Thermal Performance of Solar Water Heater Integrated Vacuum-tube Collector with Loop Thermosyphon

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Abstract

This paper investigated a thermal performance of solar water heater integrated vacuum-tube collector with loop thermosyphon. Loop thermosyphon was made of copper tube with the inner diameter of 7.94 mm. The lengths of evaporator and condenser sections were 1,200 and 200 mm, respectively. Water was used as working fluid with the filling ratio of 50% of the evaporator section. Loop thermosyphon was contained into vacuum tube with the internal diameter of 34 mm, while the length of vacuum tube was 1,500 mm. In the experimental setup, the tilt of solar collector was at an angle of 14 degrees above the horizontal. The flow rate of inlet water varied from 0.017, 0.033 to 0.067 kg/s. The experimental result showed that when the flow rate of inlet water increased from 0.017 to 0.067 kg/s, the heat flux was increased from 1,676.41 to 4,028.67 W/m^2, and the efficiency of solar collector was increased from 34.48 % to 55.72 %.

Keywords: solar water heater, loop thermosyphon, thermal performance

Introduction

Nowadays the world confronts an energy crisis. Many countries cope with it by launching energy saving campaigns, encouraging people to efficiently consume natural resources, and placing an emphasis on alternative energy research with the aim of reserving the energy for the future. Solar energy is another alternative energy that is paid attention to as it is a huge, clean, and safe energy resource with environmental friendliness. Thailand is located near the equator, getting the heat from the sun throughout the year. Its average solar radiation is 18.2 MJ/m^2/day[1]. As a result, it can be seen that Thailand has potentiality to develop solar energy. Some examples of solar energy development are solar dryer[2-6], solar water heater[7-16], and electricity generation from solar energy.

Earlier, solar water heater was in a flat plate type, which had the limitation. For example, it could not be used when the solar radiation level is low and when there is scale in its tube. Moreover, while its heat absorbing capability is low, the heat loss is high, and its efficiency decreases according to its age. Later, the thermosyphon flat-plate solar water heater has been developed[10-16], solving the inherent limitation of the flat plate solar water heater. This type of solar water heater can be used on the day the low solar radiation intensity as the vacuum tube can receive both of ultraviolet and infrared. There is no scale problem as there is heat transfer at the upper part of the tube (condenser section). This type of solar water heater provides more heat than the flat plate type. However, it has some drawbacks including the limitation of thermosyphon that transfers the heat from the evaporator section to the condenser section. This limitation is called flooding limit caused by the high axial heat flow leading to a high relative velocity between the counter current vapor and liquid flows, and consequently an increase of the shear stresses at the vapor/liquid interface. Thus, instability of the liquid flow is created, which leads to entrainment of liquid. The entrained liquid is transported to the condenser by the vapor flow and is collected there. The high shear stresses can cause the returning condensate

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flow to be completely stopped. Then the condensate flow breaks up at the flooding point. In any case, the intense entrainment of flooding causes an insufficient liquid supply to the evaporator. This leads to a local dryout and a complete dryout of the evaporator.

The research studies the thermal performance of solar water heater integrated vacuum tube collector with loop thermosyphon. Loop thermosyphon is a heat transfer device with very high thermal conductance and no additional power input to the system. Thermosyphon is operated by heat transfer from latent heat of vaporization of working fluid inside the tube. The working fluid was vaporized by receiving heat from heat source and condensed by removing the heat from heat sink. Its efficiency is higher than that of the thermosyhon because there is no limitation of counter flow effect between the vapor from the evaporator section and the liquid condensation from the condenser section.

Experimental

Figure 1 shows solar water heater integrated vacuum tube collector with loop thermosyphon, consisting of vacuum tubes with the external diameter of 47 mm., internal diameter of 34 mm., and the length of 1,500 mm. Loop thermosyphon was made of copper tube with the internal diameter of 7.79 mm. The evaporator section length was 1,400 mm. while its condenser section length was 200 mm. (shown in Figure 2). The working fluid was water with the filling ratio of 50% of the evaporator section. The solar collector was faced south and inclined 14° up from the horizontal plane since Nakhon Pathom province in Thailand, the location of the test set, is at 14°N latitude and 100°E longitude.

The schematic diagram of experimental setup is shown in Fig. 3. The setup was comprised of a vacuum-tube collector, a loop thermosyphon, a pump, a water tank, a flow meter, and a data logger (Yokogawa MW-100, accuracy ±0.1°C. Eleven Chromel-Alumel thermocouples (Omega, type K, accuracy ±0.5°C) were connected to the data logger in order to measure positions as follows: $T_{e,1}$-$T_{e,3}$ in the middle of the evaporator section, $T_{c,1}$-$T_{c,3}$ in the middle of the condenser section, and T_a outside the collector to measure ambient air temperature. In addition, four thermocouples were used to measure the temperature of the cooling water: two at the inlet and two at the outlet section of manifold header to monitor the temperature difference in order to calculate the heat transfer rate per unit area of the condenser section by using the calorific method, as shown in the following equation:

$$q = \frac{\dot{m}C_p\left(T_{out} - T_{in}\right)}{A_{cond}} \quad (1)$$

Where

q = heat transfer rate per unit area of the condenser section, (W/m^2)

$\dot{m}$ = mass flow rate of the cooling water, (kg/s)

c_p = specific heat of the cooling water, (J/kg.K)

$T_{out} - T_{in}$ = temperature difference of inlet and outlet of the cooling water, (K)

A_{cond} = surface area of the condenser section, (m^2)

The efficiency of the collector can be calculated from Equation (2).

$$\eta = \frac{\dot{m}C_p(T_{out} - T_{in})}{I_T A_c} \times 100 \quad (2)$$

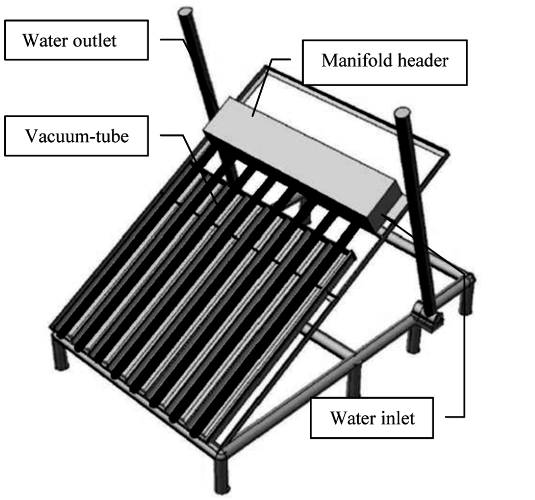
Where

η = collector efficiency (%), and

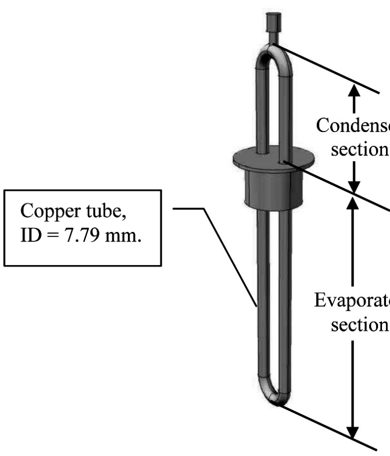
I_T = solar radiation on tilted surface (W/m^2).

A_c = surface area of the collector (m^2)

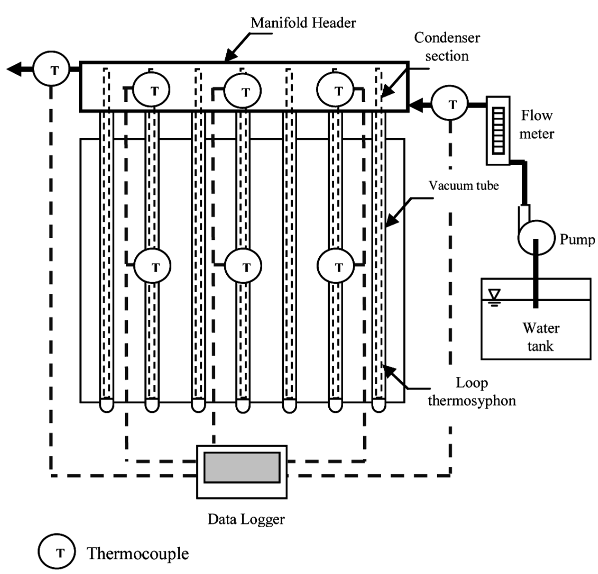
The experimental procedure was started by establishing the experimental setup as shown in Fig. 3, then recording temperature at each part of the solar collector in every minute. The water temperature differs between inlet and outlet water was used to calculate heat transfer rate per unit area of the condenser section as indicated in equation (1). The experiments were conducted during 9.00 a.m. – 5.00 p.m. by varying the inlet water flow rate of 0.017, 0.033 and 0.067 kg/s.



Figrue 1 Components of solar water heater integrated vacuum tube collector with loop thermosyphon



Figrue 2 Loop thermosyphon

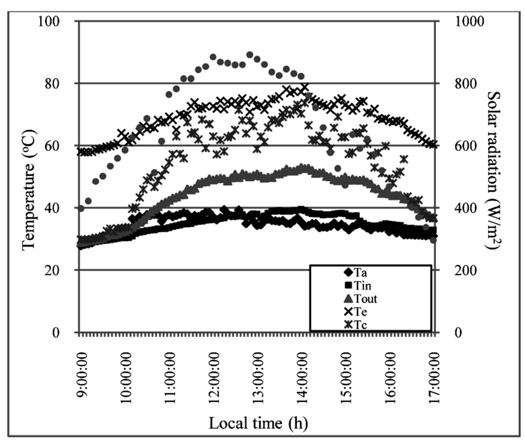


Figrue 3 Experimental setup

Results and Discussions

The results show the thermal performance of solar water heater integrated vacuum tube collector with loop thermosyphon. The flow rate of inlet water was set to be 0.017, 0.033, and 0.067 kg/s. The experiment was conducted from January 15 to March 10, 2012 on the eight floor of the Faculty of Engineering and Industrial Technology, Silpakorn University from 9.00 am to 5.00 pm.

Figure 4 shows the results on January 16, 2012. The solar radiation was unstable with the average of 652.54 W/m^2, while the highest solar radiation was at 891.29 W/m^2 measured at 12.50 pm. From the graph, between 9.00 am and 12.50 pm, the solar radiation tended to increase, which made the temperature of the evaporator section, condenser section, and outlet water increase. Later, from 12.50 pm to 5.00 pm, the solar radiation tended to decrease, which reduced the temperature of evaporator section, condenser section, and outlet water as well. The day's average temperature of the evaporator section was 68.90 ºC, with its highest temperature measured at 2.03 pm of 79.10 ºC. The day's average temperature at the condenser section was 51.40 ºC, with its highest temperature measured at 2.07 pm of 72.40 ºC. The day's average temperature of the outlet water was 44.30 ºC with its highest temperature measured at 2.04 pm of 53.50 ºC.

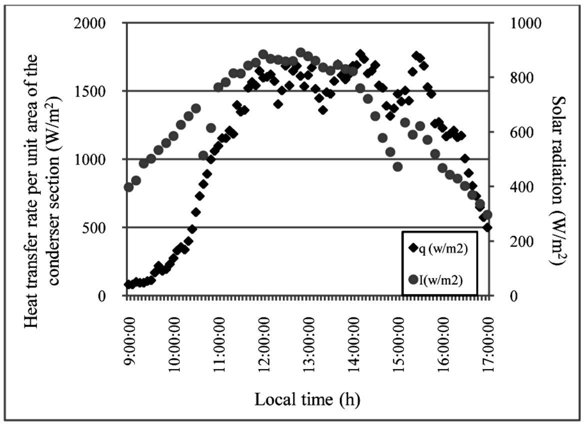


Figrue 4 The relationship of temperature, solar radiation, and time at the flow rate of 0.017 kg/s.

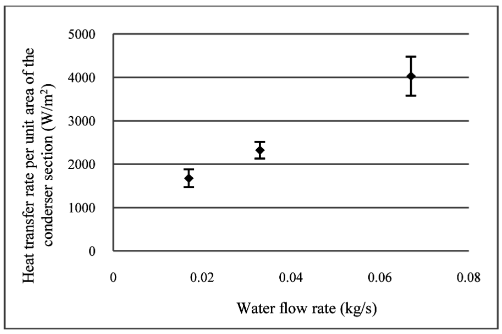
It could be seen that the temperature at various sectors of solar water heater integrated vacuum tube collector with loop thermosyphon increased because of the solar radiation falling on the vacuum tube. This tube absorbed the heat from the solar radiation and sent the heat to the evaporator section of loop thermosyphon contained in the vacuum tube. When the evaporator section of the thermosyphon received the heat, the working fluid in the tube whose state was saturated fluid changed to vapor and flowed up to the condenser section located in the manifold header. The heat in the condenser section was then transferred to the water in the manifold header. After the working fluid with vapor had exchanged the heat, it was condensed to fluid and flowed back to the evaporator section by the gravity force. As seen in figure 4, form 2.00 pm to 5.00 pm. when the solar radiation decreased, the temperature of outlet water from solar heater did not change in line with the solar radiation because the water inside the manifold header collected heat.

The temperature difference between inlet and outlet water of the solar water heater in Figure 4 could be calculated for heat transfer rate per unit area of the condenser section by calorific method as shown in Figure 5.

According to Figure 5, it was found that from 9.00 am to 12.50 pm, the heat transfer rate per unit area of the condenser section increased as the solar radiation increased. However, the heat transfer rate per unit area of condenser section kept increasing although solar radiation decreased because during this time the temperature of evaporator and condenser sections of the thermosyphon and outlet water was stable and did not change with the decrease of the solar radiation. This was because there was the heat collecting of the water in manifold header.



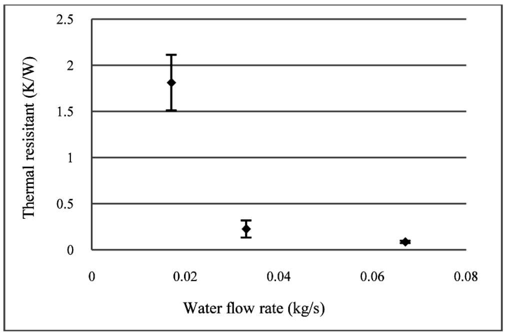
Figrue 5: The relationship of heat transfer rate per unit area, solar radiation, and time at the flow rate of 0.017 kg/s.



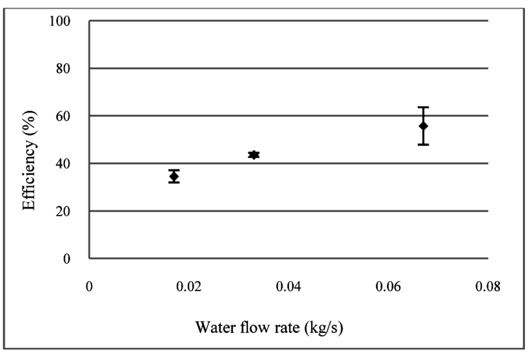
Figrue 6: The relationship between heat transfer rate per unit area of the thermosyphon's condenser section and the water flow rate

Figure 6 shows the results of heat transfer rate per unit area of the condenser section at the various water flow rates with the average solar radiation ranging from 554.193 to 665.908 W/m^2 with the reliability of 99.9%. The graph indicates that when the inlet water flow rate increased, heat transfer per unit area of the condenser section of solar water heater increased. The inlet water flow rate increased from 0.017 to 0.067 kg/s, causing the heat transfer rate per unit area of the condenser section to increase from 1,676.41W/m^2 to 4,028.76 W/m^2. Because of the increase of the inlet water flow rate of solar water heater, the heat releasing at the condenser section of thermosyphon was more efficient, which increased the heat transfer rate per unit area of the condenser section in line with the increase of inlet water flow rate of the solar water heater.

From Figure 7, it was found that when the inlet water flow rate increased, the thermal resistance decreased. The flow rate increased from 0.017 to 0.067 kg/s, contributing to the decrease of thermal resistance from 1.812 to 0.085 K/W.



Figrue 7 The relationship between thermal resistance of solar water heater integrated vacuum-tube collector with loop thermosyphon and water flow rate.



Figrue 8 The relationship between the efficiency of solar water heater and water flow rate

From Figure 8, it was found that when the inlet water flow rate increased, the efficiency increased. The flow rate increased from 0.017 to 0.067 kg/s, contributing to the increase of efficiency from 34.48 to 55.72%. The increase of inlet water flow rate contributed to the increase of efficiency as the increase of the inlet water flow rate could cause the increase of the heat transfer rate of the solar water heater. This contributed to the higher efficiency of the heater.

Conclusion

From investigating the thermal performance of solar water heater integrated vacuum-tube collector with loop thermosyphon, it was found that when the flow rate of inlet water increased, the heat transfer rate per unit area of the condenser section and the efficiency of solar water heater increased, while the thermal resistance of the solar water heater decreased.

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