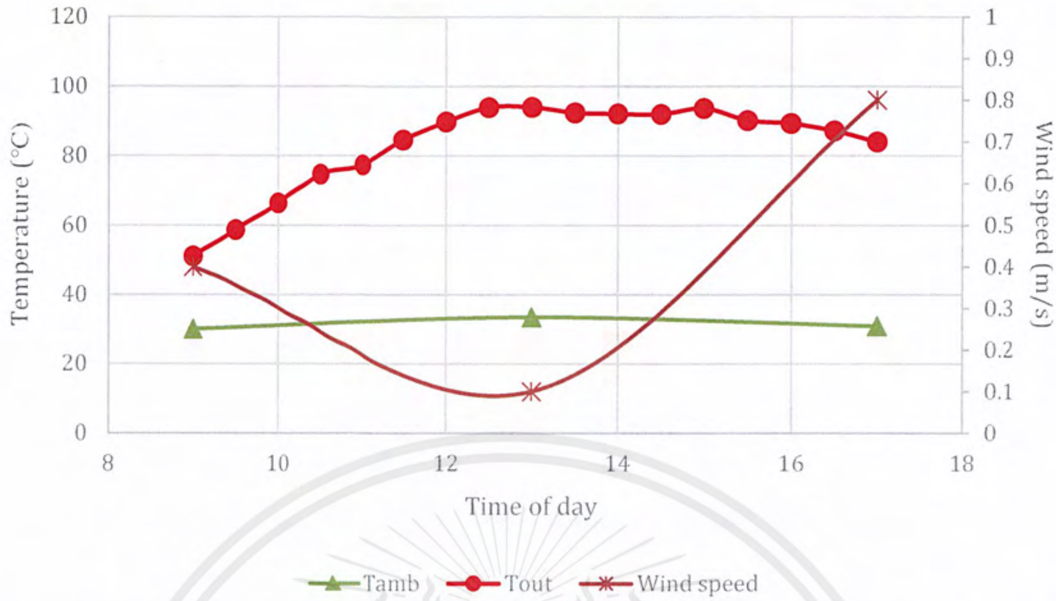


Figure 4.8 Comparison of wind velocity, ambient temperature and fluid outlet temperature at mass flow rate 200 kg/h of propylene glycol

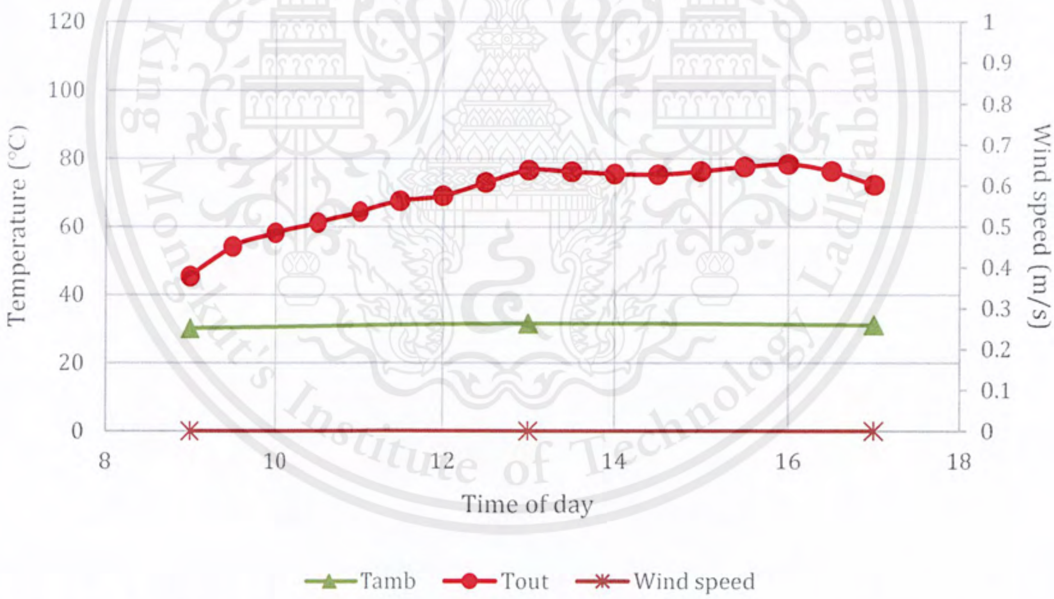


Figure 4.9 Comparison of wind velocity, ambient temperature and fluid outlet temperature at mass flow rate 100 kg/h of water

The weather information including ambient temperature, solar intensity and wind speed. Based on the graph, solar intensity is more important to outlet temperature of fluid than wind speed and ambient temperature. The solar intensity and outlet temperature of fluid were having the same tend. This means that the high solar intensity is given the high fluid temperature. Meanwhile, if there is low solar intensity fluid outlet temperature was low

4.2 The effect of heating medium type on outlet temperature

Figure 4.10 shows the comparison of outlet temperatures of water and propylene glycol with the mass flow rate of cycle fluids at 100 kg/h. The experimental data were recorded from 9:00 a.m. to 5:00 p.m. The maximum outlet temperature of propylene glycol was 94 °C which occurred at 1:00 pm and the maximum outlet temperature of water is 78.4 °C which occurred at 4:00 p.m. The results show that the both fluid temperatures changed with passage of time and increased solar intensity.

In addition, the red dashed line shows the temperature of the header manifold without the fluid flow through. Which the maximum manifold temperature was 141.2 °C this means that the fluid outlet temperature can be rise above 100°C. For this reason, polypropylene glycol is used instead of water because of the boiling point of the substance.

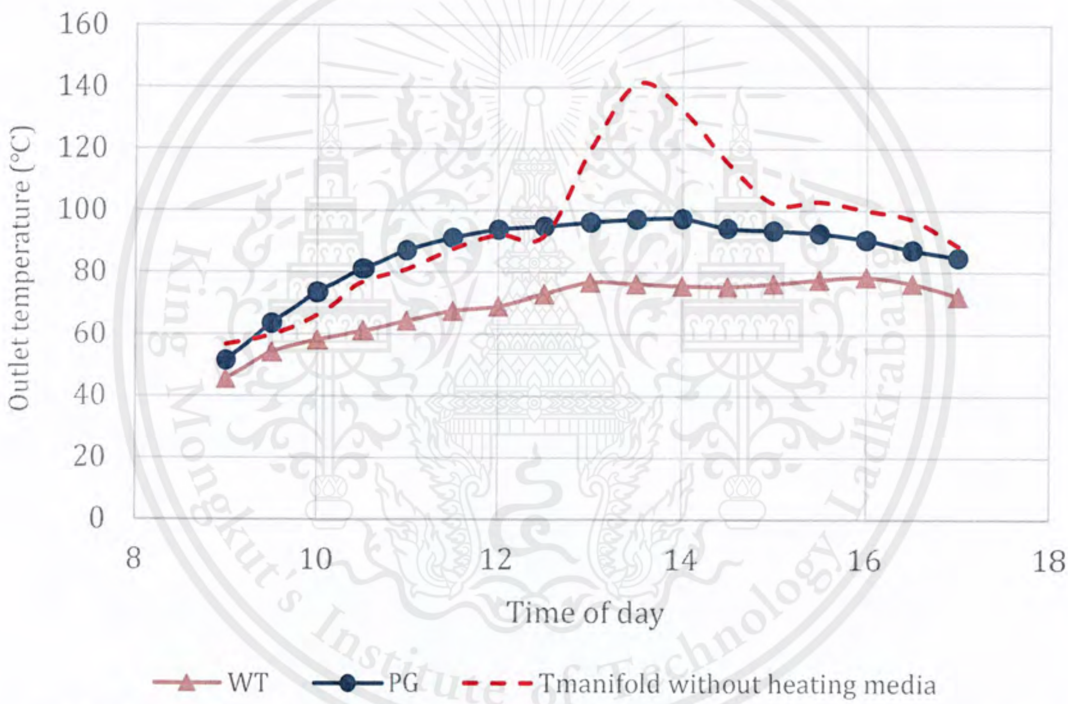


Figure 4.10 The comparison of outlet temperature with varying type of fluid (Heating media) at mass flow rate 100 kg/h

During 9:00 a.m. - 1:00 p.m., the outlet temperature of fluids increased rapidly while after 1:00 p.m. the temperature of fluids increased very slowly and it gradually decreased after 4:00 p.m. In the early stages of graph, the slope of propylene glycol temperature is more than that of water temperature. Comparing viscosity of water and propylene at a temperature of 60°C, the difference value is about 20 times. Therefore, the temperature transfer of propylene glycol is better. Viscosity of propylene glycol is higher than water as a result of the higher ability to transfer heat.

On the other hand, fluid viscosity is a result of pump energy required since if the fluid viscosity increases largely, which can lead to higher electrical energy required for pump. Include system blockage and pressure drop.

Table 4.1 Thermophysical properties of water and propylene glycol at temperature 25°C and 60°C

Heating media	Temperature	Density (ρ)	Viscosity (μ)	Heat capacity (C_p)	Boiling point
Water	25 °C	0.99	0.88	4.188	
	60 °C	0.98	0.47	4.188	
	-				100 °C
Propylene glycol	25 °C	1.032	48.60	2.496	
	60 °C	1.006	8.42	2.496	
	-				188.2 °C

4.3 The effect of mass flow rate on outlet temperature of propylene glycol

Figure 4.11 shows the outlet temperature of propylene glycol for mass flow rates of 50, 100 and 200 kg/h. The maximum outlet temperatures for the mass flow rate of 50, 100 and 200 kg/h are 119, 97.4 and 94°C, respectively and the maximum temperature occurred between 1:00 p.m. - 2:00 p.m. The trend of temperature rising is obviously different for the mass flow rate of 50 kg/h while, for 100 and 200 kg/h, there was little different in the temperature trends. Furthermore, the outlet temperature increased with increase the mass flow rate until the mass flow rate reached the level of 100 kg/h the outlet temperatures were comparable even when the mass flow rate of propylene glycol increased. This should be because of the solar intensity and wind speed. On the day of experiment was the fluid mass flow rate at 100 kg/h, the solar intensity was lower than that of 200 kg/h, including the higher wind speed.

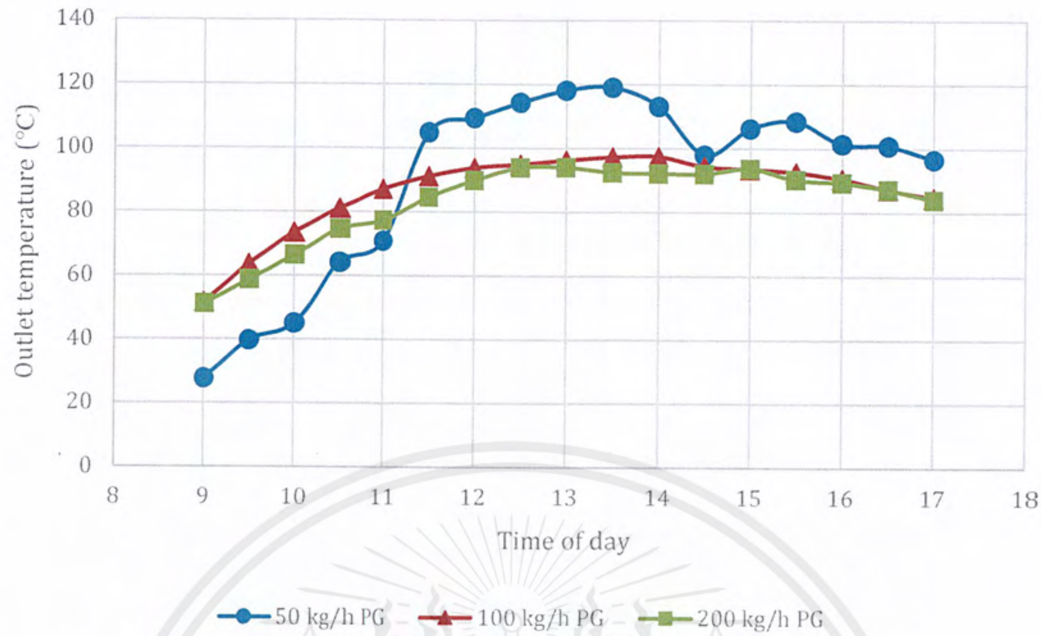


Figure 4.11 Outlet temperature of propylene glycol with different mass flow rate

4.4 Energy collected

Figure 4.12 shows the energy collected at each time of day. In the early morning and after 6:00 p.m., the solar intensity and the temperature ambient are low that make the manifold header have a temperature lower than the fluid flow so inlet temperature is higher than outlet temperature. This causes the accumulated energy at the time before 11:00 a.m. to be negative on some days of the experiment.

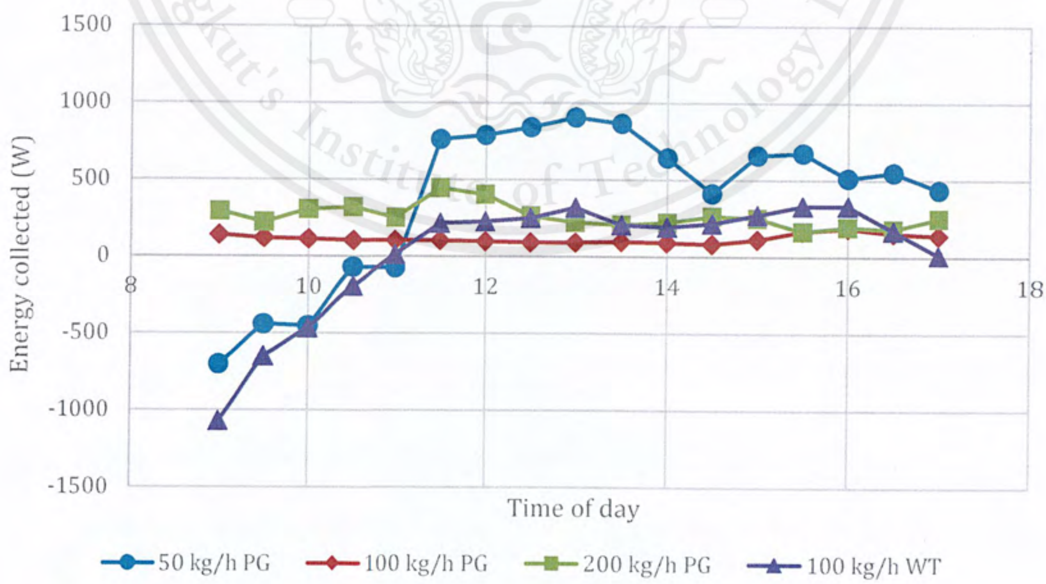


Figure 4.12 Energy collected

Figure 4.13 shows energy collected and solar intensity at each time of day at mass flow rate 50kg/h. The energy collected was directly proportional to the solar energy that was absorbed by solar collector. The total energy collected for a day was equal to area of the graph. It can be calculated by the integration of Fifth-Degree polynomials equation from fitting curve.

$$Q_{total} = \int_9^{17} (y = -2.2767x^5 + 153.07x^4 - 4060.9x^3 + 53026x^2 - 339935x + 854090)\, dx \quad (4.1)$$

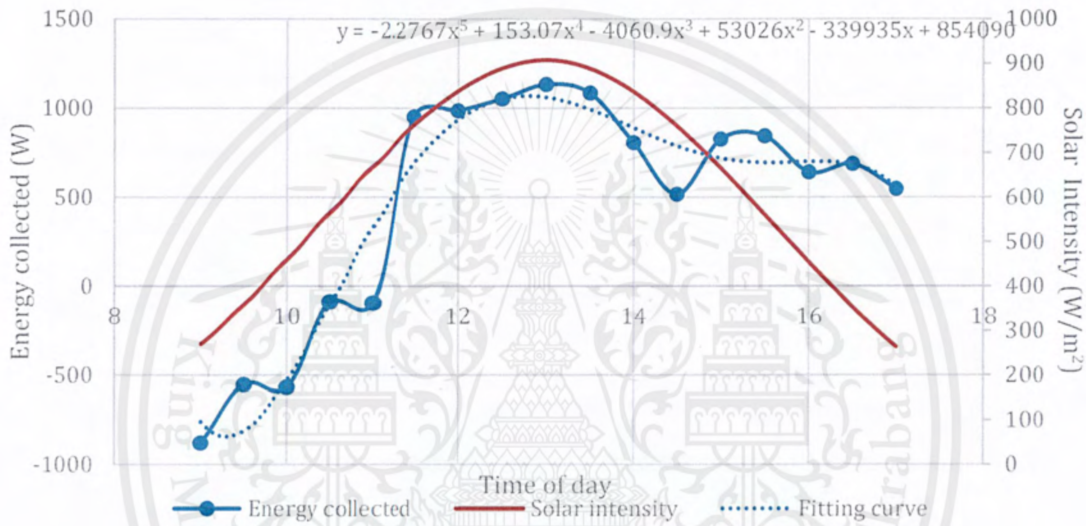


Figure 4.13 Energy collected of propylene glycol at mass flow rate was 50 kg/h

The collector efficiency can be calculated by:

$$\eta_{collector} = \frac{Q_{thermal}}{(I \times A_{SSA})} \quad (2.4)$$

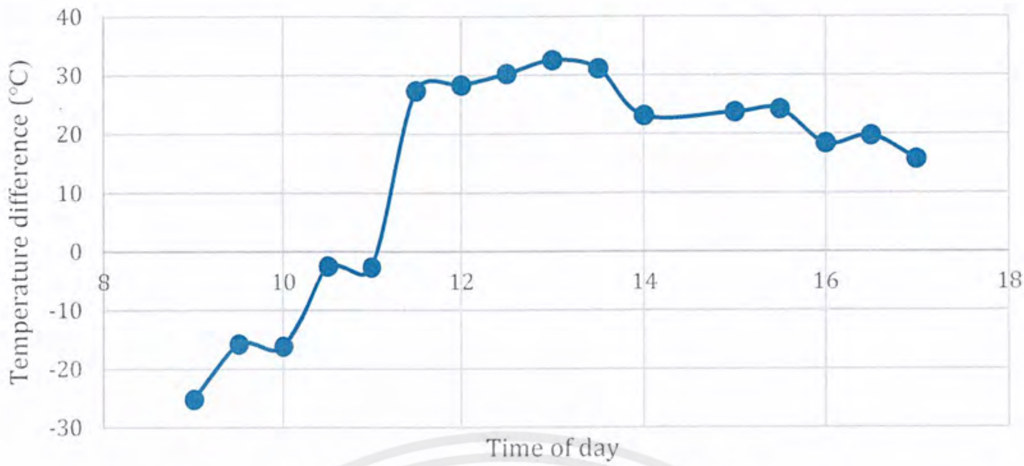


Figure 4.14 The difference between outlet and inlet temperature of propylene glycol at 50 kg/h

Figure 4.14 shows the different temperature between the inlet and outlet temperatures of the collector. It can be seen that in the first period. The temperature difference is quite high and then over time it gradually decreases and stabilizes.

Normally heat always transfers from higher temperature to lower temperature so if the difference between temperatures is very high, the heat transfer ability will be very high as well. For this system, as the fluid temperature increased, the difference of temperatures between the fluid and manifold (condenser section) of the solar collector decreases. Because the system is a closed loop system and does not bring out the heat energy from outlet fluid so the cycle of fluid will accumulate the heat continuously and results in heat transfer ability reduction. Therefore, the appropriate design to use the collected thermal energy will help consume this energy efficiently.

Table 4.3 presents the maximum fluid outlet temperature and total energy collected from 9:00 a.m. -5:00 p.m. and the solar collector efficiency in various mass flow rate of water and propylene glycol.

The maximum temperature is 119°C, the total energy collected for a day is 465.15 watt (for collector) which equals to 232.56 watt per tube. If the number of pipes more, it should be retained more amount of heat collecting than this. The maximum efficiency is 74.00 % which occurred on the day that propylene glycol was used as a fluid heating medium at the mass flow rate of 50 kg/h. This should be because the heat capacity of propylene glycol is lower than that of water. The relationship between thermal energy and temperature difference can be presented by:

$$Q_{thermal} = mC_p\Delta T \quad (2.3)$$

From Equation (2.3), the heat capacity (C_p) is inversely proportional to temperature difference (ΔT) therefore the increasing rate of propylene glycol was higher than water.

Table 4.3 Maximum fluid outlet temperature, Solar intensity, Energy collected, Collector efficiency

Heating media	Mass flow rate (kg/h)	Maximum T_{outlet}	Solar intensity (W/m^2)	$Q_{collector}$ (W)	$Q_{collector}$ for single tube (W)	Collector efficiency (%)
Propylene glycol	50	119	5558.064	4651.148	232.557	74.00
Propylene glycol	100	93.7	4521.792	1095.456	54.773	21.42
Propylene glycol	200	97.4	5219.067	1609.763	80.488	27.27
Water	100	78.4	4679.09	1202.508	60.100	22.72

CHAPTER V
CONCLUSION

5.1 Conclusions

The main advantage of heat pipe evacuated tube solar collector is the low heat loss and provide the high fluid temperature. The effect of using water and propylene glycol for various mass flow rate is show in difference temperature(ΔT) and thermal energy(Q) with time of day investigated. On clear sky day conditions in Bangkok, Thailand, the results show follows

5.1.1 The maximum temperature is 119 °C for propylene glycol.

5.1.2 The total energy collected for a day is 4651.148watt. This is equivalent to opening 10 fluorescent tubes for 10 hours. If the number of pipes more, it should be retained more amount of heat collecting than this.

5.1.3 The maximum efficiency is 74% which occurred in the day that mass flow rate equal to 50 kg/h and the heating media is propylene glycol.

5.2 Suggestions

5.2.1 Should study the angle that sun will affect the collector. To be able to absorb as much as possible.

5.2.2 Should study the weather at the time of the experiment. Because the intensity of light each month is different.

5.2.3 Every device in the system should be insulated. To prevent energy loss from natural convection

5.2.4 Should select a pump with a flow rate appropriate to the experiment. To reduce the energy loss.

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APPENDICES

APPENDIX A
EXPERIMENTAL DATA

A.1 Raw data of fluid heating medias temperature

Table A.1.1Water at mass flow rate 100 kg/h

Time	Tout	Tin
9:00	45.5	54.9
9:30	54.2	59.9
10:00	58.2	62.3
10:30	61.2	62.9
11:00	64.4	64.3
11:00	67.6	65.7
12:00	69.1	67.1
12:30	73	70.8
13:00	76.7	73.9
13:30	76.2	74.4
14:00	75.6	73.9
14:30	75.4	73.5
15:00	76.3	73.9
15:30	77.6	74.7
16:00	78.4	75.5
16:30	76.3	74.8
17:00	72.3	72.2

Table A.1.2 Propylene glycol at mass flow rate 50 kg/h

Time	Tout	Value
9:00	27.7	52.9
9:30	39.7	55.5
10:00	45	61.2
10:30	64.1	66.6
11:00	70.9	73.6
11:00	104.9	77.6
12:00	109.4	81.1
12:30	114.2	84
13:00	118.1	85.6
13:30	119	87.9
14:00	113	89.9
14:30	97.9	83.1
15:00	106.2	82.5
15:30	108.4	84.2
16:00	101.4	83
16:30	100.8	81.1
17:00	96.6	80.9

Table A.1.3 Propylene glycol at mass flow rate 100 kg/h

Time	Tout	Tin
9:00	51.6	49.6
9:30	63.6	61.9
10:00	73.5	71.9
10:30	81.1	79.6
11:00	87.1	85.6
11:00	91.1	89.6
12:00	93.8	92.4
12:30	94.9	93.6
13:00	96.2	94.9
13:30	97.2	95.8
14:00	97.4	96.1
14:30	94.3	93.1
15:00	93.5	91.9
15:30	92.6	90.2
16:00	90.5	87.8
16:30	87.2	85
17:00	84.7	82.7

Table A.1.4 Propylene glycol at mass flow rate 200 kg/h

Time	Tout	Tin
9:00	51.1	49
9:30	58.7	57.1
10:00	66.4	64.2
10:30	74.6	72.3
11:00	77.3	75.5
11:00	84.6	81.4
12:00	89.8	86.9
12:30	93.9	92
13:00	94	92.4
13:30	92.4	90.9
14:00	92.1	90.5
14:30	92	90.1
15:00	93.7	91.9
15:30	90.2	89
16:00	89.3	87.9
16:30	87.2	85.9
17:00	84	82.2

A.2 Raw data of climatic conditions of experimental date

Table A.2.1Water at mass flow rate 100 kg/h

Date	Time	Ambient temperature (°C)	Intensity (W/m^2)	wind speed (m/s)
21/3/2018	9:00	31.1	270	0.3
(50PG)	13:00	32.4	908	0.3
	17:00	30.5	264	0.5
30/3/2018	9:00	30.1	227	0.4
(200PG)	13:00	33.5	875	0.1
	17:00	30.9	187	0.8
20/4/2018	9:00	29.7	201	0
(100PG)	13:00	34.5	754	0.6
	17:00	31.2	174	0.3
27/4/2018	9:00	30.2	312	0
(100WT)	13:00	31.7	722	0
	17:00	31.2	308.5	0

APPENDIX B
CALCULATION

B.1 Energy collected

$Q_{thermal} = \dot{m} C_p \Delta T$
$Q_{thermal}$ is energy collected (kJ/h)
$\dot{m}$ is mass flow rate of fluid (kg/h)
C_p is heat capacity of fluid (kJ/(kg·K)
ΔT is difference of fluid outlet temperature and fluid inlet temperature (°C)

<u>Example of calculation</u> of energy collected of water at mass flow rate was 100 kg/h at 1:00 a.m.

$$\begin{aligned} Q_{collector} &= 100 \times 4.188 \times (76.7 - 73.9) \\ &= 1172.64\ kJ/h \\ &= 325.64\ W \end{aligned}$$

B.2 Total Energy collected for a day

B.2.1 Energy collected of water at mass flow rate was 100 kg/h

$$Q_{total} = \int_9^{17} (y = -x^5 + 61.6x^4 - 1526.8x^3 + 18515x^2 - 109322x + 249534)\, dx$$

B.2.2 Energy collected of propylene glycol at mass flow rate was 50 kg/h

$$Q_{total} = \int_9^{17} (y = -2.2767x^5 + 153.07x^4 - 4060.9x^3 + 53026x^2 - 339935x + 854090)\, dx$$

B.2.3 Energy collected of propylene glycol at mass flow rate was 100 kg/h

$$Q_{total} = \int_9^{17} (y = -0.2432x^5 + 15.427x^4 - 386.8x^3 + 4794.2x^2 - 29397x + 71508)\, dx$$

B.2.4 Energy collected of propylene glycol at mass flow rate was 200 kg/h

$$Q_{total} = \int_{9}^{17} (y = -0.2704x^5 + 17.866x^4 - 464.13x^3 + 5919.7x^2 - 37044x + 91274)\, dx$$

B.3 Heat pipe evacuated tube solar collector efficiency

$$\eta_{collector} = \frac{Q_{thermal}}{(I \times A_{SSA})}$$

$\eta_{collector}$ is solar collector efficiency
$Q_{thermal}$ is energy collected
I is solar intensity (W/m^2)
A_{SSA} is solar selective absorption area

$$A_{SSA} = \pi DL$$

D is diameter of heat pipe (m)
L is length of heat pipe (m)

<u>Example of calculation</u>

solar collector efficiency of propylene glycol at mass flow rate 50 kg/h

$$\eta_{collector} = \frac{4651.148}{(5558.064 \times 1.1309)}$$

$$= 0.7399$$

$$= 73.99\ \%$$

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