The influence of heating medium flow rate on the evacuated tube solar collector efficiency

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อัตราการไหลของตัวกลางนำความร้อนที่มีผลต่อประสิทธิภาพของระบบสะสมพลังงานแสงอาทิตย์แบบหลอดแก้วสุญญากาศ

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Title The influence of heating medium flow rate on the evacuated tube solar collector efficiency

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Abstract

At present, solar energy is widely used in the production of hot water in the household. Solar collector is a device that absorbs solar radiation and converts light energy into heat energy to the heat exchanger medium and sends it to a storage tank before exchanging heat to water. To find the suitable flow rate for solar water heaters, in this experiment, palm oil was chosen as a heating medium because it is cheap and has better heat absorption for heat exchange than water. The experiment was performed at different flow rates as follows: 80.4, 170.86, 259.09, 337.54 617.46 liters per hour. The results show that at a flow rate of 617.46 liters per hour, the efficiency of the vacuum glass tubular solar water heater was the highest. The efficiency value is 63.63%

Keywords: Evacuated Tube Solar Collector, Heating medium storage tank, Palm oil and Water Heaters

เรื่อง	อัตราการไหลของตัวกลางนำความร้อนที่มีผลต่อประสิทธิภาพของระบบสะสมพลังงานแสงอาทิตย์แบบหลอดแก้วสุญญากาศ
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บทคัดย่อ

ในปัจจุบันพลังงานแสงอาทิตย์ถูกนำมาใช้ประโยชน์กันอย่างแพร่หลาย ในการผลิตน้ำร้อนในครัวเรือน โดยผ่านตัวสะสมพลังงานแสงอาทิตย์ ซึ่งเป็นอุปกรณ์ที่จะดูดซับรังสีจากดวงอาทิตย์และแลกเปลี่ยนพลังงานแสงเป็นพลังงานความร้อนให้กับตัวกลางแลกเปลี่ยนความร้อนและส่งไปยังถังกักเก็บก่อนที่จะแลกเปลี่ยนความร้อนดังกล่าวให้แก่น้ำ โดยงานวิจัยนี้มีวัตถุประสงค์เพื่อหาอัตราการไหลที่เหมาะสมสำหรับเครื่องทำน้ำร้อนพลังงานแสงอาทิตย์ โดยในการทดลองนี้ได้มีการเลือกใช้ตัวดลางแลกเปลี่ยนความร้อนเป็นน้ำมันปาล์ม เนื่องจากมีราคาถูก และมีการดูดซับพลังงานความร้อนเพื่อนำไปแลกเปลี่ยนความร้อนได้ดีกว่าน้ำ โดยทำการทดลองที่อัตราการไหลที่แตกต่างกันดังนี้ 80.4, 170.86, 259.09, 337.54 และ 617.46 ลิตรต่อชั่วโมง ซึ่งผลจากการวิจัยพบว่าที่อัตราการไหล 337.54 ลิตรต่อชั่วโมงนั้นได้ให้ค่าประสิทธิภาพของเครื่องทำน้ำร้อนพลังงานแสงอาทิตย์แบบหลอดแก้วสุญญากาศมากที่สุด โดยมีค่าประสิทธิภาพเท่ากับ 63.63%

คำสำคัญ: ระบบสะสมพลังงานแสงอาทิตย์แบบหลอดแก้วสูญญากาศ, ตัวกลางนำความร้อน, น้ำมันปาล์ม และ เครื่องทำน้ำร้อน

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Jirawan Arunyong

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NOMENCLATURE

$\dot{Q}_{rad}$ Solar power from irradiance, Watt

Q_{tank} Heat stored in heating medium storage tank, W

A_c Gross area of evacuated tube solar collectors, m^2

G_t Solar intensity, W/m^2

$\dot{m}_{oil}$ Mass flow rate of palm oil, kg/s

$c_{p,oil}$ Specific heat capacity of palm oil, J/(kg·K)

ρ_{oil} Density of palm oil, kg/m^3

$T_{in,oil}$ Inlet temperature of palm oil from manifold, K

$T_{out,oil}$ Outlet temperature of palm oil from manifold, K

$T_{tank,oil}$ Heating medium storage tank temperature, K

$T_{i,tank}$ Initial temperature of heating medium storage tank, K

$T_{f,tank}$ Final temperature of heating medium storage tank, K

η_{ETC} Efficiency of evacuated tube solar collector system

η_{tank} Efficiency of heating medium storage tank

$\eta_{water\ tank}$ Efficiency of water heater system

CHAPTER I

INTRODUCTION

1.1 Background

At present, turning to renewable energy has become a global concern. Solar energy is an energy from nature that we can use equally. In the past, many people might have disregarded the use of solar energy because of the high cost. But nowadays, the use of solar energy is more accessible. Whether it is a building, a house in a big city or even a home, garden and farm can use solar energy efficiently.

Solar energy is considered as one of the most promising renewable energy sources, because of its abundance and easy-access to the most parts of the world, thermal energy storage (TES) is one of the most economical system in practical applications, and it allows the storage of thermal energy by heating or cooling a storage medium to be used at a later time.

Thailand is located in the tropics and therefore has a solar energy source that receives much sunlight. The combined solar potential area accounts for approximately 14.3% of the country's overall area, with average daily solar exposure at approximately 19-20 MJ / m^2-days, while the other 50% of the country receives approximately 18-19. MJ / m^2 per day.[1]

Solar water heater is a hot water generator based on the principle of absorbing energy from solar radiation to increase the temperature of the water. The main components of a heat pipe solar water heating (HPSWH) system include an HPSC, a water storage tank, a control unit, pipes and fittings, a pump, and several valves. The solar radiation that passes the vacuum glass, is absorbed and transferred to the solar working fluid using heat pipes. The pump, which is used in the solar loop, circulates the solar working fluid through the manifold section of heat pipe solar collector (HPSC) and the copper coil inside storage tank. The heated solar working fluid transfers its thermal energy to the water inside the storage tank.[2]

1.2 Objectives

1.2.1 To study the operation of heat pipe solar water heating.

1.2.2 To study the effect of solar intensity on temperature of tip.

1.2.3 Study the influence of heating medium flow rate the efficiency of this system.

1.3 Scopes of Work

1.3.1 Determine the flow rate of heating medium that makes the system most efficiency.

1.3.2 Calculate efficiency of the heat stored in heating medium storage tank.

1.4 Expected Outputs

1.4.1 The optimal flow rate of heating medium can be determined.

1.4.2 Understand the working principle of solar water heater.

CHAPTER II

LITERATURE REVIEW

2.1 Solar collector

Hot water production by solar energy is commonly used today with high temperature hot water production which has 3 types of hot water production technology as follows [3]

2.1.1 Focusing Solar Collector

Is a type that can produce hot water at high temperature it can be classified according to the type of light integration, as point-focus and line-focus solar collector.

1) Point-focus solar collectors include central receivers tower and parabolic dishes.

2) Line-focus solar collectors are Fresnel reflectors and parabolic troughs.

The technology for producing hot water using a light sensor as above has the function of the device to follow the sun. This will result in the light receiving plate to receive the full sunlight during the day causing a very high temperature.

2.1.2 Flat Plate Solar Collector

Figure 2.1 shows a type of Flat Plat Solar Collector that can produce hot water at low temperatures. The light plate of this solar collector does not have a device to follow the sun. (Non-tracking solar collector) such as a single glazed flat sheet photocopier flat collector (un glazed), etc. [4]

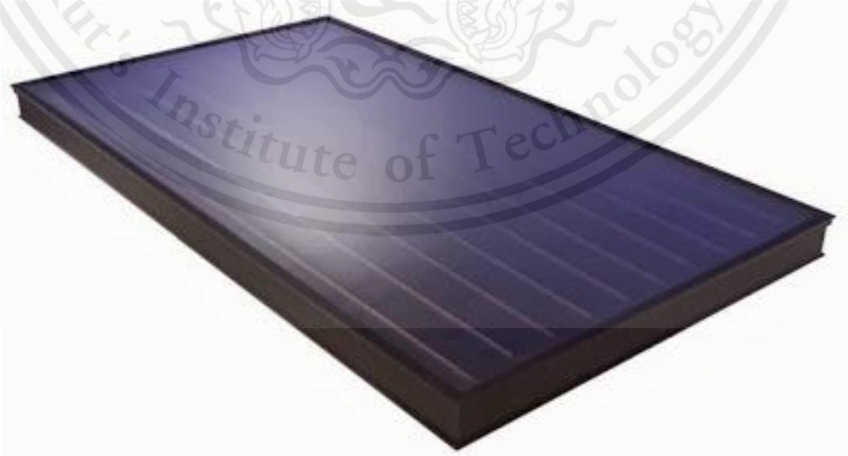


Figure 2.1: Flat Plat Solar Collector [3]

These collectors consist of a casing, a transparent cover, thermal insulation material, an absorber plate and tubes. The transparent cover produces the greenhouse effect above the absorber plate, allowing the majority of the incident solar radiation through. The absorber plate produces the energy conversion from solar radiation to internal energy in a fluid. It is normally made from metal and painted or covered with a black material that has a high solar energy absorption rate. The tubes contain the fluid that carries the energy out of the collector is shown in Figure 2.2 [4]

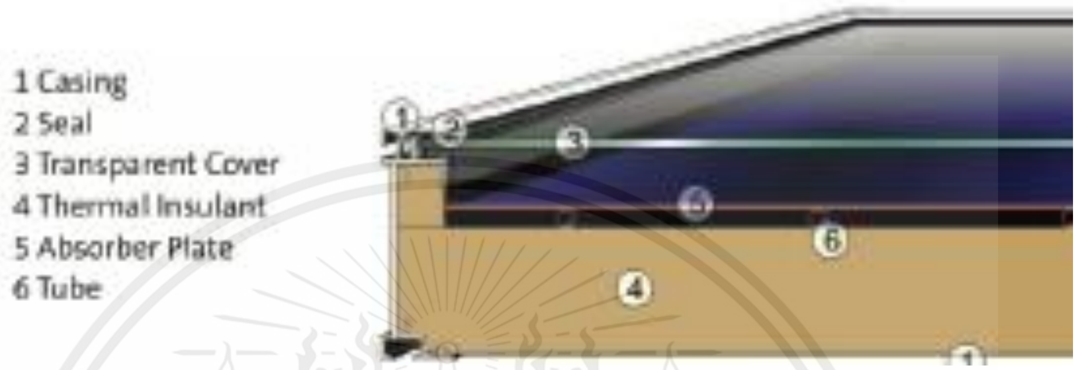


Figure2.2: Flat plate collector construction [4]

Advantage of Flat Plat Solar Collector

- Flat Plat Solar Collector is cheaper than Evacuated Tube Solar Collector. (Price including installation fee per square meter about 8,000-10,000 baht in case of large system)

- High performance, although there is a difference. The temperature of the absorber and ambient air is very high.

- Installation can be in many ways such as installed on the roof. Installed as part of the roof as a wall.

- Assembly and installation is easy.

Disadvantage of Flat Plat Solar Collector

- Flat Plat Solar Collector is lower efficiency than Evacuated Tube Solar Collector. (Due to the higher total heat loss)

- The installation support system must be a flat surface.
- Require more installation space than Evacuated Tube Solar Collector.
- Not suitable for high temperature applications such as steam production.

2.1.3 Evacuated Tube Solar Collector

Evacuated tube solar collectors are very efficient and can achieve very high temperatures. This device converts solar energy into heat as another form of energy. The evacuated tube solar collector contains several rows of glass tubes that are double layer glass tubes. Between the layers vacuum to eliminate heat loss through convection and conduction. Inside the tubes, copper fin is attached to a metal pipe. The fin is covered with selective coating that transfer heat to the fluid that is circulating through the pipe. Inside coated with radiation absorbent highly efficient, suitable for applications requiring high temperature hot water.[4]

Advantage of Evacuated Tube Solar Collector

- Higher operating temperatures can be achieved than with flat-plate collectors. The higher temperatures can be of benefit for process heat (e.g. for industry and solar cooling).

- Less thermal losses than with flat-plate collectors due to excellent heat insulation.

- Higher energy yield than flat-plate collectors with the same effective absorber area. This can be of advantage with installations in small set-up areas. However, the higher energy yield of vacuum tubes is only realised at high working temperatures.

- Close compact construction of the collector which requires no interior insulation material, and thus no penetration of moisture or dirt into the collector, and no deposits due to dispersal of interior insulation is shown in Figure 2.3 [5]

- Can be installed in variety of ways such as horizontal, flat on the roof floor that is shown in Figure 2.4, reduces wind pressure and reduce installation costs. [4]

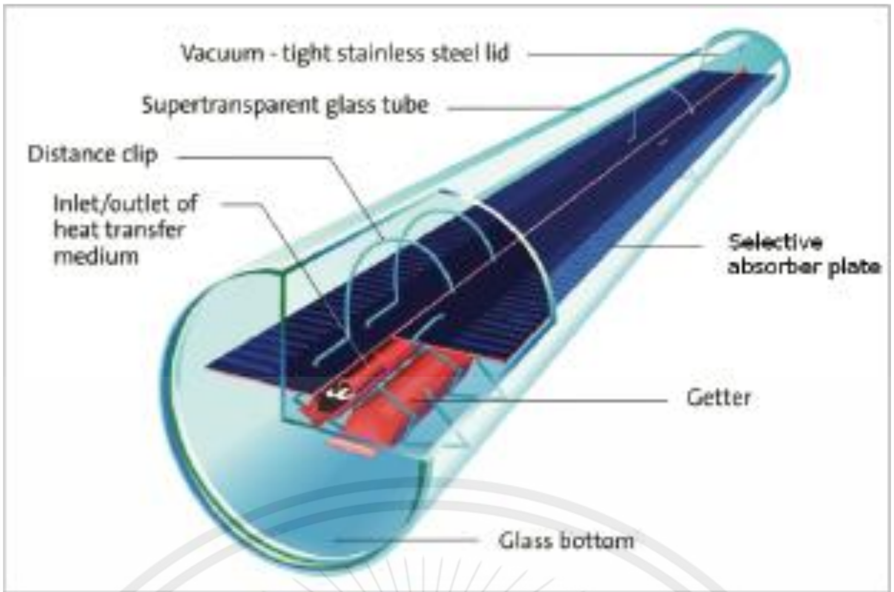


Figure 2.3: Vacuum tube collector construction [4]

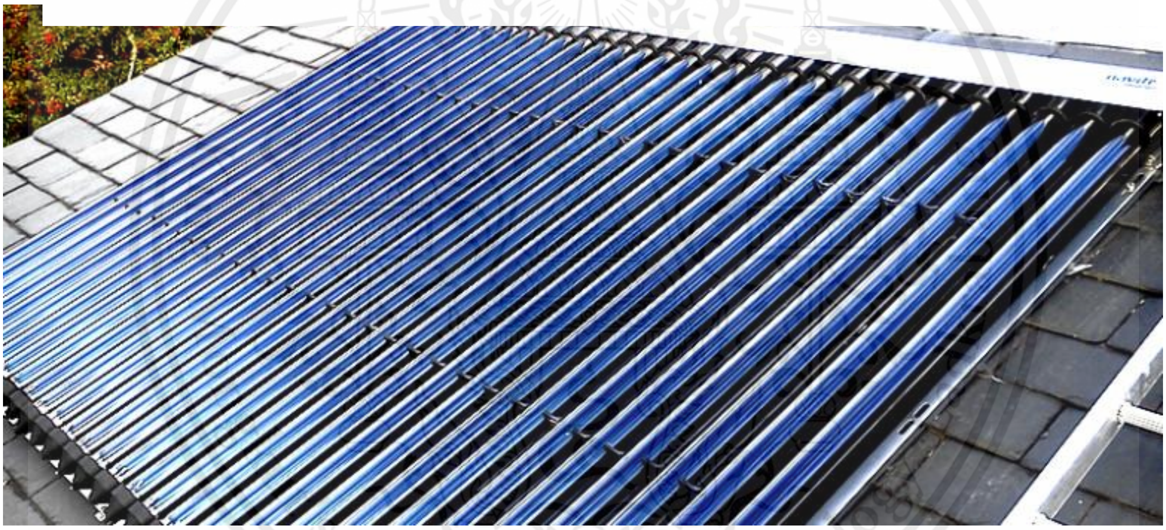


Figure 2.4: Evacuated Tube Solar Collector [4]

Disadvantage of Evacuated Tube Solar Collector

- High stagnation temperatures with corresponding demands on all materials used near the array and on the heat transfer fluid.

- Considerably higher specific costs than flat-plate collectors. The high cost is compensated for if only low to medium working temperatures are required (e.g. with solar potable water heating), despite higher efficiency and reduced array area.

- Higher costs for available solar heat at medium operating temperature range, since cost advantages are only at higher operating temperatures.[5]

2.2 Evacuated Tube Solar Collector System

2.2.1 System of Evacuated Tube Solar Collector

When the tube is exposed to the sun, the solar selective coating absorbs the solar energy and transfers it to aluminum fin to the copper heat pipe located inside the evacuated tube by conduction. The heat pipe contains a heat transfer fluid (mixture of ethylene glycol and water) that transfers the heat to the tip of copper heat pipe that located inside the manifold is shown in Figure 2.5. The liquid in the heat pipe has a high boiling point, when it is heated, the heat transfer fluid inside the pipe begins to vaporize and rapidly rises to the top of the tip. As the heat is off-loaded to the manifold, the vapor condenses and liquid returns to the bottom of copper heat pipe after releasing its latent heat. An aluminum fin, held in the tube by a spring clip, facilitates heat transfer and mechanically supports the heat pipe in place and cold fluid in the storage tank is pumped into the manifold to receive the latent heat from the tip of copper heat pipe released from heat transfer fluid. Hot fluid is returned to the storage tank for storing energy that is shown in Figure 2.6

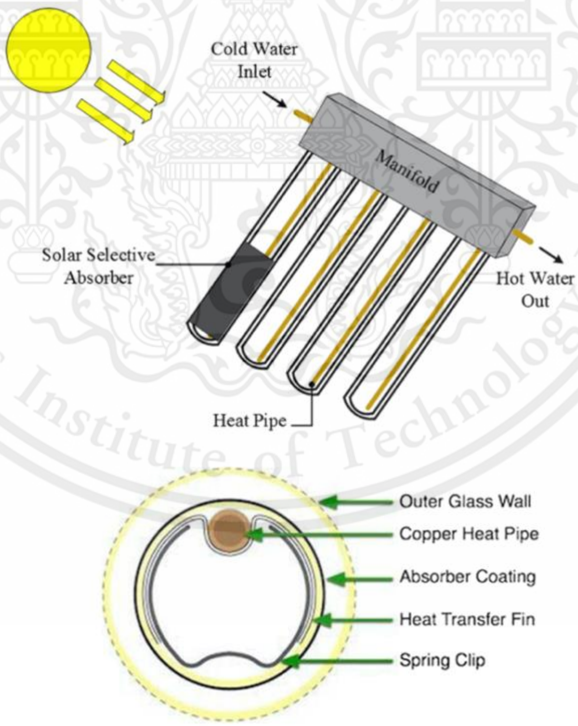


Figure 2.5: A schematic of evacuated tube solar collector and its cross-sectional [5]

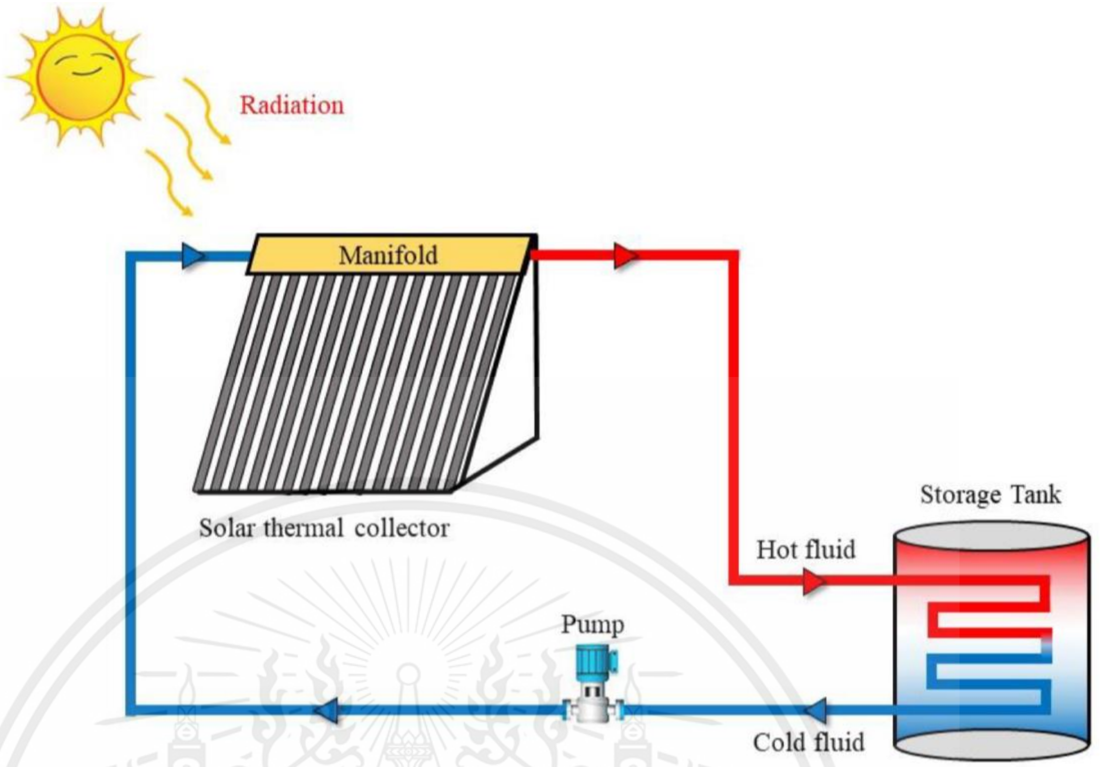


Figure 2.6: Evacuated tube solar collector system

2.2.2 Heat Transfer Fluids (Heating medium)

Heat transfer fluids carry heat through solar collectors and a heat exchanger to the heat storage tanks in solar water heating systems. In this project, palm oil was selected as heating medium due to the system requires more energy to be pumped which palm oil has the following advantages: high boiling point, good stability at high temperature, low thermal capacity, low thermal conductivity, innocuous and inexpensive and lower specific heat than water, so the amount of heat required to change the temperature of 1°C is lower. Palm oil is heated faster than water. Therefore, palm oil is more suitable as a heating medium in this system than water.[6]

2.2.3 Areas with solar power potential

Thailand receives both direct and diffuse radiation from the sun. Where direct radiation can generate more electricity or heat than diffused radiation. The highest direct radiation density in Thailand is approximately 1,350 - 1,400 kWh / m2 - year, covering 4.3% of the domestic area of the central and southern regions of the Northeast, while 19.5% of the area of the country is approximately 1200-1300 kWh / m2 - year is shown in Figure 2.7 The direct radiation intensity in Thailand tends to increase since January and the highest in April and the lowest in December.[1]

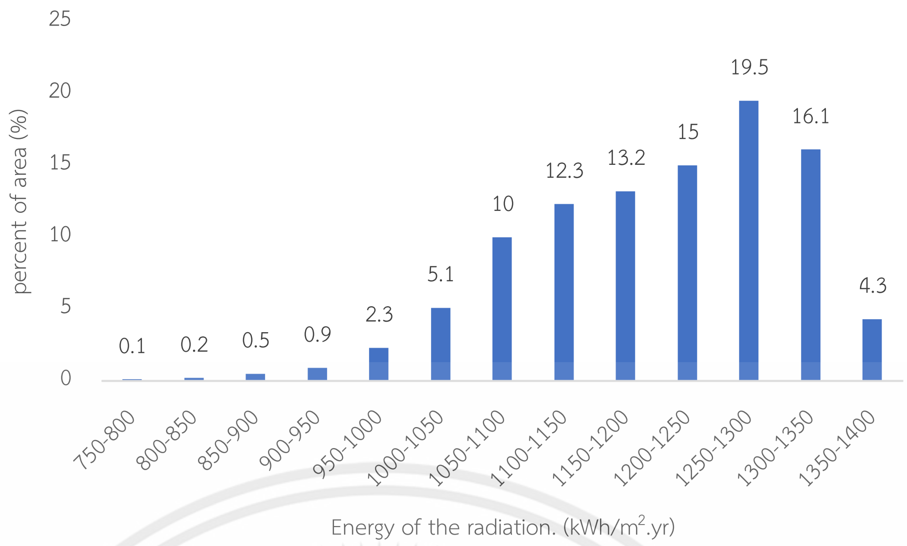


Figure 2.7: Percent area of the country where the radiation period [1]

2.3 Heat transfer equation [7]

2.3.1 Solar irradiance transfer to evacuated tube solar collector

The evacuated tubes absorb solar energy from radiation of the sun which can be shown in equation 2.1

$$\dot{Q}_{rad} = A_c\,G_t \tag{2.1}$$

where $\dot{Q}_{rad}$ = solar power from irradiance, W

A_c = gross area of evacuated tube solar collectors, m^2

G_t = solar intensity, W/m^2

2.3.2 Heat stored in heating medium storage tank

The heat stored in heating medium storage tank can be described with can be shown in equation 2.2

$$Q_{tank} = \dot{m}c_{p,oil}(T_{f,tank} - T_{i,tank}) \tag{2.2}$$

where Q_{tank} = heat stored in heating medium storage tank, W

$\dot{m}$ = mass flow rate of palm oil, l/hr

$c_{p,oil}$ = specific heat capacity of palm oil, kJ/(kg·°C)

$T_{f,tank}$ = final temperature of heating medium storage tank,°C

$T_{i,tank}$ = initial temperature of heating medium storage tank, °C

2.3.3 Efficiency of evacuated tube solar collector

The efficiency of solar collector system is calculated from the ratio of the heat transferred in pipe per unit time to the solar power from irradiance as shown in equation 2.3

$$\eta_{ETC} = \frac{\text{Total heat of of ETC } \times 100\%}{\text{Total solar radiation}} \quad (2.3)$$

where η_{ETC} = efficiency of evacuated tube solar collector system

2.3.4 Nusselt number in flow over cylinders

Nusselt number is the ratio of convective to conductive heat transfer at a boundary in a fluid as shown in equation 2.4

$$\mathrm{Nu} = 0.683\mathrm{Re}^{0.466}\mathrm{Pr}^{\frac{1}{3}} \quad (2.4)$$

where Re = Reynold Number

Pr = Prandlt number

2.3.5 Convection heat transfer coefficient

Convection heat transfer coefficient is the rate of heat transfer between a solid surface and a fluid per unit surface area per unit temperature difference as shown in equation 2.5

$$\mathrm{h} = \frac{Nuk}{D} \quad (2.5)$$

Where h = convection heat transfer coefficient, $W/m^2 \cdot {}^oC$

Nu = Nusselt number

k = thermal conductivity, $W/m \cdot {}^oC$

D = diameter of heat pipe, m

2.4 Literature Survey

2.4.1 Effect of water flow rate on daily thermal efficiency

An experimental investigation of heat pipe evacuated tube solar collector with and without phase change material for water heating application under the same weather conditions. A comparative analysis of two systems has been done in the same weather condition. Where evacuated tubes of the first system (evacuated tube collector-A) were left without phase change material and second system (evacuated tube collector-B).

In order to analyze the thermal performance of the designed system using different variable mass flow rate techniques of and working fluid, Shafieian et al. set up the experiment was conduced with five different water flow rates as 8, 12, 16,20, and 24 L/hr. The test-1, test 2, test 3, test 4 and test 5 were assigned for the water flow rate of 8, 12, 16, 20 and 24 L/hr respectively. They operated the propose system in the same whether conditions. The results of variable mass flow rate techniques were found very effective to enhance the performance of the proposed system. They discussed the novel designs and structure of heat pipe solar collector systems aiming was to enhance its thermal efficiency. They also reviewed the different techniques to store thermal energy in a more effective way to increase the overall efficiency, operation time and heat transfer in the solar system.

From the experimental and metrological data, the systems' daily thermal efficiency has been evaluated for each test by calculating useful energy gain and incident solar radiation.

Figure 2.8 is shown the variation in daily thermal efficiency for the different tests. The maximum daily thermal efficiency of 87.80% and 55.46% for ETC-B and ETC-A respectively was achieved for test-4. The second highest value of daily thermal efficiency of 84.90% and 52.17% for ETC-B and ETC-A respectively was attained for test-5. Whereas for test-1, the minimum value of daily thermal efficiency (79.98% and 42.42% for ETC-B and ETC-A respectively) was achieved. Thus 20 LPH is an optimum water flow rate in terms of highest efficiency for heat pipe ETC system.[8]

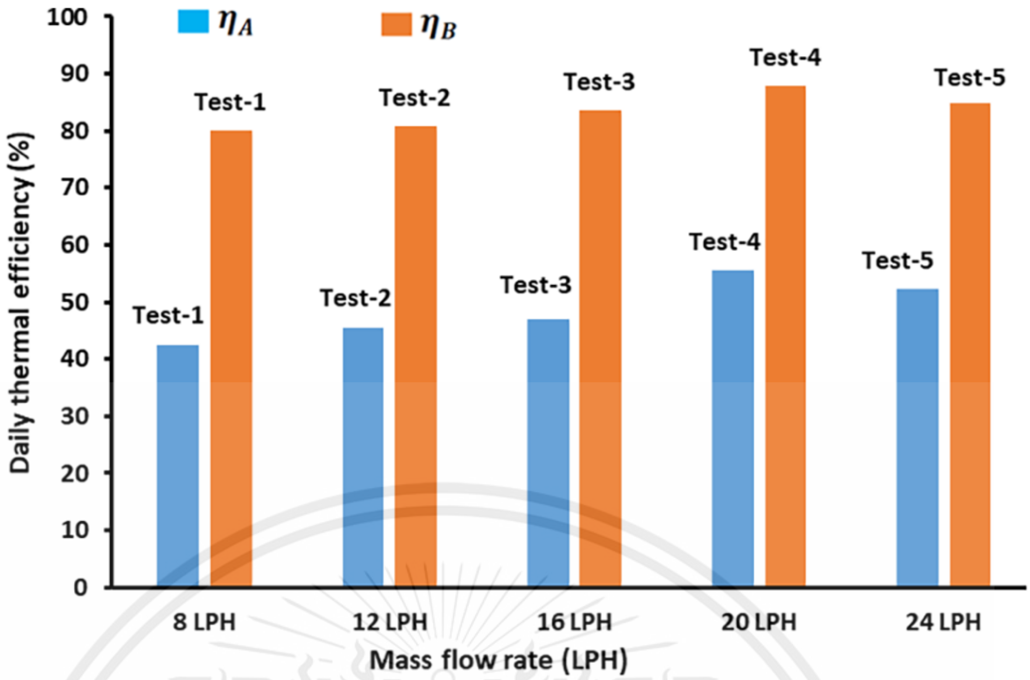


Figure 2.8: Effect of mass flow rate on the variation of daily thermal efficiency.

2.4.1 Effect of solar intensity

M. Mahendran, Lee. G.C, K.V Sharma, and A. Shahrani set up the experiment are undertaken to determine the efficiency of evacuated tube solar collector using water-based Titanium Oxide (TiO2) nanofluid. Malaysia lies in the equatorial zone with an average daily solar insolation of more than 900 W/m2 and can reach a maximum of 1200 W/m2 for most of the year.

From the results of the experiment indicated that the solar intensity is an important parameter to evaluate the efficiency of the solar collector which is dependent on the geographic location, weather, and climate. It was observed for a clear sky day the variation of solar intensity to be parabolic is shown in Figure 2.9 The maximum insolation on the tilted surface of evacuated tube solar collector was about 958 W/m^2 on that particular day. Nevertheless, on a cloudy day, the solar insolation as irregular pattern, the solar insolation rises and drop along the day according to the clouds.

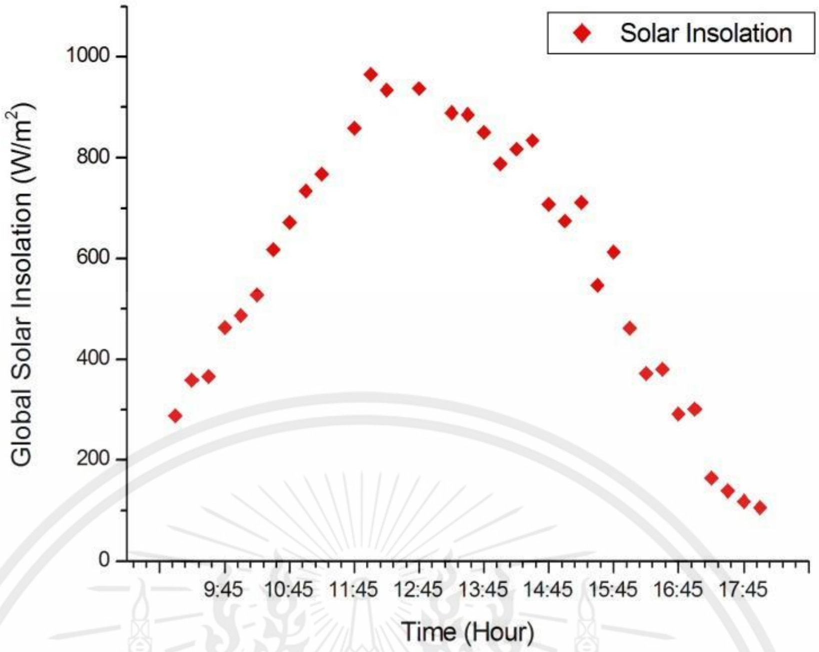


Figure 2.9: Solar Insolation against time on a clear sky day [9]

CHAPTER III

EXPERIMENTAL

3.1 An experiment to study the solar intensity effect on the temperature of the heat pipe tip

Materials and equipment

1. Evacuated tube solar collector (3 tubes)
2. Thermocouple type K and data logger
3. Solar power meter (TM-206, TENMARS)

Procedures

1. Attach the thermocouple and datalogger to the tip of the evacuated solar collector.
2. Evacuated tube solar collector is installed under the sunlight as shown in Figure 3.1
3. Measure solar intensity every 30 minutes from 9.00 AM. - 4.00 PM.
4. Measure the temperature of tip every 30 minutes from 9.00 AM. - 4.00 PM.
5. Measure the atmospheric temperature every 30 minutes from 9.00 AM. - 4.00 PM.

Figure 3.1: Evacuated tube solar collector with thermocouple and data logger

3.2 An experiment to study the influence of heating medium flow rate affects the efficiency of this system

Materials and equipment

1. Evacuated tube solar collector (20 evacuated tubes)
2. Heating medium storage tank (120 L)
3. Pump (0.55 kW)
4. Inlet and outlet copper pipe
5. Thermocouple type K and data logger
6. Solar power meter (TM-206, TENMARS)
7. Tubtim palm oil (Heating medium)
8. Measuring Cylinder 1000 ml
9. Stopwatch

Procedures

1. Install the evacuated tube solar collector system as shown in Figure 3.2 and locate this system at 13o43’35’’N, 100o46’20’’E of CCA Building, Bangkok, Thailand. This experiment is operated between 9.00 AM to 0.00 AM.

2. Adjust the flow rate equal to 50 l/min.

3. Start the pump for circulating palm oil in the system.

4. Measure and record inlet palm oil temperature, outlet palm oil temperature, storage tank temperature and solar intensity every 30 minutes.

5. Stop the pump at 4.00 PM.

6. Repeat step 1 to 4 but adjust the flow rate of palm oil in the range of 100 – 300 l/hr.

Figure 3.2: Evacuated tube solar collector in the experiment

CHAPTER IV

RESULTS AND DISCUSSION

4.1 The effect of solar intensity on the temperature of heat pipe tip

In this study, two tests were performed. Each test was carried out on different days with different solar radiation. In Test 1, the experiment was conducted on 17/09/2020 with an average atmospheric temperature of 38.1 ºC where the highest atmospheric temperature on 17/09/2020 was at 12.00 AM with a temperature of up to 42 ºC. The relationship of atmospheric temperature and solar intensity is shown in Figure 4.2. Figure 4.1 shows that the solar intensity increases from 9:00 AM to the maximum at 12:00 AM with a value of 1076 W/m^2, while observed temperature of tip also increases until the maximum at 12.00 AM. The maximum temperatures of tip for each tube of 153.4 ºC, 157.1 ºC and 170.7 ºC, respectively. The solar intensity decreases from 12:00 AM until 4:00 PM. In this experiment, it was found that the trend of the relationship between temperature of tip and solar intensity was similar.

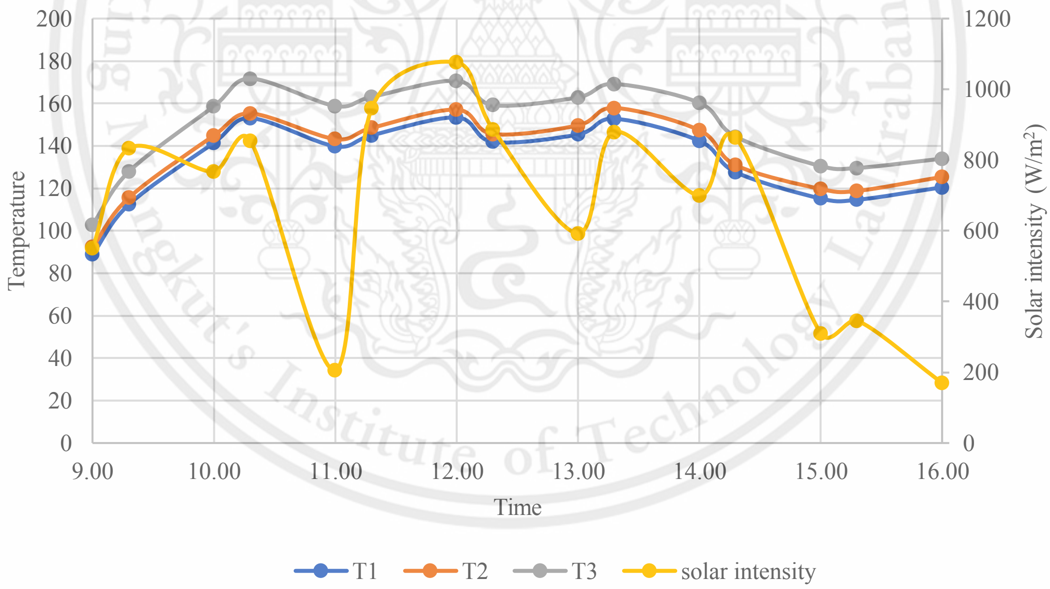


Figure 4.1: Temperature of tip and solar intensity during 17/09/2020

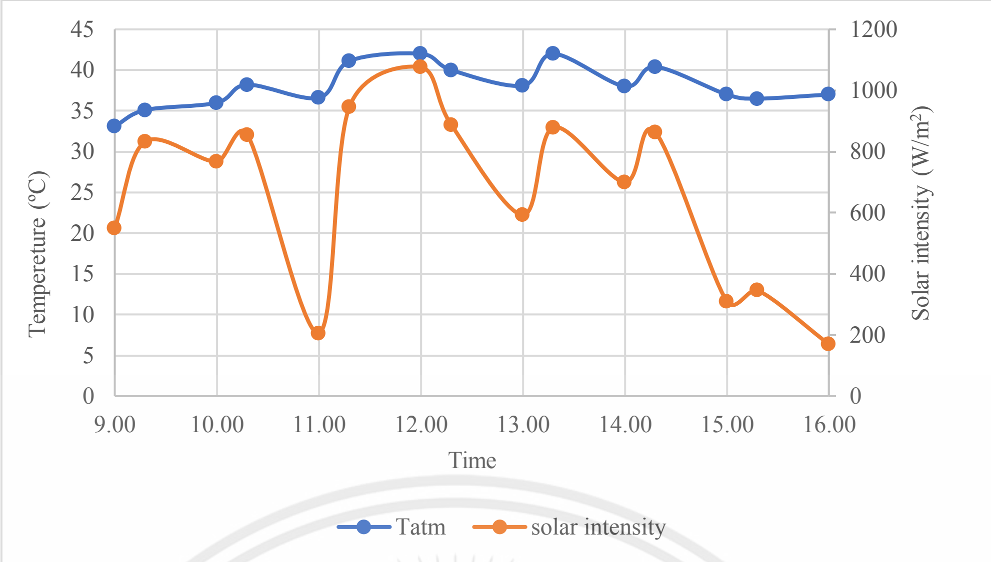


Figure 4.2: Atmospheric temperature and solar intensity during 03/09/2020

In Test 2, the experiment was conducted on 03/09/2020 with an average atmospheric temperature of 34.8 ºC where the highest atmospheric temperature on 3/09/2020 was at 12.00 AM with a temperature of 37.5 ºC. The relationship of atmospheric temperature and solar intensity is shown in Figure 4.4.

Figure 4.3 shows that on 03/09/2020 from 9:00 AM until 10:00 AM solar intensity has been steadily increasing, which causes the temperature of tip in each tube to increase as well, and as of 10:30 AM until 11:00 AM solar intensity is reduced due to cloudy or polluted weather, which causes the temperature of each tip to also reduce. At 12:00, the solar intensity and temperature of tip are the highest, with solar intensity of 960 W/m^2 and temperatures of tip for each tube of 142.9 ºC, 148.9 ºC and 121 ºC respectively.

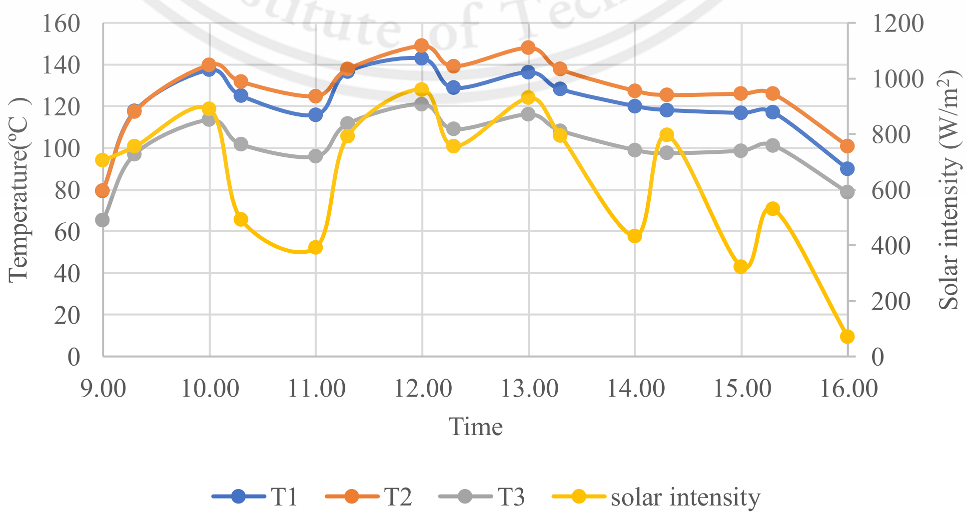


Figure 4.3: Temperature of tip and solar intensity during 3/09/2020

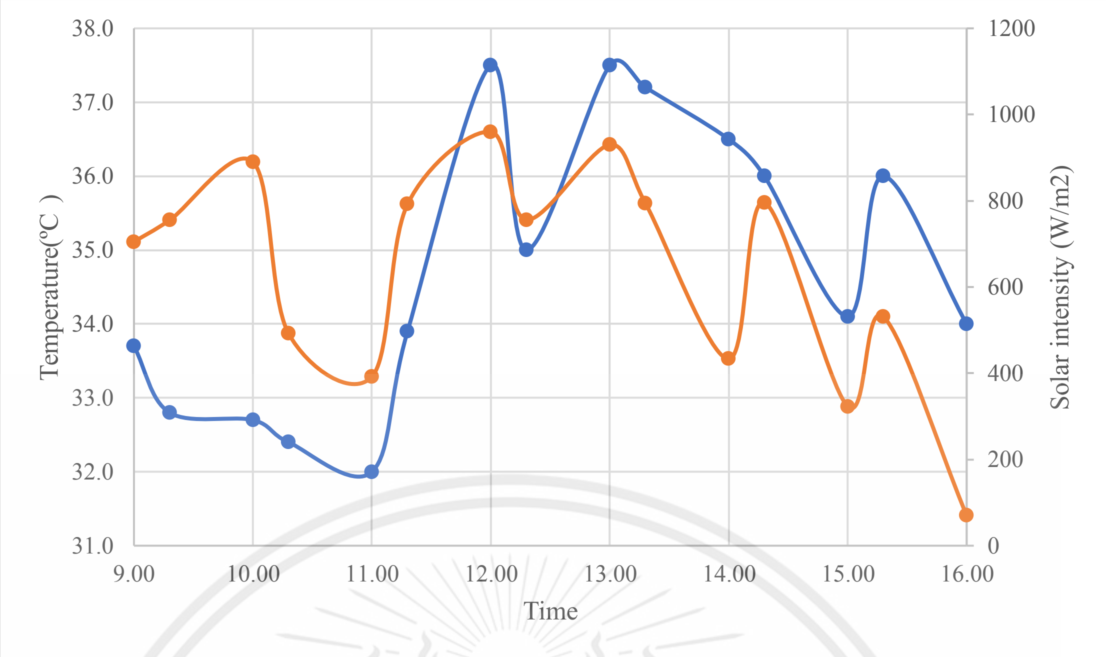


Figure 4.4: Atmospheric temperature and solar intensity during 3/09/2020

Table 4.1 shows that the maximum and average temperatures of each tube in Test 1 was higher than in Test 2, This might be due to the higher average solar intensity, so the temperatures of tip were higher. The value of the T3 tube was higher than the first and second tubes in both Test 1 and Test 2 This should be because the volumes of working fluid stored inside the heat pipe are not equal causing in the different fraction of the fluid to evaporate and condense inside the heat pipe. In addition, there are contaminants in each tube, and it is found that the assembly of evacuated tubes from production within the structure of the evacuated tube solar collector are not exactly the same as there is an unequal fin design which gives each tube an unequal quality.Therefore, the heat transfer rate of each tube is different. Thus, the measured temperature of tip of the T3 tube is different from the T1 tube and T2 tube.

Table 4.1: Results of maximum temperature of tip and average temperature and solar intensity of each experiment.

Test 1 (17/09/2020)				Test 2 (03/09/2020)		
Experiment	T1	T2	T3	T1	T2	T3
Maximum temperature of tip (ºC)	153.4	157.1	170.7	142.9	148.9	169.2
Avg. Atmospheric Temperature (ºC)	34.8			38.1		
Avg. Temperature of tip (ºC)	132.96	136.82	149.58	120.68	127.36	143.17
Avg.Solar Intensity (W/m^2)	687.21			659.39		

4.2 The influence of heating medium flow rate on the efficiency of this system

The data of solar intensity during the days of experiment were examined by using solar power meter (TM-206, TENMARS). The recorded data of solar intensity during the days of experiment are shown in Figure 4.5. The graph shows that the trend of solar intensity in each day is different. The solar intensity increases during 9:00 AM to 1:00 PM and starts to decrease during 1:00 PM to 4:00 PM. However, due to the cloudy effect, some variation in solar intensity was observed at 1.30 PM of the flow rate of 337.54 l/hr which from Table 4.2, it was found that on 17/02/2021, the 337.54 l / hr flow rate it was cloudy compared to other days of the experiment and had the lowest average solar intensity.The quantity of solar intensity depended on cloud factor and air pollutant factor. If quantity of cloud and air pollutant are high, the quantity of solar intensity will be low.

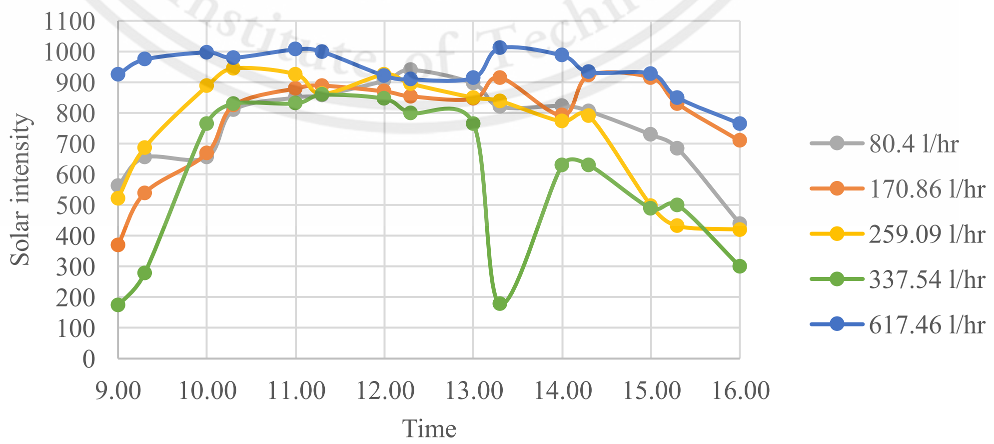
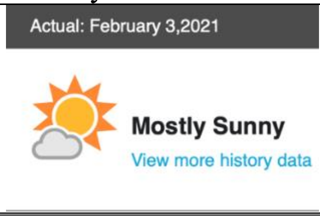
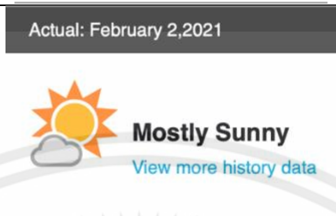


Figure 4.5: Data of solar intensity in the days of experiment

Table 4.2: Daily cloud volume and solar intensity at different flow rates[10]

Flowrate (l/hr) / Date	Daily cloud volume	Avg.solar intensity (W/m^2)
80.4 (3/02/2021)		780.79
170.86 (2/02/2021)		805.96
259.09 (11/02/2021)		770.00
337.54 (17/02/2021)		616.89
617.46 (2/1/2021)		946.79

Optimization of a hot water loop requires correctly setting the flow rate and temperature. This is observed from the Equation (2.2)

$$Q_{tank} = \dot{m}c_{p,oil}(T_{f,tank} - T_{i,tank}) \tag{2.2}$$

where the specific heat capacity of palm oil ($c_{p,oil}$) is assumed constant, mass flow rate of palm oil would direct variation with the heat stored in heating medium tank and reverse variation with the change of palm oil temperature which could be described from Equation 4.1.

$$Q \propto m\,\Delta T \tag{4.1}$$

If the flow rate of palm oil is relatively high, there will be high heat transfer and the maximum temperature of palm oil from heating will be low because the solar energy during the day is not enough to heat the palm oil in the storage tank. On the other hand, if the palm oil flow rate is low, there will be low heat transfer and the maximum temperature of the palm oil from heating will be high. But the efficiency in heat retention will be reduced. Therefore, a suitable mass flow rate is assessed for the best performance of the solar collector.

The Nusselt number shown in Equation (2.5) represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across the same fluid layer. The larger the Nusselt number, the more effective the convection is

$$h = \frac{Nuk}{D} \tag{2.5}$$

Figure 4.6 shows the temperature in the storage tank at different times, with experiments from 9:00 AM to 4:00 PM, the experiment was conducted with five different water flow rates (80.4, 170.86, 259.09, 337.54 and 617.46 l/hr). The result shows that the temperature of each mass flow rate of palm oil increases rapidly of in the beginning. After that, the temperature of each mass flow rate increases slowly to the maximum temperature at 4:00 PM.

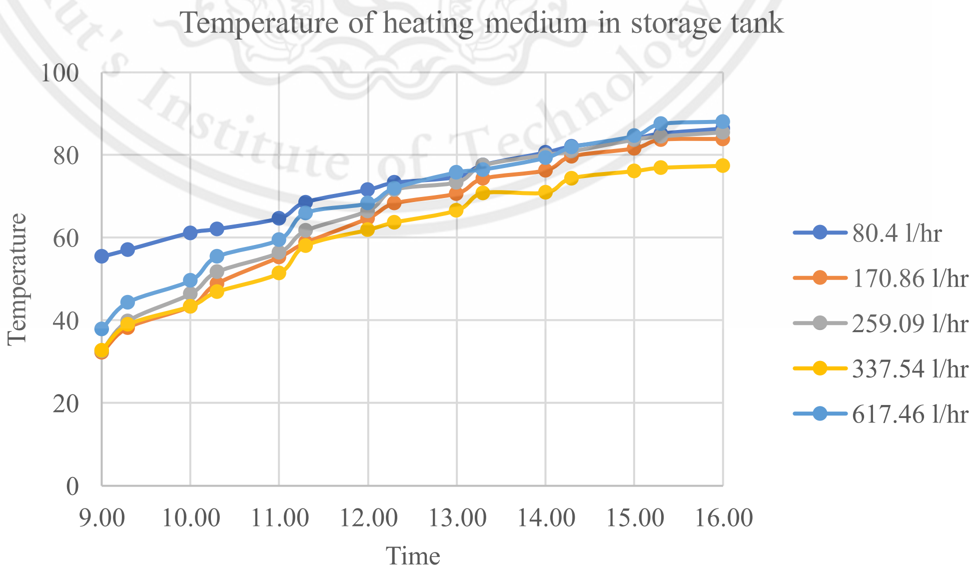


Figure 4.6: Temperature of heating medium in storage tank

Table 4.3 shows that at a flow rate of 617.46 l/hr, the storage tank temperature was 88.1 ºC, the heat transfer in evacuated tube solar collector was 903.67 W and the greatest Nu number was 95.56. When increasing the flow rate he heat transfer also increases, which is in line with the function of the flow rate that is directly proportional to the heat transfer, as well as the large Nu number, resulting in more efficient convection. The experimental results are according to theory but it is noticed that at a flow rate of 80.4 l/hr, the storage tank temperature is similar to that of the 617.46 l/hr flow rate, which is 86.4 ºC. It has a large temperature difference and a higher contact time than other flow rates, thus accumulating or retaining large amounts of heat. Therefore, at a flow rate of 80.4 l/hr, the temperature in the storage tank is close to the flow rate of 617.46 l/hr.

In the optimization of the mass flow rate of palm oil, the flow rate of palm oil was significant with the efficiency of the evacuated tube solar collector system more than a change of the palm oil temperature and heat transfer in evacuated tube solar collector shown in Table 4.3 The maximum temperature of heating medium at the flow rate 617.46 l/hr was more than other mass flow rates and the highest efficiency is 63.63%. Therefore, a suitable volume for the current system was analyzed through the energy of each flow rate that could provide maximum energy for heating 120 l of the heating medium is at a flow rate of 617.46 l/hr because at this flow rate, the efficiency is the highest and the Nusselt number is the highest, resulting in highly efficient convection.

Table 4.3: Efficiency and convection heat transfer coefficient in storage tank of evacuated tube solar collector system

Flow rate (l/hr)	Maximum temperature(ºC)	Heat transfer ETC system (Q)	Efficiency of ETC system (%)	Nusselt number	Convection heat transfer coefficient (W/m^2·ºC)
80.4	86.4	371.69	31.74	36.83	437.36
170.86	83.9	307.2	27.01	51.54	612.32
259.09	85.5	415.93	36.01	63.61	755.40
337.54	77.4	406.89	43.97	70.60	841.10
617.46	88.1	903.67	63.63	95.56	1133.69

CHAPTER V

CONCLUSION

5.1 Conclusion

Experiments to study the relationship between solar intensity and temperature of tip showed that solar intensity increased from 9.00 AM to 12.00 AM and began to decrease from 12.00 AM to 4.00 PM. If cloud volume and air pollution are high, the amount of solar intensity will be low, which can be observed by Test 2 at 10.30 to 11.00. As a result, the temperature of the tip is also lower. It can be seen that in Test 1 the atmospheric temperature and the average solar intensity are higher than that of Test 2, the temperature of the tip in Test 1 is higher than Test 2.

From the results of the experiment to find the flow rates from different flow rates to get the maximum efficiency of the solar water heater, it was found that the optimum flow rate was 617.46 l / hr, providing a water heater efficiency of 63.63%

5.2 Suggestions

1. Evacuated tube solar collector system should be installed at open space or terrace for receiving more solar intensity.

2. The number of evacuated tubes should be increased for improving the efficiency of system.

3. There should be an instrument to measure the flow rate accurately.

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APPENDIX

Appendix A: Properties of material

Appendix B: Experimental result and calculation

Appendix B-2: Experimental result of the influence of heating medium flow rate affects the efficiency of this system

Appendix B-3: Calculation of optimization of the mass flow rate of heating medium in the storage tank

Appendix A: Properties of material

Table A-1: Properties of palm oil

Temperature, °C	Viscosity mPas	Heat Capacity KJ/kg·°C	Conductivity W/m·°C	Density kg/m^3
20	106.8	1.848	0.1726	890.1
25	77.19	1.861	0.1721	887.5
30	57.85	1.875	0.1717	885
35	44.68	1.888	0.1712	882.5
40	35.41	1.902	0.1708	880
45	28.68	1.916	0.1704	877.5
50	23.68	1.93	0.1699	875.1
55	19.88	1.944	0.1695	872.6
60	16.93	1.959	0.1691	870.2
65	14.61	1.973	0.1687	867.8
70	12.75	1.988	0.1683	865.4
75	11.23	2.003	0.1679	863.1
80	9.99	2.018	0.1675	860.7
85	8.955	2.034	0.1671	858.4
90	8.087	2.049	0.1668	856.1
95	7.351	2.065	0.1664	853.8
100	6.721	2.081	0.166	851.6

Appendix B: Experimental result and calculation

Appendix B-1: Experimental result of the solar intensity effects to temperature of tip

Table B-1-1: Result of solar intensity and temperature of tip of each tube (Test 1)

Test 1					
Time	solar intensity (W/m^2)	T1	T2	T3	T4
9.00	705	79.5	79.5	65.3	75.3
9.30	755	117.7	117.3	97.1	126.3
10.00	890	137.4	139.8	113.5	153.5
10.30	492	125	131.7	101.7	146.7
11.00	392	115.9	124.9	95.9	136.1
11.30	792	136.5	137.8	111.7	157.9
12.00	960	142.9	148.9	121	169.2
12.30	756	128.8	139.2	109	156
13.00	930	136.3	148	116.1	166.5
13.30	794	128.2	137.7	108.3	156.2
14.00	433	120.1	127.4	99	150.4
14.30	796	118.2	125.4	97.5	146.6
15.00	323	116.8	126	98.7	146.9
15.30	531	117	125.9	101.2	147.1
16.00	70	89.9	100.9	78.6	112.9

Table B-1-2: Result of solar intensity and temperature of tip of each tube (Test 2)

Test 2				
Time	solar intensity (W/m^2)	T1	T2	T3
9.00	550	88.8	92.3	102.8
9.30	833	112.4	115.6	127.9
10.00	767	141.5	144.9	158.7
10.30	855	153.1	155.3	171.7
11.00	206	139.8	143.2	158.8
11.30	946	145	148.5	163.1
12.00	1076	153.4	157.1	170.7
12.30	887	141.9	145.6	159.2
13.00	593	145.4	149.7	162.9
13.30	879	152.8	157.9	169.2
14.00	700	142.4	147.4	160.3
14.30	863	127.6	130.9	144.3
15.00	310	115.2	119.7	130.5
15.30	346	114.6	118.8	129.6
16.00	170	120.5	125.4	134

Appendix B-2: Experimental result of the influence of heating medium flow rate affects the efficiency of this system

Table B-2-1: Result of inlet temperature, outlet temperature, storage tank temperature and solar intensity from mass flow rate at 617.46 l/hr.

617.46 l/hr (2/1/2021)				
Time	$T_{in,oil,°C}$	$T_{out,oil,°C}$	$T_{tank,°C}$	solar intensity (W/m^2)
9.00	37.7	43.8	37.9	925
9.30	43.6	47.7	44.4	974
10.00	49	52.5	49.6	997
10.30	53.9	56	55.4	980
11.00	60.6	62.4	59.5	1007
11.30	64.7	66.1	66	999
12.00	67.3	67.3	68.3	921
12.30	70.5	72.6	72	909
13.00	74.2	76.6	75.8	914
13.30	76.8	77.5	76.5	1011
14.00	79.2	79.5	79.3	987
14.30	81.6	82	81.9	933
15.00	82.6	84.1	84.6	928
15.30	85.4	88.9	87.5	850
16.00	86.5	89.5	88.1	765

Table B-2-2: Result of inlet temperature, outlet temperature, storage tank temperature and solar intensity from mass flow rate at 170.86 l/hr.

170.86 l/hr (2/2/2021)				
Time	$T_{in,oil,°C}$	$T_{out,oil,°C}$	$T_{tank,°C}$	solar intensity (W/m^2)
9.00	31.2	38.8	32.2	370
9.30	37.4	43.8	38.3	539
10.00	44	48.6	43.4	668
10.30	46.6	54	48.9	824
11.00	53.7	58.4	55.3	880
11.30	57.9	64.1	58.8	889
12.00	62.9	69.8	64.7	870
12.30	66.5	73.7	68.3	854
13.00	70.2	76.7	70.7	846
13.30	73.5	80.4	74.3	915
14.00	75.8	82.4	76.3	792
14.30	78.2	86.5	79.7	922
15.00	80.8	88.4	81.6	915
15.30	82.5	88.7	83.7	830
16.00	83.6	87.3	83.9	709

Table B-2-3: Result of inlet temperature, outlet temperature, storage tank temperature and solar intensity from mass flow rate at 80.40 l/hr.

80.40 l/hr (3/2/2021)				
Time	$T_{in,oil,°C}$	$T_{out,oil,°C}$	$T_{tank,°C}$	solar intensity (W/m^2)
9.00	52.9	63.7	55.4	563
9.30	55.7	66.7	57.1	655
10.00	59.2	76	61.2	655
10.30	60.2	74.3	62.1	809
11.00	62.3	77.4	64.7	850
11.30	65.5	81.7	68.6	858
12.00	68.5	85.4	71.6	905
12.30	69.2	85	73.3	940
13.00	73.1	89.5	74.7	896
13.30	75	90.9	77.6	820
14.00	78	90.8	80.6	823
14.30	79.6	93.7	82.1	806
15.00	81.6	94.7	84	729
15.30	83.9	93.3	85.2	684
16.00	83.7	93.2	86.4	439

Table B-2-4: Result of inlet temperature, outlet temperature, storage tank temperature and solar intensity from mass flow rate at 259.09 l/hr.

259.09 l/hr (11/2/2020)				
Time	$T_{in,oil,°C}$	$T_{out,oil,°C}$	$T_{tank,°C}$	solar intensity (W/m^2)
9.00	33.7	39.2	32.6	522
9.30	39.9	43.9	39.9	687
10.00	46.5	51	46.4	887
10.30	51.6	55.3	51.7	945
11.00	55.7	63.9	56.4	926
11.30	60.9	67.1	61.7	862
12.00	65.9	71.1	66.5	925
12.30	70	75.9	71.6	895
13.00	72.5	77	73.4	850
13.30	75.9	78.6	77.5	839
14.00	78.3	81.8	80	772
14.30	81	82.2	80.9	791
15.00	82	84.7	83.7	498
15.30	83.1	85.6	84.5	432
16.00	84	87.3	85.5	420

Table B-2-5: Result of inlet temperature, outlet temperature, storage tank temperature and solar intensity from mass flow rate at 337.54 l/hr.

337.54 l/hr (16/2/2020)				
Time	$T_{in,oil,°C}$	$T_{out,oil,°C}$	$T_{tank,°C}$	solar intensity (W/m^2)
9.00	33.3	39	32.8	173
9.30	38.9	44	39	278
10.00	43	46	43.4	765
10.30	46.4	49	46.9	830
11.00	50.3	53.9	51.4	831
11.30	57	59.9	58.1	859
12.00	60.3	63.7	61.9	846
12.30	62.5	65.1	63.7	800
13.00	65.3	67.5	66.6	765
13.30	69	70.2	70.8	177
14.00	69.9	71	70.9	630
14.30	72.8	76	74.4	630
15.00	74.7	76.1	76.1	489
15.30	75.5	77.6	76.9	500
16.00	76	78.5	77.4	300

Appendix B-3: Calculation of optimization of the mass flow rate of heating medium in the evacuated tube solar collector at flow rate 617.46 l/hr

ρ = 857.98 kg/m^3

$\dot{v}$ = 0.172 l/s

$c_{p,oil}$ at 87.3 °C = 2.0496 kJ/kg ·°C

$T_{in,oil}$ = 86.5°C

$T_{out,oil}$ = 89.5 °C

$$Q_{tank} = \dot{m}c_{p,oil}(T_{out,oil}-T_{in,oil}) \qquad 2.2$$

$$Q_{tank} = 857.98\,\frac{kg}{m^3} \times 0.172\,\frac{l}{s} \times 2.0496\,\frac{kJ}{kg{\cdot}°C}\,(89.5\text{-}86.5)\ °C$$

$$Q_{tank} = 903.67\ W$$

<u>Average of solar intensity</u>

The total of solar intensity can be determined from area under the curve relation between solar intensity (W/m2) and time (s).

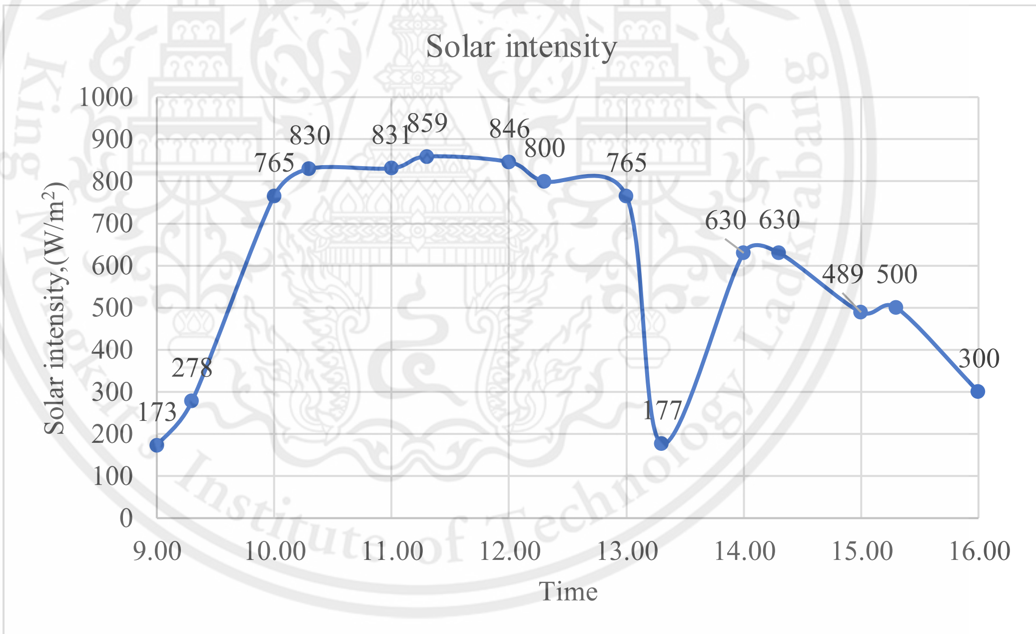

Figure B2-1: Relation between solar intensity and time (Experiment date 16/2/20)

Total of solar intensity = Area under the curve

Total of solar intensity = 1 × 3,600 s × [(173 + 278) + (278 + 765) + (765 +830) + (830 + 831) + (831 + 859) + (859 + 846) + (846 + 800) + (800 + 765) + (765 +177) + (177 + 630) + (630 + 630) + (630 + 489) + (489 + 500) + (500 + 300)] W/m^2 = 15,545,700 W/m^2

Average of solar intensity (Gt) = 15,545,700 W/m^2 ÷ (7 × 3600) s = 616.89 W/m^2

The efficiency of heating medium storage tank can be calculated by

$$\eta_{ETC} = \frac{\text{Total heat of ETC} \times 100\%}{\text{Total solar radiation}}$$

Total heat of storage tank = 903.67 W

Total solar radiation = A_cG_t = 1.5 m^2 × 946.79 W/m^2

Total solar radiation = 1420.18 W

$$\eta_{ETC} = \frac{903.67\ \text{W}}{1420.18\ \text{W}} \times 100$$

$$\eta_{ETC} = 63.63\%$$

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