

A Study on the Heat Exchange Performance of Hybrid Solar Collector with Air to Water Heat Exchanger Type

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Abstract. Solar assisted heat pump system is the heat pump system using solar thermal energy as a heat source of evaporator of the heat pump and most of these systems have been used ordinary solar collector that can get a thermal energy only from solar radiation. Thus, the hybrid solar collector that has air to water heat exchanger of fin-and-tube type have been developed for obtaining thermal energy from not only solar radiation but also ambient air. It is the flat plate solar collector installed fin-and-tube heat exchanger beneath absorbing plate. Thus the thermal energy obtained from ambient air can be supplied to evaporator of heat pump when the solar radiation is not enough. At this time, heat exchange performance between air and circulated water is one of most important factor. Hence, in this study, heat exchange performance of hybrid solar collector and effect of parameters that affect heat exchange performance were investigated experimentally. As a result, heat transfer rate between air and water was shown from 180 W to 820 W and it was increased linearly with increment of temperature difference between inlet air and water. In case of effectiveness, it was shown from 0.5 to 0.6 and it was increased by decrement of air mass flow rate independently on temperature difference between inlet air and water. From these results, heat exchange performance of the collector is considered as a sufficient capacity for applying for heat pump system and it also could be confirmed that optimal operation condition of solar assisted heat pump system integrated with hybrid solar collector need to be established base on the relationship obtained from this research as a further study.

Keywords: Solar thermal energy · Solar assisted heat pump · Flat plate solar collector · Fin-and-tube heat exchanger · Energy saving

Nomenclature

\dot{Q} : Heat transfer rate [W]
 \dot{m} : Mass flow rate [kg/s]
 C_p : Specific heat of heating medium [kJ/kgK]
T: Temperature [°C]

Greek symbols ε : Effectiveness [-]**Subscripts***w*: Water*air*: Air*avg*: Average*in*: Inlet*out*: Outlet

1 Introduction

Solar assisted heat pump system is the heat pump system using solar thermal energy by integrating solar collector. Temperature of heat source for evaporating refrigerant of heat pump system can be increased than traditional heat pump system when the heated water or air by solar collector was used and it lead to the increment of C.O.P. (coefficient of performance) of heat pump system. Besides, utilization of solar energy of collector also can be increased due to the lower operating temperature than traditional solar collector. Hence, many researches about these systems have been conducted [1–3]. However, these systems can be worked when the solar radiation is enough.

Thus, a hybrid solar collector that has air to water heat exchanger of fin-and-tube type for obtaining thermal energy from not only solar energy but also ambient air has been developed [4–6]. This collector is flat plate solar collector and it has fin-and-tube heat exchanger beneath absorbing plate. Therefore, circulated water in the collector can be heated by using thermal energy of ambient air like an outdoor unit of heat pump system when the solar radiation is not enough such as rainy, cloudy day and night. Hence, the heated water by ambient air can be used as a heat source for evaporating refrigerant of heat pump system even the solar radiation is not enough and, at this time, heat exchange performance between air and water in hybrid solar collector is one of most important factor for design heat pump system integrated with this collector.

Thus, in this study, heat exchange performance of hybrid solar collector and effect of parameters that affect heat exchange performance were investigated experimentally.

2 Experimental Apparatus and Method

2.1 Experimental Apparatus

Figures 1 and 2 show the exploded view of hybrid solar collector and fin-and-tube heat exchanger in the collector for experiment. The collector consist of glass cover, absorbing plate, fin-tube heat exchanger, case and two air channel for inlet and outlet air. In case of fin-and-tube heat exchanger, it was installed beneath absorbing plate and heat exchange between air and water occurred by counter flow. Also, thermal energy can be obtained from incident solar radiation and ambient air depend on the weather because of this structure.

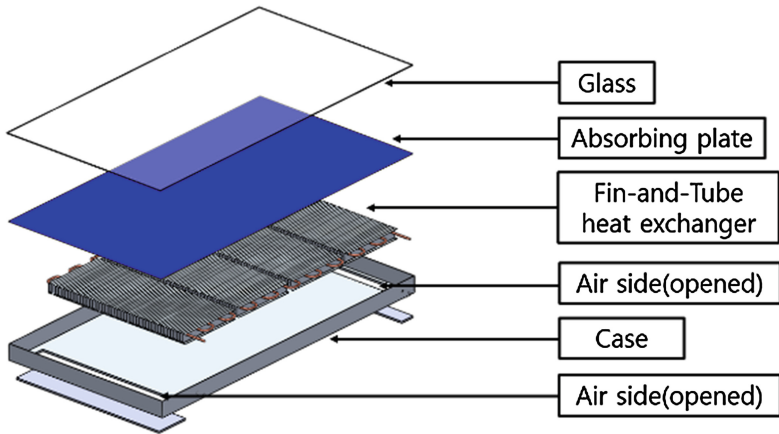


Fig. 1. Exploded view of hybrid solar collector

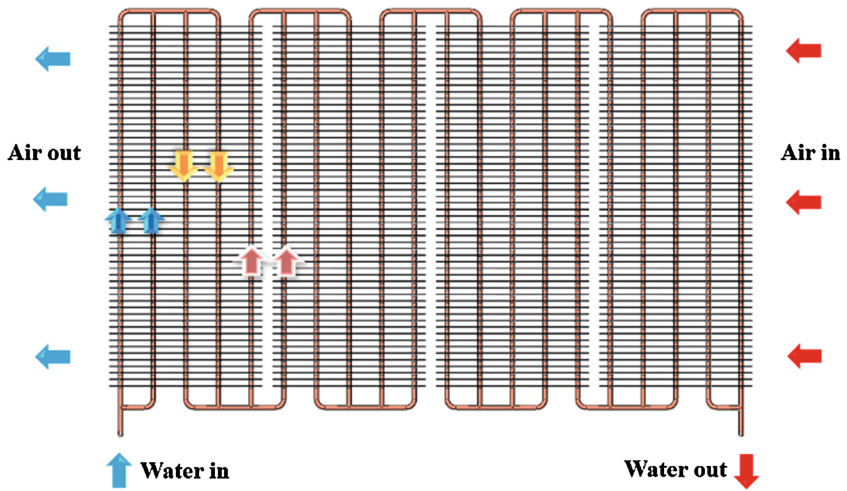


Fig. 2. Fin-and-tube heat exchanger in hybrid solar collector

Actual view of experimental apparatus was shown in Fig. 3. Size of hybrid solar collector is 1800 mm(L) \times 980 mm(W) \times 110 mm(H) and height of fin-and-tube heat exchanger is 50 mm.

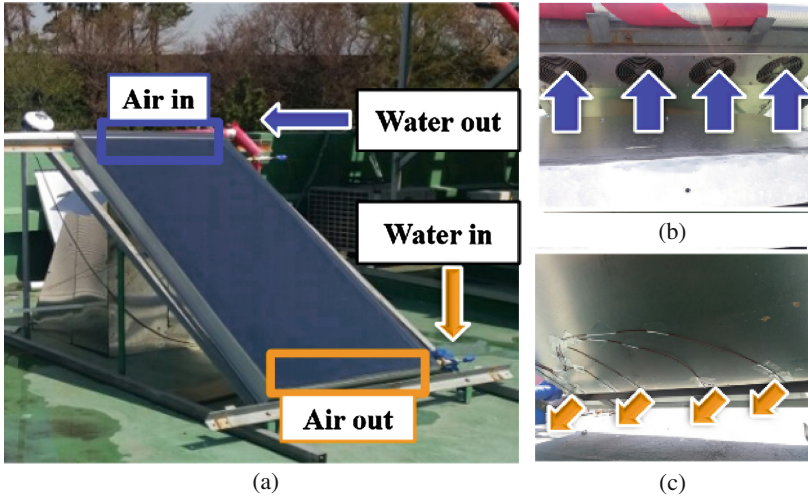


Fig. 3. Actual view of experimental apparatus; (a) hybrid solar collector (b) inlet air side of the collector with blower (c) outlet air side of the collector

2.2 Experimental Method

Experiment for confirming heat exchange performance of the collector was carried out from 19:30 without any incident solar radiation and data was acquired until the temperature difference between inlet air and water reach to 4 °C from 12 °C. Flow rate of water was 5 L/min and volumetric flow rate of air was 230 m³/h, 280 m³/h and 330 m³/h respectively. T-type thermocouple was used to measure the inlet air, outlet air, inlet water, outlet water temperature. All of data were recorded by a data acquisition at an interval of 30 s and more detail experimental conditions are tabled in Table 1.

Table 1. Experimental conditions

| Parameter | Value | |
|---|--|------|
| Install direction of the collector | Installation angle 30°, Azimuth angle 171° | |
| Time (hh:mm) | From 19:30 (without solar radiation) | |
| Collector size | Length (mm) | 1800 |
| | Width (mm) | 980 |
| | Height (mm) | 110 |
| Height of fin-and-tube heat exchanger (mm) | 50 | |
| $T_{w,in} - T_{air,in}$ (°C) | From 12 to 4 | |
| Flow rate of water (L/min) | 5 | |
| Volumetric flow rate of air (m ³ /h) | 230, 280, 330 | |

Heat gain of air and water can be calculated by experimentally acquired data and Eqs. (1) and (2):

$$\dot{Q}_{air} = \dot{m}_{air} C_{p,air} (T_{air,out} - T_{air,in}) \quad (1)$$

$$\dot{Q}_W = \dot{m}_w C_{p,w} (T_{w,in} - T_{w,out}) \quad (2)$$

Average heat transfer rate between air and water can be obtained by Eq. (3):

$$\dot{Q}_{avg} = \frac{\dot{Q}_{air} + \dot{Q}_w}{2} \quad (3)$$

Effectiveness is defined as ratio of actual heat transfer rate to maximum possible heat transfer rate and it can be written as Eq. (4):

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{\dot{Q}}{C_{min} (T_{h,in} - T_{c,in})} \quad (4)$$

At this time, C_{min} means that smaller heat capacity rates between air and water and actual heat transfer rate is average heat transfer rate obtained from experimental data and Eq. (3). Thus, the Eq. (4) can be rewritten as Eq. (5):

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} = \frac{\dot{Q}_{avg}}{\dot{m}_{air} C_{p,air} (T_{w,in} - T_{air,in})} \quad (5)$$

3 Results and Discussion

Figure 4 shows temperature change of air with respect to flow rate of air and temperature difference between inlet air and water. Temperature difference between inlet and outlet air was shown from 2 °C to 7 °C and it was increased linearly with increment of temperature difference between inlet air and water and this value was decreased with increment of flow rate of air. From these results, it could be confirmed that temperature change of air can be predicted on the specific inlet air and water temperature with flow rate of air by the equation of linear curve obtained from experiment.

Temperature change of water with respect to flow rate of air and temperature difference between inlet air and water was shown in Fig. 5. Temperature difference between inlet and outlet water was shown from 0.5 °C to 2 °C lower than air because of higher heat capacity rate and it was also increased linearly with increment of temperature difference between inlet air and water. But, the temperature difference of water was increased with increment of flow rate of air different with air side because the heat transfer performance between air and water was increased with increment of flow rate of air on the constant flow rate of water and it was confirmed that temperature change of water also can be predicted similar with air by the equation of linear curve represent in the Fig. 5.

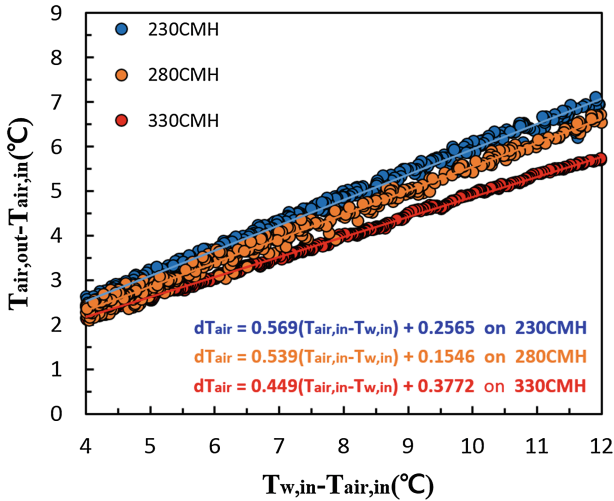


Fig. 4. Temperature change of air with respect to flow rate of air and temperature difference between inlet air and water

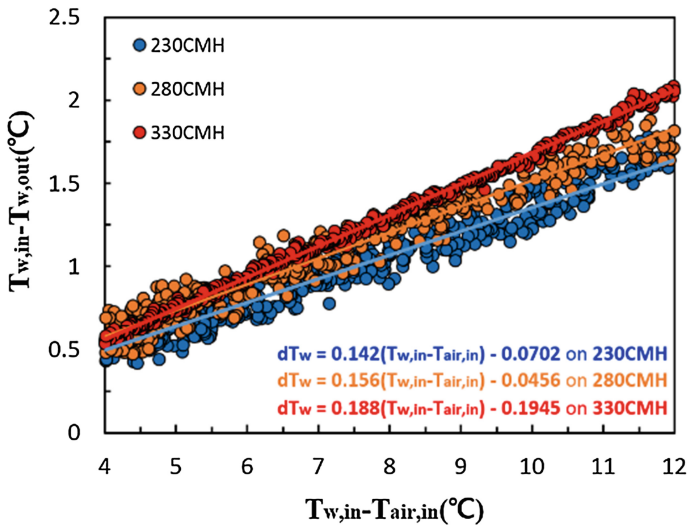


Fig. 5. Temperature change of water with respect to flow rate of air and temperature difference between inlet air and water

Figure 6 shows average heat transfer rate between air and water with respect to flow rate of air and temperature difference between inlet air and water. It was shown from 180 W to 820 W and it was increased with increment of temperature difference between inlet air and water. According to flow rate of air, higher heat transfer rate was obtained on the higher flow rate of air because heat transfer coefficient on outer surface

of tube and fin contacting with flow air is usually improved when the air velocity is increased caused by increment of flow rate of air. In addition, the heat transfer rate was also changed linearly with change of temperature difference between inlet air and water. Thus, the average heat transfer rate also can be estimated on the specific inlet air and water temperature with flow rate of air from the equation of linear curve in Fig. 6.

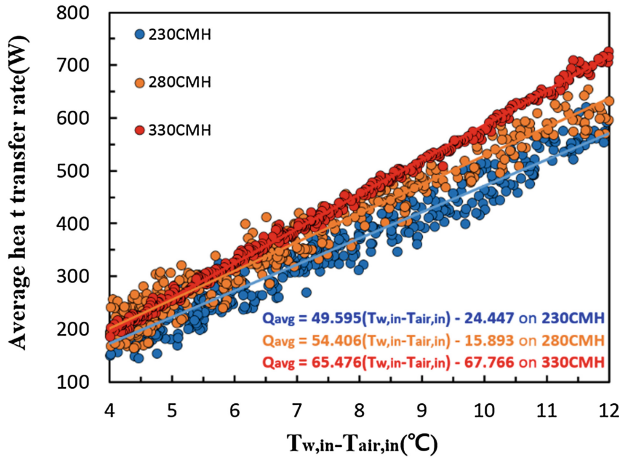


Fig. 6. Average heat transfer rate between air and water with respect to flow rate of air and temperature difference between air and water

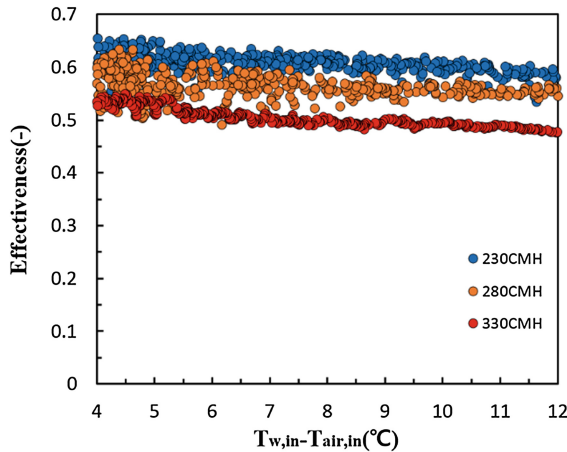


Fig. 7. Effectiveness of hybrid solar collector with respect to flow rate of air and temperature difference between inlet air and water

Effectiveness obtained from acquired data and Eq. (5) was shown in Fig. 7 with respect to flow rate of air and temperature difference between air and water. It was decreased with increment of flow rate of air independently on the temperature difference between inlet air and water. Average values of effectiveness were 0.6073, 0.5626 and 0.5048 on the flow rate of air of 230 m³/h, 280 m³/h and 330 m³/h respectively. Also, heat transfer rate on the specific inlet air, inlet water temperature and flow rate of air can be predicted by these effectiveness using Eq. (5) and also it is considered that these relationship can be used for design solar assisted heat pump system integrated with hybrid solar collector.

4 Conclusion

In this study, Heat exchange performance between air and water in hybrid solar collector that has air to water heat exchanger of fin-and-tube type and the effect of parameters that affect heat exchange performance were investigated experimentally.

As a results, temperature change of air and water and average heat transfer rate were increased linearly with increment of temperature difference between inlet air and water while effectiveness was independent on that parameter. In case of the effect of flow rate of air, temperature change of water and heat transfer rate were increased with increment of flow rate of air due to the increment of heat transfer coefficient of outer surface of tube and fin on the constant flow rate of water. On the contrary to this, temperature change of air and effectiveness were decreased with increment of flow rate of air because of the decrement of heat exchange time in air side.

Also, it was confirmed that temperature change of air and water, heat transfer rate on the specific inlet air and water temperature and flow rate of air can be predicted by the equation obtained from this study and it was considered that these relationship can contribute to design solar assisted heat pump system integrated with this hybrid solar collector. But, the temperature difference between inlet air and water and the flow rate of air can have a more wide range and flow rate of water also can be changed. Thus the relationship between operation condition and heat exchange performance need to be confirmed with the more operation conditions as a further study base of the result of tis research.

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