Numerical Analysis on Thermal Efficiency of Hybrid Solar Collector with Fin-and-Tube Heat Exchanger

H. U. Choi, R. Fatkhur, C. H. Son, J. I. Yoon, Y. B. Kim, and K. H. Choi

***Abstract*—A solar assisted heat pump system uses solar thermal energy as a heat source for evaporator in the heat pump by applying solar collector. The COP (coefficient of performance) of the heat pump can be increased when the evaporating temperature increases. The efficiency of the solar collector can be increased because it has lower operating temperature compare to traditional solar collector. Thus, as a part of these researches, a hybrid solar collector that has fin-and-tube heat exchanger has been developed. This collector is flat plat solar collector that can get thermal energy from ambient air for heating the circulating water in the collector by heat exchanging between the air and water side in fin-and-tube heat exchanger. This heated water can be used as heat source of the evaporator in the heat pump even if the solar energy is not enough. So, in this study, an numerical analysis was conducted for confirming the heat gain and pressure drop of water in the collector when the solar energy was provided. As a result, lower thermal efficiency and higher overall heat loss coefficient were obtained when the air channel of the fin-and-tube heat exchanger was opened. But, in case of the closed air channel type, similar maximum thermal efficiency and slightly higher overall heat loss coefficient was obtained. Thus, the significant effect of open and close of the air channel on thermal efficiency was confirmed, and the lower pressure drop of the water side was confirmed with similar thermal efficiency on two row distribution type tube compared to the traditional series type tube. So, it is confirmed that the closed air channel with two row distribution tube can be regarded as proper type.**

***Index Terms*—Solar thermal energy, flat plate solar collector, solar assisted heat pump, fin-and-tube heat exchanger.**

I. Introduction

For increasing the usage of the solar thermal energy, many researches already conducted research and one of these study is a solar assisted heat pump system [1]-[3].

This system uses the solar thermal energy as heat source of the evaporator in the heat pump. So the COP (coefficient of performance) of heat pump can be increased when the evaporating temperature is higher than that of traditional system. And the collector efficiency also can be increased when the operating temperature is lower than that of traditional collector. But these systems are hard to be operated when the solar energy is not enough to operate the system, such as cloudy, rainy day and at night.

Thus, a hybrid solar collector that can give the thermal energy to circulating water in the collector through the ambient air has been developed [4]-[7]. This collector has a fin-and-tube heat exchanger beneath absorbing plate, so circulating water of the collector can get the thermal energy from the ambient air. The water gets the thermal energy from the ambient air and it can be used as the heat source for evaporator in the heat pump when the solar radiation is not enough like outdoor unit of traditional heat pump system. And also, when the solar radiation is enough to heating water, hot water made from this collector using solar energy can be used as heat source for evaporator in the heat pump system similar with traditional solar assisted heat pump system.

In this study, thus, the thermal efficiency and pressure drop of water in the collector were investigated at the same time for three cases based on numerical analysis, and it aims to accumulate a basic data and to find a proper type of collector for real product by considering both thermal efficiency and pressure drop.

II. Numerical Model and Methods

A. Hybrid Solar Collector

The hybrid solar collector that has fin-and-tube heat exchanger composes of a glass cover, absorbing plate, fin-and-tube heat exchanger, case and many air channels. The fin-and-tube heat exchanger was installed near under absorbing plate of the collector. Thus, circulating water of the collector can get the thermal energy from the ambient air when the solar radiation is not enough and the material of glass cover, absorbing plate, copper pipe and the plate fin were defined by the glass, copper, copper and aluminum respectively.

The schematics of the hybrid solar collector for analysis has shown in Fig. 1, and Fig. 2 shows a schematic view of series type and two row distribution type tube in the fin-and-tube heat exchanger in the collector.

Also simulation was conducted for three cases of the collector according to the open and close of the air channel of collector and the tube type in fin-and-tube heat exchanger. Each case of the collector was tabled in Table I for simulation.

TABLE I: Three Case of Hybrid Solar Collector for Simulation

	Air channel	Tube
Case A	Open	Series type
Case B	Close	Series type
Case C	Close	Two row distribution type

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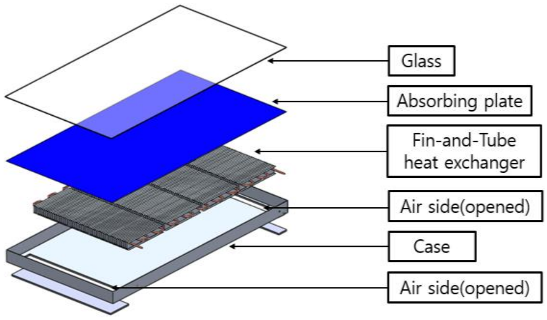
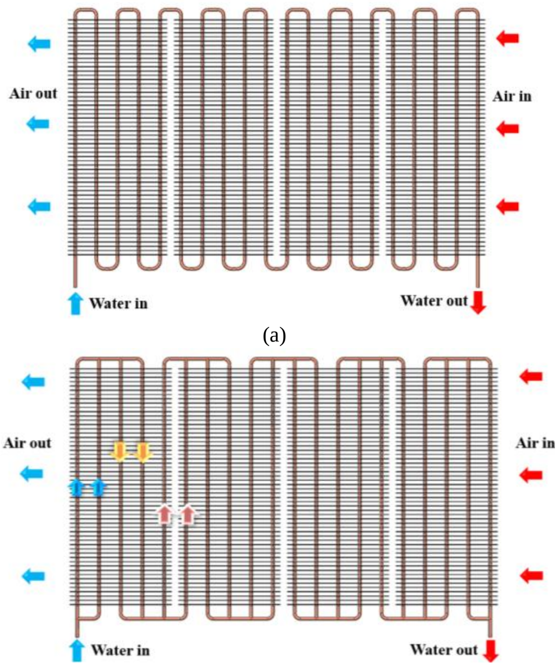


Fig. 1. Exploded view of hybrid solar collector with a fin-and-tube heat exchanger.



(b)

Fig. 2. Tube types of fin-and-tube heat exchanger in hybrid solar collector: (a) series type and (b) two row distribution type.

B. Simulation Method

In this study, the constant thermal supplying was given to the absorbing plate instead of solar irradiance and the quantity of thermal supplying on absorbing plate can be expressed as multiplication of the solar intensity G, transmission coefficient of glazing, τ, and the absorption coefficient of the absorbing plate, α, as follows:

$$Q_{ab} = G\tau\alpha \tag{1}$$

The convection heat transfer coefficient on the top and bottom side of the collector used in this study can be expressed by equation (2), (3) for considering heat loss [8],

$$h_t = 5.7 + 3.8V \tag{2}$$

$$h_b = 2.8 + 3.0V \tag{3}$$

Useful energy gain of the collector is heat gain of water passing through the tube and it can be obtained from simulation results and equation (4).

$$Q_u = \dot{m}C_p(T_{out,water} - T_{in,water}) \tag{4}$$

Thermal efficiency of collector is defined as the ratio of the useful energy gain to the solar irradiance and it can be obtained from simulation results and equation (5) mentioned as "Hottel-Whillier-Bliss equation" [9].

$$\eta = \frac{Q_u}{GA_c} = F_R\tau\alpha - F_R U_L\left(\frac{T_{in,water} - T_{amb}}{G}\right) \tag{5}$$

In equation (5), A_c is the area of absorbing plate, F_R is the heat removal factor of collector that means the ratio of actual useful energy gain to maximum possible useful energy gain in the collector, U_L is overall heat loss coefficient of collector and T_{amb} is ambient temperature.

In addition, other simulation conditions for hybrid solar collector model including geometric and boundary conditions were tabled in Table II.

TABLE II: SPECIFICATION OF HYBRID SOLAR COLLECTOR AND SIMULATION CONDITIONS

Parameter		Specification
Collector size	Length(mm)	1790
	Width(mm)	980
	Height(mm)	100
Inner diameter of tube(mm)		8.5
Outer diameter of tube(mm)		9.5
Fin	Height(mm)	50
	Pitch(mm)	15
Solar intensity(W/m^2)		800
Area of absorbing plate(m^2)		1.645
Flow rate of water(L/min)		4, 6
Temperature	Ambient(℃)	10
	Initial temperature of solid(℃)	10
	Inlet water(℃)	10, 18, 26, 34, 42, 50
$(T_{in,L}-T_a)/G$		0, 0.01, 0.02, 0.03, 0.04, 0.05

III. RESULT AND DISCUSSION

The collector thermal efficiencies of the open and close of the air channel with series type tube of fin-and-tube heat exchanger were shown in Fig. 3 and Fig. 4 respectively.

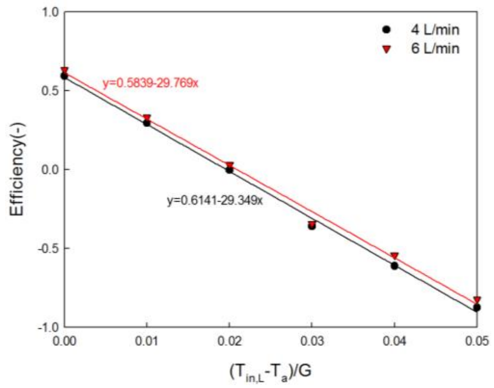


Fig. 3. Thermal efficiency of hybrid solar collector with series type tube and open air channel.

In the case of the open air channel, the lower maximum thermal efficiency of 0.6141 and higher heat loss coefficient of 29.349 on 4L/min were obtained highly compared to traditional flat plate solar collector. It was caused by heat exchange between outdoor air and circulating water in the fin-and-tube heat exchanger occurred by open air channel. But the similar maximum thermal efficiency of 0.7307 and heat loss coefficient of 4.4975 with traditional flat plate solar collector on 4L/min were obtained when the air channel was closed well, even if the fin-and-tube heat exchanger was installed in the collector.

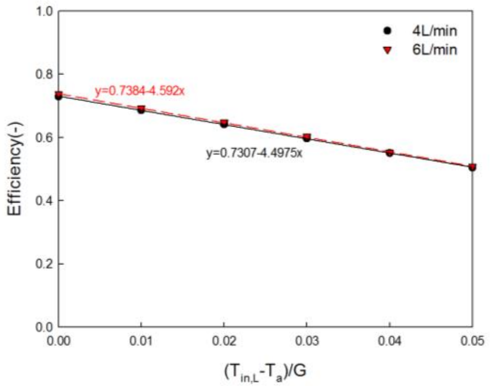


Fig. 4. Thermal efficiency of hybrid solar collector with series type tube and closed air channel.

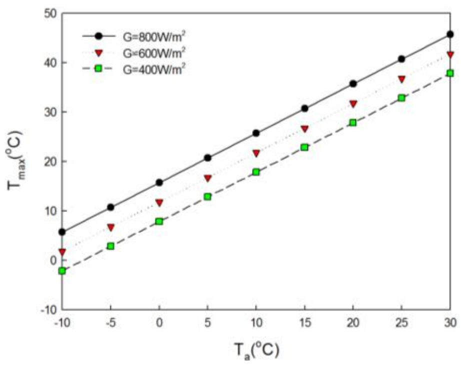


Fig. 5. Theoretical value of maximum temperature of water that can be reached by collector with open air channel and series type tube.

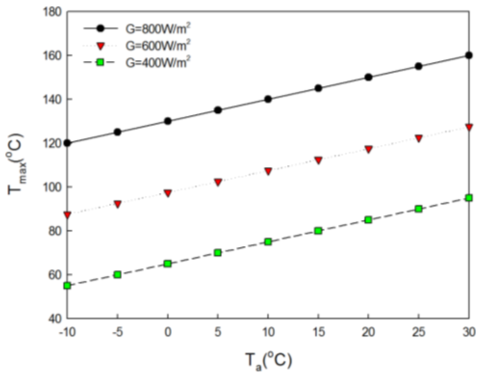


Fig. 6. Theoretical value of maximum temperature of water that can be reached by collector with closed air channel and two row distribution type tube.

The theoretical values of maximum temperature of water that can be reached by the collector with respect to ambient temperature and solar radiation were shown in Fig. 5 and Fig. 6. From these results, it was confirmed that the thermal efficiency of collector with open air channel is not enough to make hot water for hot water supply or space heating using only this collector. On the contrary, the thermal efficiency of collector with closed air channel is enough to make hot water for hot water supply and space heating using only this collector.

Thus, the significant effect of the open and close of the air channel was confirmed and it is considered that the open and close way of the air channel in this collector should be discussed sufficiently afterward.

Fig. 7 has shown the thermal efficiency of the collector when the air channel was closed with two row distribution type tube, and the pressure drop while water passing through the tube of fin-and-tube heat exchanger in the collector was shown in Fig. 8.

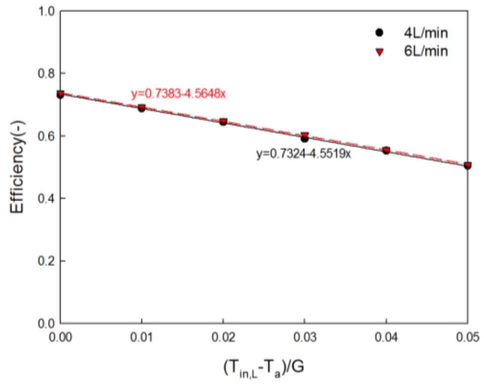


Fig. 7. Thermal efficiency of hybrid solar collector with two row distribution type tube.

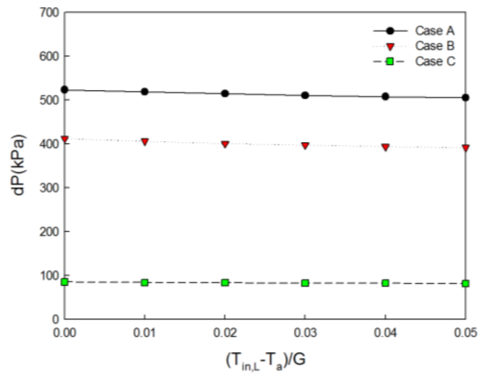


Fig. 8. Pressure drop of water according to collector type.

As a result, the similar maximum thermal efficiency of 0.7324 and the heat loss coefficient of 4.5519 with series type tube on 4L/min were obtained when the only tube changes into two row distribution type and the air channel was closed. However, as shown in the pressure drop, lower pressure drop of the water side was confirmed by changing tube in the fin-and-tube heat exchanger from series type to two row distribution type on the similar thermal efficiency. It was caused by the decrease of velocity of flow water on the same volumetric flow rate by distribution of tube.

Thus the tow row distribution type of tube of fin-and-tube heat exchanger in this collector was confirmed as proper type compare with series type tube considering both thermal efficiency and pressure drop.

IV. CONCLUSION

In this study, the thermal efficiency and pressure drop of the hybrid solar collector with the fin-and-tube heat exchanger were investigated for combining the heat pump system according to open and close of air channel and tube type of fin-and-tube heat exchanger.

As a result, the lower maximum thermal efficiency and higher overall heat loss coefficient were confirmed when the air channel was opened. On the contrary to this, the similar maximum heat transfer coefficient and overall heat loss coefficient were obtained when the air channel was closed well irrespective of tube type. Thus, the significant effect of the open and close of the air channel could be confirmed. And the lower pressure drop was shown with two row distribution type tube against series type tube with similar thermal efficiency. Thus, the closed air channel model with two row distribution type tube was regarded as proper type for the real product. However, it is considered that the optimal structure of the collector needs to be found through a valid model in the future with real hybrid solar collector made based on the results because these results were simulation values by numerical model with general boundary conditions.

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REFERENCES

[1] M. S. Buker and S. B. Riffat, "Solar assisted heat pump systems for low temperature water heating applications: A systematic review," *Renewable and Sustainable Energy Reviews*, vol. 3, pp. 399-413, 2016.

[2] H Y. Liu, J. Ma, G. Zhou, C. Zhang, and W. Wan, "Performance of a solar air composite heat source heat pump system," *Renewable Energy*, vol. 87, pp. 1053-1058, 2016.

[3] M. N. A Hawlader, S. K. Chou, and M. Z. Ulah, "Ther performance of a solar assisted heat pump water heating system," *Applied Thermal Engineering*, vol. 21, pp. 1049-1065, 2000.

[4] R. Fatkhur, H. U. Choi, N. J. Lyu, C. H. Son, J. I. Yoon, and K. H. Choi, "Numerical study on the heat gain of liquid from ambient air by installation of v-groove obstacle in an air channel of hybrid solar collector," in *Proc. the KSES 2015 Autumn Annual Conference*, pp. 23, 2015.

[5] H. U. Choi, R. Fatkhur, N. J. Lyu, C. H. Son, J. I. Yoon, and K. H. Choi, "Numerical study on the optimum structure of air channel for heat gain of liquid from ambient air in hybrid solar collector," in *Proc. the KSES 2015 Autumn Annual Conference*, 2015, p. 24.

[6] H. U. Choi, R. Fatkhur, N. J. Lyu, J. I. Yoon, C. H. Son, and K. H. Choi, "Numerical analysis on heat gain of liquid from ambient air with various fin heights and pitches of fin-and-tube heat exchanger in hybrid solar collector," *Journal of the Korean Solar Energy Society*, vol. 36, pp. 53-61, 2016.

[7] H. U. Choi, R. Fatkhur, N. J. Lyu, C. H. Son, J. I. Yoon, and K. H. Choi, "A numerical analysis on the heat transfer characteristic according to a number of distributed tube row of fin-and-tube heat exchanger in hybrid solar collector," in *Proc. the KSES 2015 Autumn Annual Conference*, 2016, p. 17.

[8] W. He, X. Hong, B. Luo, H. Chen, and J. Ji, "CFD and comparative study on the dual-function solar collectors with and without tile-shaped covers in water heating mode," *Renewable Energy*, vol. 86, pp. 1205-1214, 2016.

[9] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes*, 4th ed. New York: Wiley, 2013, ch. 6, pp. 288-302.

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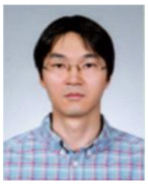

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