Experimental study on the heat gain of water in hybrid solar collector integrated with fin-and-tube heat exchanger with respect to air and water flow rate

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Abstract. Solar assisted heat pump system is the system using solar thermal energy that can lead to the improvement of performance of heat pump by transferring solar thermal energy obtained from solar collector to evaporator of the heat pump for evaporation of refrigerant. In traditional system, solar collector can get a thermal energy only from solar radiation. So, the collector is hard to be used when the solar radiation is not enough such as cloudy day or night even though these collector take up much space. Thus the hybrid solar collector that has fin-and-tube heat exchanger have been developed for getting a thermal energy from not only solar radiation but also ambient air. Due to the fin-and-tube heat exchanger, this collector can get a thermal energy from ambient air for heating chilled water by evaporation of refrigerant in heat pump system. At this time, heat gain of water from ambient air by the collector needs to be confirmed before combining with real heat pump system. Thus, in this study, heat gain of water in the hybrid solar collector was investigated experimentally with respect to air and water flow rate on the various temperature difference between inlet air and water. As a results, heat gain of water was shown maximum value of 900W and it was increased with increment of air and water flow rate. Also, heat gain of water was changed linearly with increment or decrement of temperature difference between inlet air and water on the specific air and water flow rate. Furthermore, relationship between heat gain of water and operating conditions was also confirmed that can be used for decision of collector area and heat pump capacity for designing solar assisted heat pump integrated with this collector.

1. Introduction

Solar assisted heat pump system is the system using solar thermal energy by combining traditional heat pump system and solar collector. Thermal energy obtained from solar collector is used for evaporation of refrigerant in the heat pump system and the evaporation temperature can be increased than traditional heat pump system that can lead to the increment of C.O.P.(coefficient of performance). Also, solar collector can be operated with the higher thermal efficiency than traditional solar collector due to the lower operating temperature. Thus the many researches related to solar assisted heat pump system have been conducted for improving the performance of these systems [1-3]. But solar collector
in the traditional solar assisted heat pump system is hard to operating when the solar radiation is not enough even though these collector take up much space.

Thus, the hybrid solar collector that can retrieve thermal energy from not only solar irradiance but also ambient air has been developed [4-6]. This collector is flat plate solar collector that has fin-and-tube heat exchanger installed under the absorbing plate. Thus the circulated water chilled by evaporating of refrigerant in the heat pump system can get a thermal energy from ambient air similar with the outdoor unit of air source heat pump system by the collector when the solar radiation is not enough. Consequently, heated water by ambient air in the collector transfer thermal energy to evaporator of heat pump system as a heat source for evaporation of refrigerant. At this time, heat gain of water from ambient air in the collector needs to be confirmed before apply the hybrid solar collector to the heat pump system.

Thus, in this study, heat gain of water from ambient air in the collector was investigated experimentally with respect to air and water flow rate on the various temperature difference between inlet air and water and the relationship between heat gain of water and inlet fluid temperature difference in the collector was also confirmed on the each air and water flow rate.

2. Experimental apparatus and method

2.1. Experimental apparatus

Hybrid solar collector that has fin-and-tube heat exchanger is composed of glass cover, absorbing plate, fin-and-tube heat exchanger contact with absorbing plate, aluminum case and two open air side for inlet and outlet air as shown in figure 1 and fin-and-tube heat exchanger in the collector was shown in figure 2. Because of this heat exchanger, circulated water chilled by evaporation of refrigerant in the heat pump system can get a thermal energy from the ambient air even though the solar radiation is not enough to heating water.

![Figure 1. Exploded view of hybrid solar collector.](image1)

![Figure 2. Fin-and-tube heat exchanger in hybrid solar collector.](image2)
mode at the Campus of University of Pukyong National University in Busan( at 36°.6.98’N and 129°5.39E).

![Image](a)

![Image](b)

![Image](c)

**Figure 3.** Actual view of experimental setup; (a) hybrid solar collector, (b) Inlet air side, (c) outlet air side.

![Image](d)

**Figure 4.** Schematic view of experimental setup.

2.2. **Experimental method**

Experiment was conducted at night for preventing the effect of solar radiation and data was acquired until the temperature difference between inlet air and water reach to almost 0°C from 16°C.

| Parameter                                | Value                      |
|------------------------------------------|----------------------------|
| Collector size[(Length) x (width) x (height)] | 1810 x 800 x 800 mm        |
| Installation angle                       | 30°                        |
| Height of air channel in fin-and-tube heat exchanger | 50mm                      |
| $T_{\text{air,in}} - T_{\text{w,in}}$   | 4°C - 16°C                 |
| Water flow rate                          | 2L/min, 4L/min, 6L/min     |
| Air flow rate                            | 0.07kg/s, 0.09kg/s, 0.11kg/s |

In case of air, ambient air was used directly and water was chilled by water chiller. Air and water flow rate were 0.07 kg/s, 0.09 kg/s, 0.11kg/s and 2L/min, 4L/min, 6L/min, respectively. Temperature of inlet air, outlet air, inlet water and outlet water were measured by T-type thermocouple and all of data were recorded by a data acquisition at an internal of 20s. More detail experimental conditions are tabled in table 1.

3. **Results and discussion**
Heat gain of water from ambient air by the collector with respect to water flow rate and inlet fluid temperature difference was shown in figure 5 with the air flow rate of 0.07 kg/s. Heat gain of water obtained from the collector was shown from almost 0 to maximum value of 600W and it was increased with increment of water flow rate and inlet fluid temperature. Also, linear change of heat gain of water with the change of inlet fluid could be confirmed.

![Figure 5](image)

**Figure 5.** Heat gain of water with respect to water flow rate and inlet fluid temperature difference($\dot{m}_{air}=0.07$kg/s).

In case of the air flow rate of 0.9 kg/s, all of heat gain of water by the collector was increased compare with the case of air flow rate of 0.7 kg/s on the same conditions as shown in figure 6 and maximum value of 800W was obtained. In addition, the improvement of the heat gain of water by the collector with increment of inlet fluid temperature difference was also confirmed.

Heat gain of water with the air flow rate of 0.11 kg/s was shown in figure 7. Maximum value of the heat gain of water was shown 900W and all of heat gain of water by the collector was higher than other lower air flow rate conditions on the same water flow rate and inlet fluid temperature difference similar with previous results. But the lower effect of water flow rate on the heat gain of water by the
collector was also confirmed from the decrement of increase ratio of heat gain of water to increment of water flow rate.

![Figure 7](image.png)

**Figure 7.** Heat gain of water with respect to water flow rate and inlet fluid temperature difference ($\dot{m}_{\text{air}}=0.11\,\text{kg/s}$).

At this time, relationship between heat gain of water by the collector and operation conditions such as air and water flow rate, inlet fluid temperature difference needs to be confirmed for designing heat pump system integrated with this collector.

| $\dot{m}_{\text{air}}$ | $\dot{m}_{\text{w}}$ | 2 L/min | 4 L/min | 6 L/min |
|-----------------------|-----------------|---------|---------|---------|
| 0.07 kg/s             | $Q_{\text{w}}=31.84(T_{\text{air, in}}-T_{\text{w, in}})+2.11$ (R$^2=0.984$) | $Q_{\text{w}}=36.43(T_{\text{air, in}}-T_{\text{w, in}})+14.44$ (R$^2=0.967$) | $Q_{\text{w}}=39.82(T_{\text{air, in}}-T_{\text{w, in}})+23.51$ (R$^2=0.844$) |
| 0.09 kg/s             | $Q_{\text{w}}=35.42(T_{\text{air, in}}-T_{\text{w, in}})+1.48$ (R$^2=0.987$) | $Q_{\text{w}}=43.40(T_{\text{air, in}}-T_{\text{w, in}})+3.62$ (R$^2=0.981$) | $Q_{\text{w}}=46.10(T_{\text{air, in}}-T_{\text{w, in}})+22.85$ (R$^2=0.923$) |
| 0.11 kg/s             | $Q_{\text{w}}=39.78(T_{\text{air, in}}-T_{\text{w, in}})-4.54$ (R$^2=0.990$) | $Q_{\text{w}}=49.20(T_{\text{air, in}}-T_{\text{w, in}})+4.43$ (R$^2=0.974$) | $Q_{\text{w}}=48.67(T_{\text{air, in}}-T_{\text{w, in}})+28.13$ (R$^2=0.976$) |

Table 2. Correlation of heat gain of water with inlet fluid temperature difference.

Thus the relationship between heat gain of water and inlet temperature difference was confirmed on the specific air and water flow rate as shown in table 2 and it was expected that these equations obtained from experiment can be used for decision of the collector area, heat pump capacity of solar assisted heat pump system integrated with this hybrid solar collector that has fin-and-tube heat exchanger.

4. Conclusion

In this study, heat gain of water from ambient air by the hybrid solar collector that has fin-and-tube heat exchanger was investigated experimentally with respect to air and water flow rate with various inlet fluid temperature difference. As a result, heat gain of water was shown maximum value of 900W and it was increased with increment of air and water flow rate and inlet fluid temperature difference.
Also linear change of heat gain of water with increment or decrement of inlet fluid temperature difference was confirmed on the specific air and water flow rate.

Furthermore, from these results, the relationship between heat gain of water and inlet fluid temperature difference was confirmed on the specific air and water flow rate and it was expected that the relationship obtained from this study contribute to better design for solar assisted heat pump system integrated with this hybrid solar collector including decision of collector area, heat pump capacity and so on.

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