Thermal Performance of Mixed Asphalt Solar Water Heater

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Received: 08.02.2019 Accepted:22.03.2019

Abstract- This paper deals to investigate the thermal performance of the mixed asphalt solar water heater. The mixed asphalt solar water heater composes of mixed as asphalt as an absorber plate, copper tube, glass cover, and insulation material. The mixed asphalt solar water heater area is 0.5 m^2, and always constant feed water at 0.02 kg/s. The air gap between glass cover and absorber plate is 0.004 m, and inclination angle was fixed at 30°. The copper tube of length 9 m with 0.135 m^2, cross-section area. The experimental set-up was located at latitude 13°47'41.3"N, and the longitude 100°17'56.7"E Thailand. The experimental data were used to assess thermal performance, based on the following parameters such as the absorbers surface temperature, the temperature difference between inlet and outlet water temperature, useful energy, and energy efficiency. The result shows that the maximum absorber plate temperature and the temperature difference between the inlet and outlet water temperature are obtained to 60°C and 17.2 °C respectively. While, the feed water has been obtained amount of heat in the range 100-380 W/m^2. As above results is found to range 70-79%.

Keywords Absorber plate; Mixed asphalt; Solar water heater; Thermal performance.

1. Introduction

Nowadays, in Thailand, energy consumption has been increasing because of economic development due to the dependency on fossil energy was growing. It was leading to energy stability concerns at the national level in the future because more than half of the domestic energy demand depends on energy imports [1]. The Royal Thai governments have been enacted Alternative Energy Development Plan (ADEP) to the country's energy pertinacity. The primary target is to expand the proportion of renewable energy of the total energy consumption in the country up to 25 percent. Therefore, energy conservation and energy efficiency improvements are not sufficiently designed to advocate energy consumption in Thailand. The energy demand is forecasted to reach 99,838 ktoe in 2021 and 151,000 ktoe in 2030. Solar energy is the renewable energy extensively used and environmentally friendly that can be controlled by directly deriving energy from sunlight or indirectly. Also, it was endless energy resources for humans [2]. The water heater is an important energy source in the part of building, plant, and habitat. However, the water heater has overall energy consumption tends to be the second in the house. There are many different obtainable water heater models in the store, but the water heaters use natural gas and electric were the most popular [3]. Solar Water heater system is another option for solar energy that has received a lot of attention from researchers in this field [4]. The solar water heater was the most successful of solar thermal technology [5]. It the most plausible and effective device. Besides, it has the commercial equipment for converting solar radiation into thermal energy.

A Solar collector is type of heat exchanger, which the heat exchanges occur between a heat transfer fluid flowing in the collector and a distance source [6]. The thermal efficiency of solar water heaters was investigated by many researchers, that suggesting developments for their operation and there are works on the solar water heater with a different design. Currently, the main target is to improve performance and reduce costs of the solar water heater [7]. From the literature reviews of previous research, daraj et al. [8] studied a solar parabolic trough collector (PTC) integrated with a storage tank which contains Therminol 55 as the fluid heat transfer and found the maximum efficiency at 62.5% depends on useful heat gain and the incident beam radiation. Meanwhile, Evren et al. [9,10] had developed low-cost flat mirror Solarux CSP System for heat storage without using electrical, which is two axis sun tracking system. On the other hand, Zhanga et al. [11] tested the capacity of the solar collector affect their thermal performance more than 1000 SWHs (water-in-glass evacuated tube) according to Chinese standards. It found that the inclination angle and the heat loss from the storage tank did not affect the performance of the SWHs. The main research related to improve performance for energy efficient collection and storage of heat [12]. Similarly, Zhou et al. [13] investigated energy storage with phase change material (PCM) by use testing stainless ball. The results showed that the heat storage within 2–4.5 h at the solar radiation, 10.8 to 19.4 MJ/m^2. The average heat discharge rate was 78% to 83%. Flat plate solar collector is one that has been popular for use. Hence, Roonprasang et al. [14] created a solar water heater that used solar water pumps. Flat plate collector used for producing the steam. The temperature of water in the flat plate collector is around 75 – 78 °C and water temperature within the storage tank is high for residential use when compared with a conventional. Then, Chen et al. [15] was studied the energy storage of a flat plate solar collector. Structure filled aluminum foam porous was integrated on flat plate solar collector with the phase-change medium as, paraffin. The energy gain was about 35–44% and the aluminum sheet made to reflectors has been effect positive [16]. Moreover, the solar roof has been developed to utilize solar energy from the rooftop in many years [17]. Yusuke and Yuzuru [18] considered the performance of the PV array and the solar thermal water heater (STWH) on the roof with different weather conditions in the 10 regions of Japan.

In addition, Jafar et al. [19] used energy and exergy analyzed flat plate solar collectors by assumption fluid inlet temperature and a variable heat loss coefficient. The maximum exergy efficiency and energy of flat plate solar collector is 8% and 80%. Moreover, the solar water heater was designed utilizes mini-channel tubes from aluminum attached to headers. It did not require a flat fin attached with the hose to heat transfer to the fluid, which the average thermal efficiency of 13% obtained to a mini-channel collector, as well as, energy collection during the day [20]. Thus, the solar water heater systems having the best thermal performance compared to other water heater systems in the present because the absorber plate cannot radiation emitted through the glass, and the reflector [21]. Likewise, the effects of pipe length-diameter, absorber plate thickness, the environmental conditions, inclination angle and the orientation of the solar collector fruitful on the thermal performance of collector for the design and optimization of the flat plate solar collector [22]. Besides, the thermal performance of absorber tubing of the extended surface in a flat plate solar collector was analyzed by Balaji et al. [23]. The aim to increase the effective heat transfer area between the absorber fluid and the surface with minimum pressure drop. The efficiency of the tube velocity and rod velocity enhances is achieved by 10 % and 15%. Meanwhile, the sustainable assessment was used for the heat transfer enhancer flat plate collector. From environmental, economic and energy analyzed has environmental damage cost increased slightly [24].

Furthermore, the various programs and mathematical models were applied for help optimize the solar water heater system. Bracamonte et al. [25] used experimental and numerical simulation the inclination angle of solar collector that the flow patterns inside storage tanks and stratification. The inclination angle has a low effect on thermal efficiency to maximize the solar heat gain of water in glass evacuated tube solar water heater. however, the collectors should be inclined at an angle that maximizes the receive solar radiation. While, Kalogeria [26] investigated to optimize the performance of the system by experiment and simulation header tube diameters and a number of risers were considered from 6 mm to 35 mm, distances between the top of a collector to the bottom side of storage tank from ±15 cm and slopes from latitude ±10°. Thus the distance between the top of a collector and the bottom of the storage tank affect the performance of the system. The riser pipes and the smaller the diameter of the heater is the better performance of the system. Moreover, Zhou et al. [27] Using programs and mathematical models to simulate complex operations can reduce the cost of doing business or industry, help decision-making, and perform various experiments before applying. Whereas Ampuño et al. [28] examined the possibility of using a model was developed to simulate the temperature outlet of the plant AQUASOL-II to analyze the operational situation is different. The mathematical model confirmed that the experimental result was similar with high exactness for the freezing and cooling of flat plate collector. That significantly improves the antifreeze efficacy of flat plate collector. Recently, Pukdum et al. [29] studied the theoretical evaluation of the performance of a mixed asphalt solar water heater (MASWH) by analyzing the inclination angle was varied from 10° to 80°. Theoretical evaluation of MASWH for unsteady condition is applied to each element by assumes that the thermal capacities of absorber plate, tube, fluid and insulation to the mean temperature of the fluid. It was found the maximum water temperature of 49.8 °C at an angle of 10°. Which higher than at an angle of 80° about 8.7°C. The inclination angle is significant for a MSAWH to obtain solar radiation and involve of water temperature outlet from the collector.

In Thailand, many pieces of research of solar water heater have studied the appropriate of the solar roof collector for improving natural ventilation [30]. The results are shown that the optimum inclination of the solar roof collector should be at 30° from the horizontal plane. It corresponds to the tilt of roof houses in Thailand [32,33]. Moreover, the numerical results of a mixed asphalt solar water heater, which has an inclination angle between 10 and 30, are shown that the outlet water temperature is quite the same. The difference is less than 5%.

This paper proposes the mixed asphalt as an absorber plate of the solar water heater. To investigate the thermal performances and factors affecting the temperature of the glass cover, copper pipe, absorber plate and water temperature.

2. Experimental Set-up and Description

To carry out the experimental study, the experiments were conducted as shown in Fig.1. The mixed asphalt solar water heater (MASWH) uses mixed asphalt as an absorber plate. Mixed asphalt was a selective collector which has the length of 1 m width of 0.5 m and thickness of 0.05 m. The glass cover was thickness 0.004 m, the air gap between the mixed asphalt and the glass cover was 0.05 m. The copper pipe has the inner diameter of 9.52 mm. It has a total length pipe of 9 m. The insulation made from polyurethane with the thickness of 0.01 m as shown in Fig. 2. The inclination angle was fixed at 30° from the horizontal and oriented to the south. The experiments were tested at latitude 13°47'41.3"N, and the longitude 100°17'56.7"E, Salaya, Nakhon Pathom, Thailand.

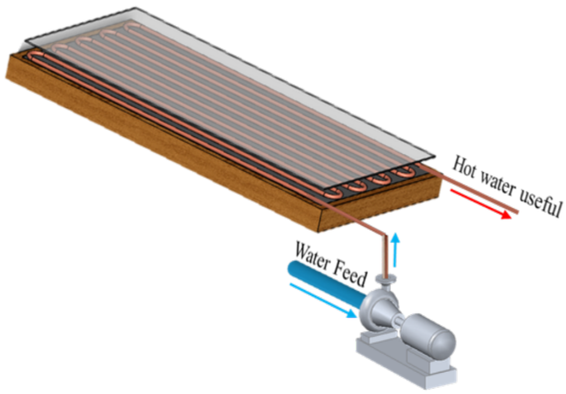

Fig. 1. Diagram of MASWH

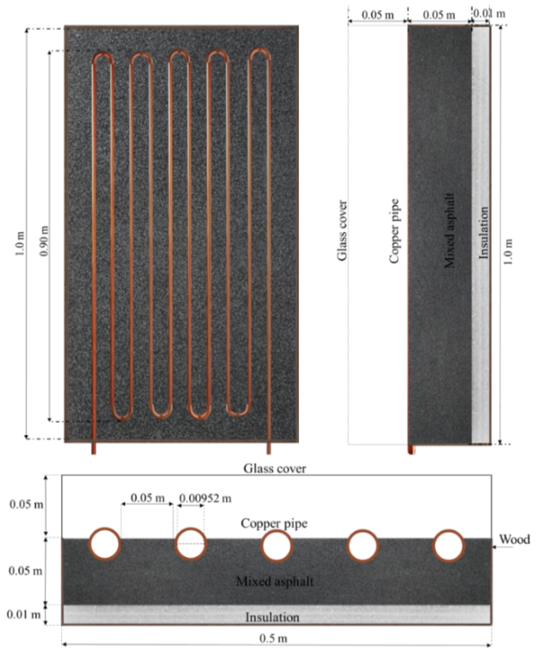

Fig. 2. The schematically of mixed asphalt solar collector

The main frame structure was made from steel. The thermocouples were connected to the data logger (Hioki: Model LR8422–20, ± 0.7%). The thermocouples were used type K (range: 0 – 800 °C, ± 0.4 °C) installed at different positions as shown in Fig. 3. The measure of solar radiation was used pyranometer and installed on the collector (Kipp & Zonen), Model: CMP11, range: 310 –2800 µm, < 2%. The flowmeter was used for measure water flow rate (Nitto), Model: Z-5015 accuracy ± 5%. The interval data was recorded every 1 minute during 6:00 to 18:00. This experimental study was conducted on the rooftop of Faculty of Architecture and Design, Rajamangala University of Technology Rattanakosin, Salaya campus from October 2018 to November 2018.The propose of investigating this condition needs to check the performance of a solar water heater during winter season. The results, shown in this paper, was selected from logical and theoretical information during experiment period.

The specification of various components MASWH were showed in Table 1.

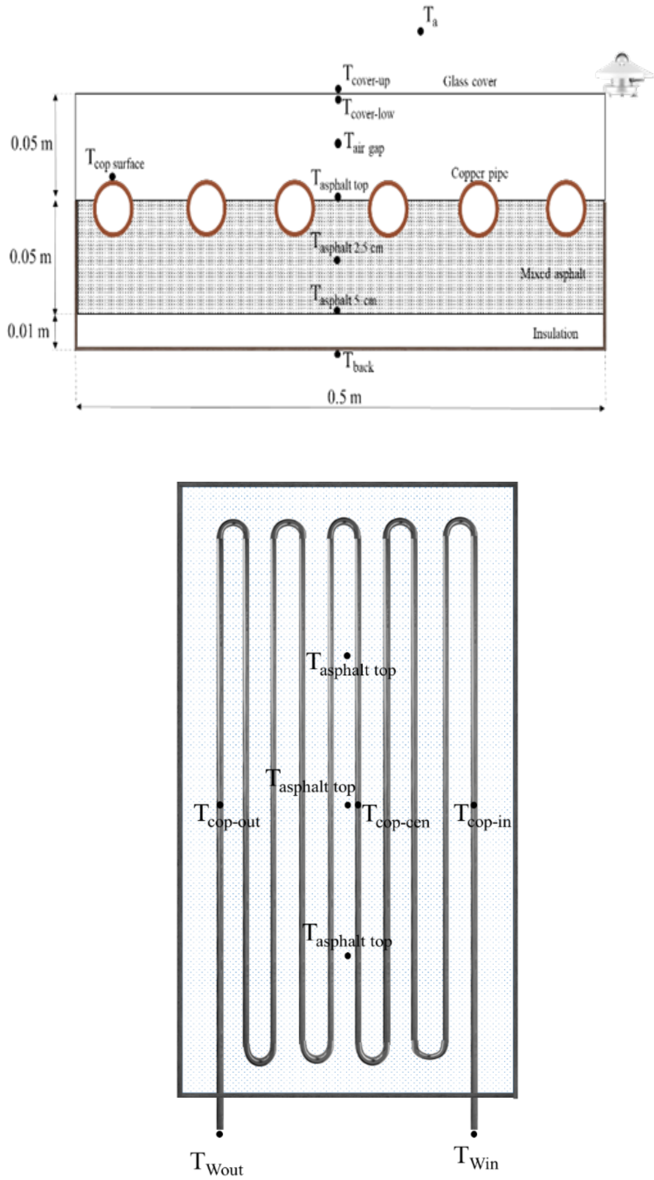

Fig. 3. Position of temperature

Table 1. The specification of various components MASWH

Description	Mixed Asphalt [29]	Coper [31]	Glass [31]	Polyure -thane [31]
Thickness (m)	0.05	0.014	0.004	0.05
Density (kg/m^3)	2300	8960	2.4	18
Specific heat Capacity (J/kg°C)	700	0.39	0.84	0.045
Emissivity	0.93	0.65	0.92	0.1
Thermal Conductivit, k (W/m°C)	0.75	380	1.05	0.026

3. Data Reduction

The useful energy in equation (1) can be explained in term of the energy absorbed and energy lost on absorber plate

$$Q_u = A_c F_R [S - U_L (T_{pm} - T_a)] \quad (1)$$

Where: Q_u is useful energy gain (w), A_c is collector area (m^2), F_R is the collector heat removal factor, S is absorbed solar radiation per unit area (W/m^2), U_L is collector overall heat loss coefficient, T_{pm} is the mean of absorber plate temperature (°C) and T_a is ambient temperature (°C), re-spectively.

The useful gain as calculated by Equation (2) is heat transferred to the fluid. By the fluid inlet to the collector at temperature T_{fi} and the temperature of fluid increases until at the outlet it is T_{fo}, $\dot{m}$ is mass flow rate and C_p is The specific heat of water.

$$Q_u = \dot{m} C_p (T_{f,o} - T_{f,i}) \quad (2)$$

The collector flow efficiency factor F is given as

$$F' = \frac{\frac{1}{U_L}}{W\left[\frac{1}{U_L(D+(W-D)F)} + \frac{1}{C_b} + \frac{1}{\pi D_i h_{f,i}}\right]} \quad (3)$$

Where W is the distance between the tubes, D is the tube diameter, Di is the inside tube diameter, F is fin efficiency and hf,i is the heat transfer coefficient between the tube surface and the fluid. The bond conductance Cb can be estimated from knowledge of the collector efficiency factor and temperature diffusion between tubes.

The relation between the heat removal factor F_R and the collector efficiency factor F' is given as

$$F'' = \frac{\dot{m} C_p}{F' A_C U_L}\left[1 - \exp\left(-\frac{A_C U_L F'}{\dot{m} C_p}\right)\right] \quad (4)$$

The term can be calculated using the collector efficiency factor. the heat removal factor is

$$F_R = \frac{\dot{m} C_p}{A_C U_L}\left[1 - \exp\left(-\frac{A_C U_L F'}{\dot{m} C_p}\right)\right] \quad (5)$$

In equation (3) F is the fin efficiency factor:

$$F = \frac{[(\tanh m(W-D)/2]}{m(W-D)/2} \quad (6)$$

$$m^2 = \frac{U_L}{k\delta} \quad (7)$$

Where k is thermal conductivity of the absorber plate, δ is the thickness of the absorber plate and U_L is collector overall heat loss coefficient. The instantaneous collector efficiency correlates the useful energy to the total solar radiation incident on surface of the collector by Equation (8).

$$\eta_I = \frac{Q_u}{A_C I_t} \quad (8)$$

The absorbed radiation per unit area of solar collector absorber plate (S) is defined by,

$$S = I_t(\alpha\tau) \quad (9)$$

The coefficient top surface loss from the collector is evaluated by considering both convective and radiative from the absorber plate to ambient. Thermal resistance circuit of mixed asphalt solar water heater for single glass cover is shown in Fig. 4.

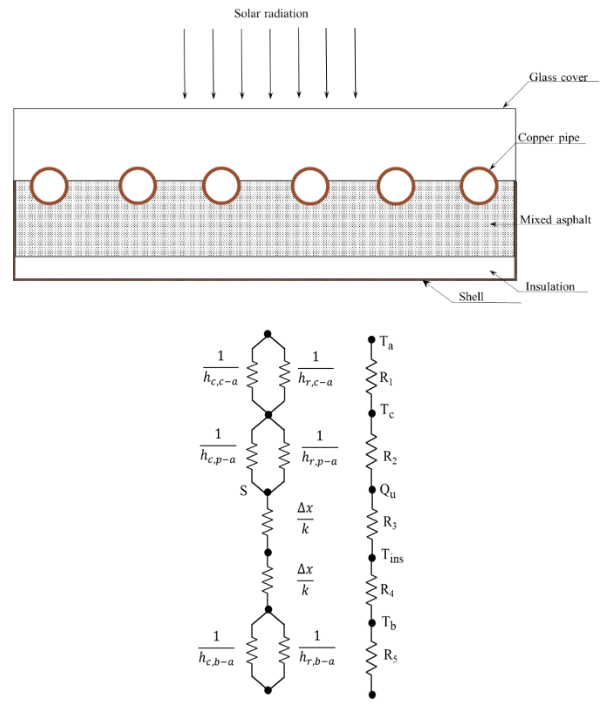

Fig. 4. Thermal network diagram for single glass cover mixed asphalt solar water heater

The resistance to the environment R_1 is then given by

$$R_1 = \frac{1}{h_w + h_{r,c-a}} \quad (10)$$

The resistance R_2 can then be expressed as

$$R_2 = \frac{1}{h_{c,p-c} + h_{r,p-c}} \quad (11)$$

Where $h_{c,p-c}$ is convection heat transfer coefficient between the absorber plate and glass cover (W/m^2 °C) and $h_{r,p-c}$ is radiation heat transfer coefficient between the absorber plate and glass cover (W/m^2 °C), respectively.

The resistance R_3 and R_4 can then be expressed as

$$R_3 = R_4 = \frac{\Delta x}{k} \quad (12)$$

$$R_5 = \frac{1}{h_{c,b-a} + h_{r,b-a}} \quad (13)$$

Where, k is thermal conductivity (W/ m °C) , Δx is thickness of material, $h_{c,b-a}$ is convection heat loss coefficient from back to ambient (W/m^2°C) and $h_{r,b-a}$ is radiation heat loss coefficient from back to ambient (W/m^2°C), respectively.

4. Results and Discussion

4.1 Ambient condition

The experiment conducts on a daily basis from 6:00 to 18:00 with feed water at 0.02 kg/sec into the solar collector panel. The data were recorded in every 1 minute for observing the difference between inlet temperature and outlet temperature of the MASWH. Figure 5 shows the experimental data of summer period and clear sky. Obviously, the ambient temperature and solar radiation are low in the morning (6.00-7.00). On the other hand, the relative humidity shows high values at 90-93%. However, when the ambient temperature and solar radiation increase, the relative humidity is reduced rapidly. The maximum of solar radiation is impacted on the solar collector at 11:30. It shows the maximum value of 1008 W/m^2 and the solar radiation all day has averaged value of 616 W/m^2. Therefore, the solar energy can be utilized effectively. In addition, the ambient temperature ranges from 26 to 36.7 °C, and the daily average is 31.5 °C, which is the optimum temperature for experiment.

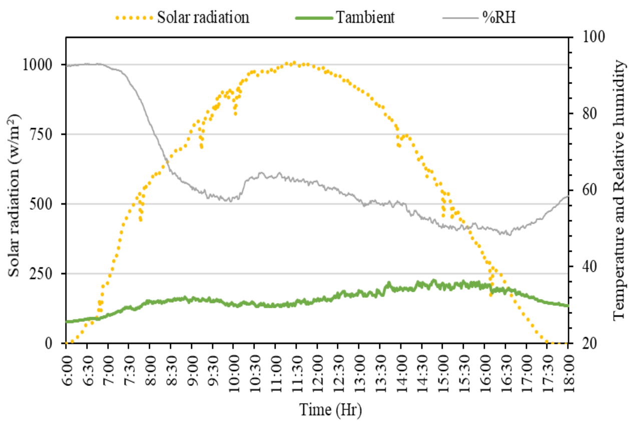

Fig. 5. The variation of relative humidity, ambient temperature and solar radiation.

4.2 Glass cover temperature

Figure 6. shows the upper temperature and lower temperature of glass cover compared with ambient temperature. It can be observed that the lower temperature of the glass surface is more than the upper with maximum value about 5.85 °C at 11:18. From the heat transfer at the upper surface to the lower surface of the glass, the air gap temperature is gradually accumulated heat increases and has a maximum value of 62.35 °C at 12:10. It is found that the air gap temperature is the highest. While the maximum temperature of the upper glass surface is 51.5 °C and the lower surface is 53.7 °C respectively.

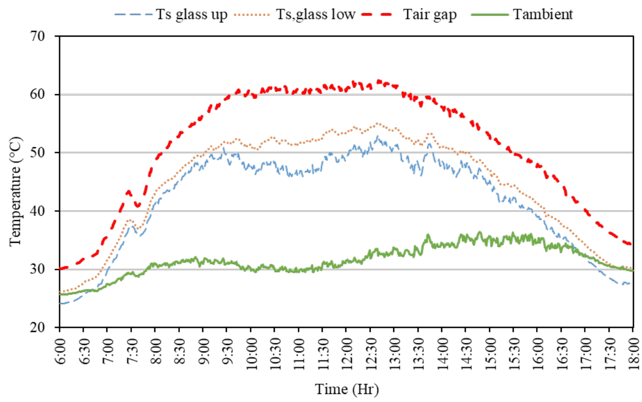

Fig. 6. The variation of glass cover temperature and ambient temperature during the day

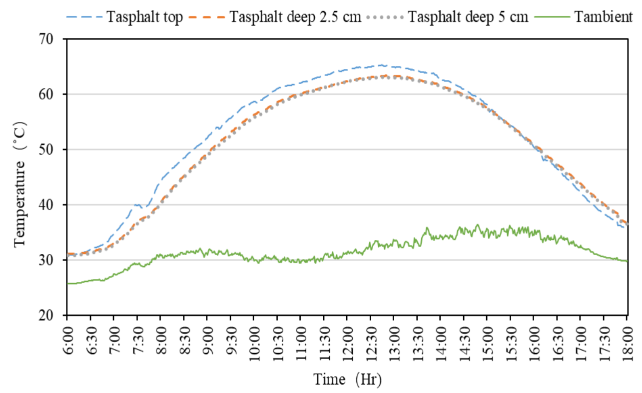

Fig. 7. shows the temperatures of the collectors absorbing plates and the ambient temperature.

4.3 Asphalt temperature

Solar radiation passes through the glass cover to the absorber plate. The temperature of the mixed asphalt in each level is nearly in the morning due to low solar radiation. It is evident from Fig.7 at 6:00 - 18:00 that the surface temperature at the top of the mixed asphalt absorber plate was the highest temperature throughout the day with a maximum temperature of 65.35 ˚C at 12:44. It is gradually decreased when approaching in the evening. The mixed asphalt at a depth of 2.5 cm has a maximum temperature of 63.5 ˚C at 12:54 and at a depth of 5 cm has a maximum of 63.2 ˚C at

12:49. From the behavior of the thermal collector at the top of the mixed asphalt surface was directly area to receive the solar radiation, resulting in the highest average daily temperature of 52.4 ˚C, the depths of 2.5 cm shows 51.15 ˚C and 5 cm shows 50.1 ˚C, respectively. Therefrom, the accumulated heat in the mixed asphalt is transferred to the copper pipe surface as shown in Fig. 8.

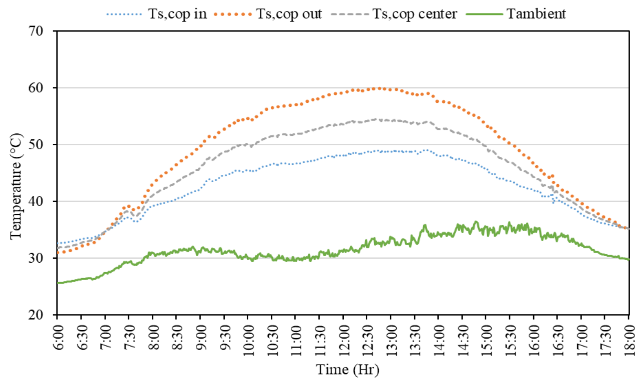

Fig. 8. The temperatures of the copper surface and the ambient temperature.

4.4 Copper surface Temperature

The copper pipes are embedded in the mixed asphalt, approximately ¾ of the copper pipes, resulting in the copper pipes heated from the mixed asphalt heat transfer to the copper pipe surface and some parts of the copper pipe are heated by the solar radiation. The temperature at the surface of the inlet and middle copper pipe, when the water temperature is low, draws the heat from the surface of the pipe. Therefore, the maximum inlet temperature is 49.1 ˚C at 12:20 and the average temperature throughout the day is about 42.8˚C. In the middle of the copper surface pipe, the maximum temperature is 54.5 ˚C at 12:41 and the average temperature throughout the day is approximate 45.9˚C. While the outlet surface of the copper pipe has a maximum temperature of 60 ˚C, the average temperature at 12:41 throughout the day is 49.1 ˚C. Because the water can be drawn heat from the surface of copper pipes, the entrance and the middle of the panel are quite high. As a result, the surface temperatures of the inlet and middle are lower than the surface temperature of the outlet copper pipe as shown in Fig. 8.

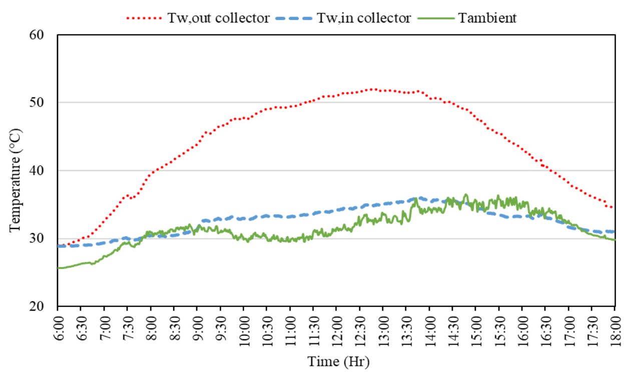

Fig. 9. The temperatures of the Water inlet, outlet and the ambient temperature.

4.5 Water temperature inlet, outlet

For this experiment, the water inlet to the copper pipe uses feed water at a flow rate 0.02 kg/sec as shown in Fig. 9. Obviously, the maximum outlet water temperature at 12:41 shows water temperature of 52 °C when there was a solar radiation of 946.29 W/m^2. The inlet water has the maximum temperature of 36.1 °C at 13:50. From the outlet water temperature increase, the maximum temperature difference between the water inlet and the outlet is 17.15 °C at 12:50. After that, the temperature of the water gradually decreases due to the gradual decrease of solar radiation, causing the temperature of the water to decline during the period from 13:30 to 18:00.

4.6 Useful Energy

Figure 10 shows the converted energy to utilization and the influence of solar radiation on the MASWH. The solar energy can be utilized in the range of 100-380 W/m^2 during time 6:20 to 16:00 at the solar radiation incident on the MASWH panel in the range of 200-1000 W/m^2, or in the range of 30-37% of the incident energy on the water heater panel.

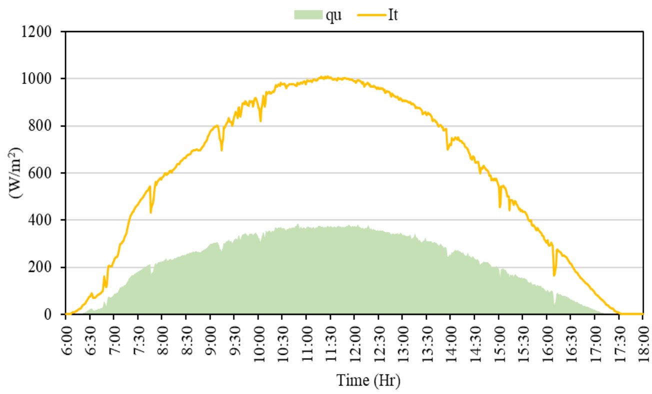

Fig. 10. The useful energy and solar radiation

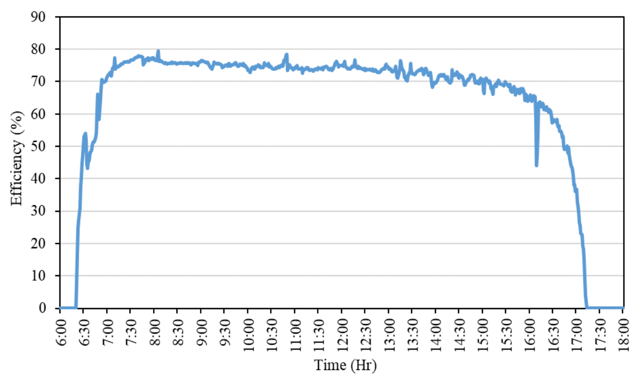

Fig. 11. The Efficiency of MASWH

4.7 Efficiency

The efficiency of a MASWH as shown in Fig. 11. The efficiency is in the range of 70 -79 and the maximum efficiency of the MASWH is 79% at the maximum solar radiation value of 981.04 W/m^2. Hence, the efficiency of the

MASWH varies with the intensity of solar radiation on the MARSH panel.

4.8 Collector Characterizations

Figure 12 shows linear-regression between thermal efficiency of the MASHW (Tin-Ta)/G_T hourly by solving the equation in the order to plot the graph to determine the efficiency and result in the efficiency equation.

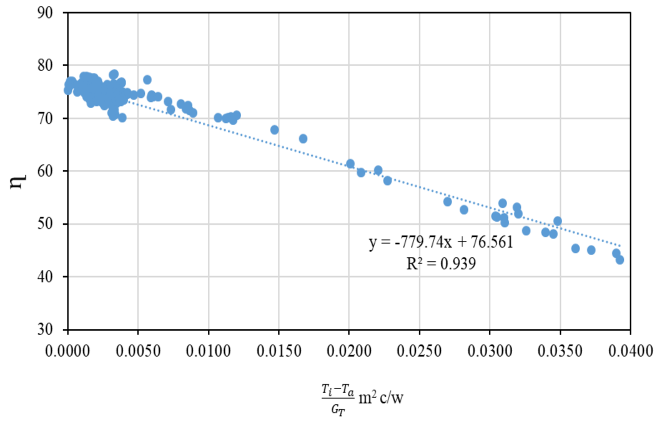

Fig. 12. Collector Characterizations

4.9 Uncertainty analysis

Uncertainty is the imperfection of the various factors of measurement. At each level of measurement, the uncertainty of the measurement will be more or less dependent on the ability to convey the measurement of each task. Uncertainty can occur for many reasons, such as measurement methods, measuring instruments, operators and the environment. The uncertainty analysis is essential to appraise the accuracy of the results from the measure. For this reason, the validity of these data is check, and a detailed methodology for a correct and comprehensive uncertainty calculation is proposed. The uncertainties occurring in a result of calculating (W_R) due to several independent variables as show in Equation (14).

$$w_R = [\left(\frac{\partial R}{\partial x_1} w^1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 \dots + \left(\frac{\partial R}{\partial x_n} w_n\right)]^2 \quad (14)$$

Where the result R is a function in terms of its independent variables as $X_1, X_2, X_3, \dots X_n$, thus $R = R(x_1, x_2, x_3, \dots, x_n)$, $w_1, w_2, \dots, w_n$ are the uncertainties in the independent variables and W_R is the uncertainty of the result.

This study, the temperature water inlet, outlet and flow rate were measured by proper equipment explained formerly. Each calculated and measured parameters uncertainties are using equation (15). The uncertainty evaluates in the temperature water inlet, outlet and flow rate can be given as follows.

$$Q^{\cdot} = f(\dot{m}, c_p, T_i, T_o) \quad (15)$$

$$w_R = [\left(\frac{\partial \dot{Q}_u}{\partial \dot{m}} w_{\dot{m}}\right)^2 + \left(\frac{\partial \dot{Q}_u}{\partial cp} w_{cp}\right)^2 + \left(\frac{\partial \dot{Q}_u}{\partial T_i} w_{T_i}\right)^2 + \left(\frac{\partial \dot{Q}_u}{\partial T_o} w_{T_o}\right)^2]^{1/2} \quad (16)$$

Algebraic manipulation, we obtained

$$\frac{w\dot{Q}_u}{\dot{Q}u} = [\left(\frac{w_{\dot{m}}}{\dot{m}}\right)^2 + \left(\frac{w_{cp}}{c_p}\right)^2 + \left(\frac{w_{To}}{(T_o - T_i)}\right)^2 + \left(\frac{w_{Ti}}{(T_o - T_i)}\right)^2]^{1/2} \quad (17)$$

The total of uncertainties from the measurements are appraised to be ± 0.15 % for inlet water temperature and ± 0.14% for outlet water temperature. The mass flow rate can be calculated from the measured parameters. The analysis of the results shows the mass flow rate of overall accuracy as ±2.1 %.

5. Conclusions

This research attempted to investigate thermal performances of a solar water heater by using mixed asphalt as a solar collector. The results presented heat transfer rate and the MASWH efficiency are depending on solar radiation. It affects the ambient temperature and surface temperature of mixed asphalt. The mixed asphalt can be high thermal storage and because the selector surface of the mixed asphalt is black color and the adhesion of the mixed asphalt is not too dense. Thus, the maximum inlet temperature surface of copper pipe is 49.1 ˚C and the maximum outlet temperature surface of copper pipe is 60 ˚C. As a result of the heat transfer from the mixed asphalt, the maximum water temperature is 52 °C the maximum difference temperature between the water inlet and the outlet is 17.15 ° C (from 34.93˚C to 51.98˚C) or about 48.81%. Therefore, the energy useful is 100-380 W/m^2 or in the range of 30-37% of the solar radiation on MASWH panel. Furthermore, the maximum efficiency of MASHW is in the range of 79%.

In conclusion, the result of MASWH has a high accumulated heat. It has a performance in the range of 70-79%, while the MASWH is area only 0.5 m^2. Undoubtedly, it can be applied to the design for reducing energy consumption in building and industrial.

Acknowledgements

The authors are thankful to Rajamangala University of Technology Rattanakosin, Rattanakosin College for Sustainable Energy and Environment (RCSEE) for providing financial support for this research work. Cordial thanks to Assistant Professor Withaya PUANGSOMBUT (Ph.D.) for his moral and scientific advices in this research.

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