

Collection Performance of a Hybrid Solar Collector that Produces Warm Water and Air Warmed by Solar Energy

Hidetoshi AOKI*

ABSTRACT

A solar collector is an equipment that transfers solar energy into warm water and air as thermal energy. Conventional collectors produce warm water or air using a flat plate of stainless steel as a black selective surface for the heat absorption plane. In this study, a hybrid solar collector was devised to produce simultaneously warm water and air using finned tubes for the heat absorption plane. An experiment was conducted both in a laboratory with an artificial solar light source and outside in direct sunlight. The maximum overall solar collection efficiency was 74–79%. The outdoor experiment produced similar values. The year-round operability of the apparatus can be improved by changing the medium for washing depending on the season. Therefore, this hybrid solar collector would be suitable as a water heater and supply device for general public use.

Keywords : Solar collector, Solar thermal energy, Finned tube, Hybrid, Solar collection efficiency

太陽熱から温水と温風を同時に取り出す ハイブリッドコレクターの集熱特性

青木秀敏 *

論文要約

太陽熱を温水または温風に変換するものに太陽集熱器がある。市販の集熱器は熱吸収面として黒色塗装されたステンレス平板を用いて、温風あるいは温水を得ている。本研究では熱吸収面としてフィン付き管を用いることによって温水と温風を同時に獲得するハイブリッドコレクターを考案した。実験は人工太陽光源での空調室内と太陽光線が降り注ぐ屋外で行った。総合集熱効率は最大 74～79%を示し、日射量変動がある屋外実験でも同様な結果を得た。季節によって流す媒体を変えることにより年間稼働率を高くすることができる。したがって、ハイブリッドコレクターは民生用の暖房給湯機器として適している。

キーワード：太陽集熱器、太陽熱、フィン付き管、ハイブリッド、集熱効率

1. Introduction

Large amounts of fossil fuel are to heat homes and supply hot water. In recent times, alternative energy has become intertwined with measures to combat global warming, and the use of natural energy has increased in importance. One source of natural energy being used to power residences is solar energy. Solar cells and solar collectors are devices that use solar energy.

A solar collector utilizes solar thermal energy to heat water and air. Solar collectors are generally classified as either air- or water-type collectors. Currently, a water-type solar collector with very large heat capacity is being used, thus capturing the largest amount of heat in the heat reserve. However, the level of heat radiation from this collector is highly dependent on meteorological conditions. It is not being used extensively in colder regions because of concerns about the pipe arrangement suffering damage due to freezing in the wintertime. In contrast, an air-type solar collector easily recovers heat, but it cannot maintain it in the heat reserve. Conventional collectors produce warm water or air using a flat, stainless steel plate as a black selector for the heat absorption plate.

In this study, a hybrid solar collector that simultaneously produces warm water and air using finned tubes for the heat absorption plane was devised. Finned tubes are often used in heat exchangers. In one method, water is run through the finned tubes as part of a system in which heat radiation is recovered from the finned tubes by an aerial flow.

In regards to previous research on hybrid solar collectors, Garg¹⁾ studied a hybrid photovoltaic-thermal solar water heater, Agarwal et al.²⁾ studied a thermosyphonic solar water heater combined with solar cells, Sopian et al.³⁾ studied a double-pass photovoltaic thermal solar collector, and Hamada et al.⁴⁾ carried out experiments and analyses on the characteristics of power and heat generation through a hybrid solar collector. Most hybrid solar collectors use solar cells and the heat radiating from those cells.

In this study, an experiment was conducted both in a laboratory with an artificial solar light source and outside in direct sunlight, which irradiates with a change in the amount of water and in the volume of the air. The effects of various conditions on the heat collection efficiency of the collector were investigated as part of the basic research on the development of the hybrid solar collector.

2. Experimental Equipment and Methods

A schematic diagram of the experimental equipment is shown in Fig. 1. The solar collector consists of transparent flat glass that is 3 mm thick, a tin plate that is 0.3 mm thick, thermal insulation that is 30 mm thick, and a crate. It also has 19 circular finned tubes with an inside diameter of 20 mm and a fin diameter of 50 mm. The tube is made of copper and the fin is made of aluminum. The finned tubes are connected by a U-type tube. The solar collector is 0.62 m wide, 1.31 m long, and 0.205 m high, while the glass that receives the solar rays is 0.98 m long and 0.6 m wide. The total heat transfer area of the finned tube is 6.422 m².

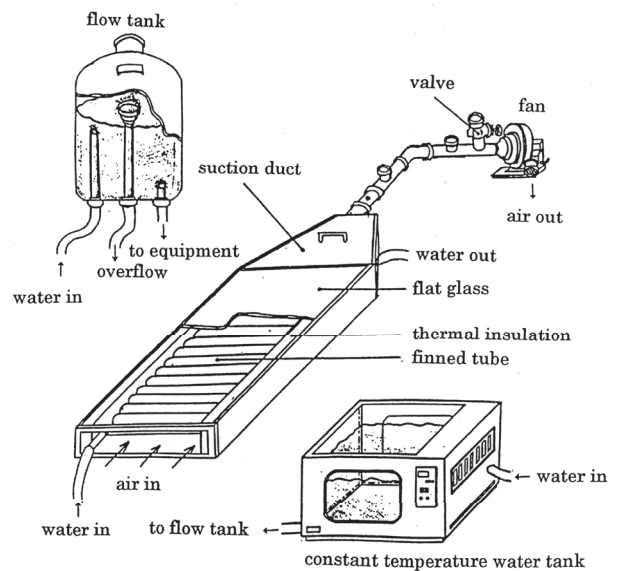


Fig.1 Schematic diagram of the experimental equipment

The heat absorption plane of the solar collector consists of a fin tube that is painted black and a tin plate for the unit base. Warm water is provided by running water through the finned tube. As the temperature of the water inside the pipe rises, heat loss occurs on the glass side. Heat radiating from the finned tube is recovered by the aerial flow, and thus the system provides warm air.

In this experiment, a solar simulator was constructed to create stable conditions for solar radiation. A solar simulator consists of 13 artificial solar light source lamps. The amount of solar radiation on the glass surface is 1/5 of that observed on a clear day, and the dispersion of the amount of solar radiation on the surface is within 10%.

The hybrid solar collector was installed on the roof of a school building, and the outdoor experiment

was conducted before and after 12:00 p.m., when the sun was shining due south. The water flow rate increased five times compared to the rate in the indoor experiment; however, the air flow rate remained the same. A pump brought water to the collector from the constant-temperature water tank, and water with the same temperature as the entry air was supplied to the unit. Air was absorbed by a fan. Thermocouples were installed in 29 locations inside the unit to measure the temperature of each portion of the unit, and individual temperatures were measured at fixed times. In this experiment, the curvature on both ends of the fin tube was insulated thermally in order to allow for a separate examination of the solar collection properties of the finned tube.

The heat collection of warm air and water from the solar collector Q is given by the equation below. Solar collector efficiency η was calculated using the equation below. The heat balance of this experiment is within 10%.

$$Q = W_a \cdot C_{pa} \cdot \rho_a \cdot \Delta T_a + W_w \cdot C_{pw} \cdot \rho_w \cdot \Delta T_w \quad (1)$$

$$\eta = Q / (I \cdot A) \times 100 \quad (2)$$

3. Results and Discussion

3.1 Variation in solar collector efficiency due to the angle of inclination

The variation in solar collector efficiency was studied experimentally in relation to an increase in the insolation area of the finned tube through a five-degree increase in the slope. This variation in efficiency is shown in Fig. 2 with respect to a five-degree increase from the horizontal with a constant water flow of 5.5 L/h and an air flow of 0.52 m³/min. The heat collection efficiency for warm water does not change even if the angle of inclination and the insolation

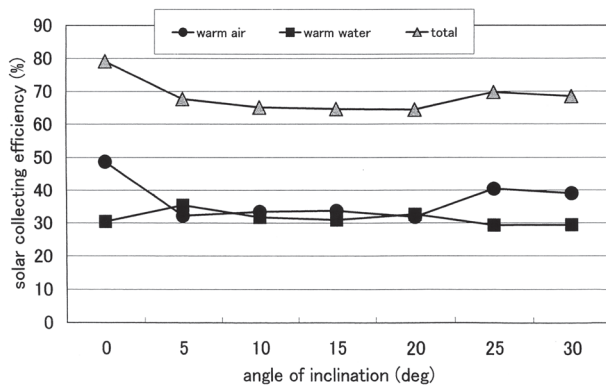


Fig. 2 Variation in solar collecting efficiency due to the angle of inclination

area of the finned tubes increase. However, when it was installed horizontally such that solar radiation might contact a portion of the pipe directly, the heat collection efficiency for warm air reached its highest value. It may be possible that the air flow recovered heat radiation from the warm water to produce the temperature rise; solar radiation might not contact a portion of the fin, but it might contact a portion of the pipe directly in contact with the device positioned horizontally, resulting in the rise in water temperature.

3.2 Variation in solar collector efficiency due to the amount of flow

1) When the air flow rate is constant, the water flow rate varies

As mentioned before, it is clear that the device achieved maximum total heat collecting efficiency in a horizontal position. Next, when the quantity of the flow was changed, the variation in solar collecting efficiency in a horizontal position was studied to ascertain the most appropriate values for the quantity of water flow and air flow. First, variations in the inlet and outlet temperature over time are shown in Fig. 3 for a water flow of 2 L/h and an air flow of 0.5m³/min. as an example of temperature variations in individual portions. Although the temperature rise of the warm

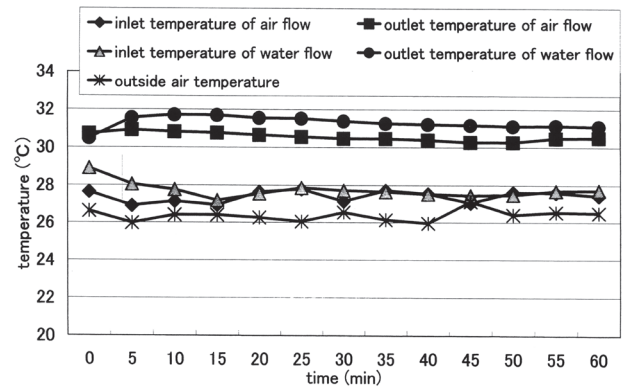


Fig. 3 Variation in the inlet and outlet temperature over time

water is larger than that of warm air, the amount of heat collection of warm air is about 3.5 times greater than that of warm water under conditions in which each portion's inlet temperature and outside air temperature are kept almost constant.

The variation in solar collecting efficiency under conditions involving changes in water flow rate with a fixed air flow rate of 0.5 m³/min is shown in Fig. 4.

Contrary to results in which the solar collecting

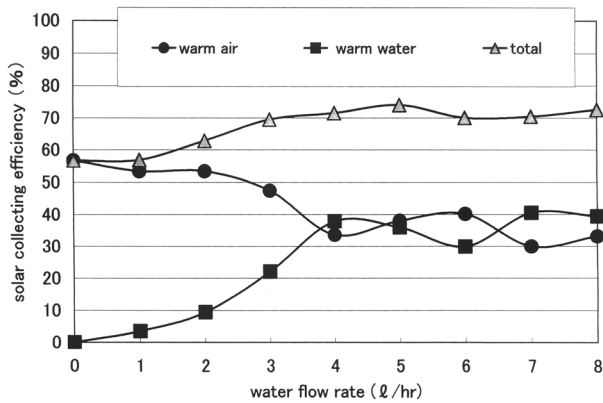


Fig. 4 Variation in solar collecting efficiency under conditions involving changes in the water flow rate with a fixed air flow rate of $0.5 \text{ m}^3/\text{min}$

efficiency of warm air decreases with a large water flow, the solar collecting efficiency of warm water increases. This result may be due to the fact that the heat recovery rate for warm air decreased because the surface temperature of the fin decreased with the circulation of a large water flow. In this manner, the total solar collecting efficiency increased by no less than 15% due to the flow of water through the finned tubes. Therefore, water in the hybrid system reduced the heat loss from the solar collector from 35% to 15% or less.

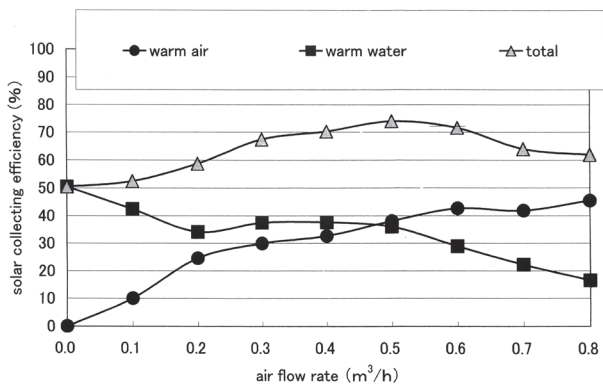


Fig. 5 Variation in solar collecting efficiency under conditions involving changes in the air flow rate with a fixed water flow rate of 6 L/h .

2) When the water flow rate is constant, the air flow rate varies

The variation in solar collecting efficiency under conditions involving changes in the air flow rate with a fixed water flow rate of 6 L/h is shown in Fig. 5.

Contrary to the results in which the solar collecting efficiency of warm water decreases with a large

air flow, the solar collecting efficiency of warm air increases. This may be due to the fact that heat filling the space between the glass and the tin plate is recovered with a large air flow, thus resulting in reduced heat loss. Total solar collecting efficiency reached a maximum of 73.9%, when the solar collecting efficiency of the warm water was about the same as the solar collecting efficiency for warm air with a water flow of 6 L/h and an air flow of $0.5 \text{ m}^3/\text{min}$. This value is nearly the same as the limiting value with reference to the value for the permeability of the transparent flat glass.⁵⁾

3.3 Outdoor experiment

An outdoor experiment with the equipment was performed in sunlight, and the results were compared with those from indoor experiments. Variation in solar collecting efficiency under conditions involving changes in the water flow rate with a fixed air flow rate of

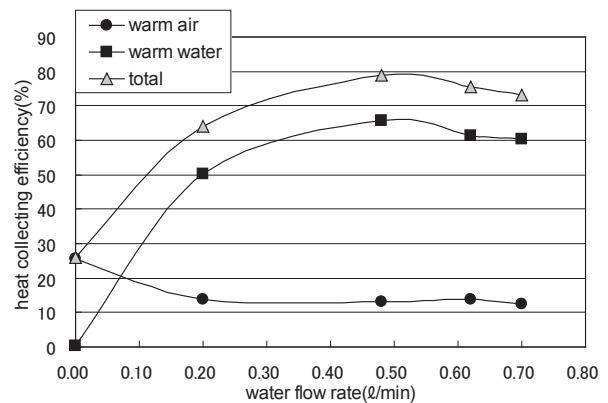


Fig. 6 Variation in solar collecting efficiency under conditions involving changes in the water flow rate with a fixed air flow rate of $0.4 \text{ m}^3/\text{min}$

$0.4 \text{ m}^3/\text{min}$ is shown in Fig. 6. The experiment was performed with a water flow of $0.1\text{--}0.7 \text{ L/min}$, which was higher compared to the indoor experiments. The outdoor experiment produced similar tendencies, and the overall solar collection efficiency was 79%.

The temperature increase in the water and the air is shown in Fig. 7 under the same conditions as in Fig. 6. The temperature increase of the warm air to produce a water flow of 0.0 L/min and an air flow rate of $0.4 \text{ m}^3/\text{min}$ is about 18°C .

As the water flow rate increases, the temperature at the water and air outlets decrease to about $2\text{--}6^\circ\text{C}$. The increase in temperature is marginal, but if this value is applied to a commercial collector that is 1 m wide and 2 m long, the increase in temperature will be

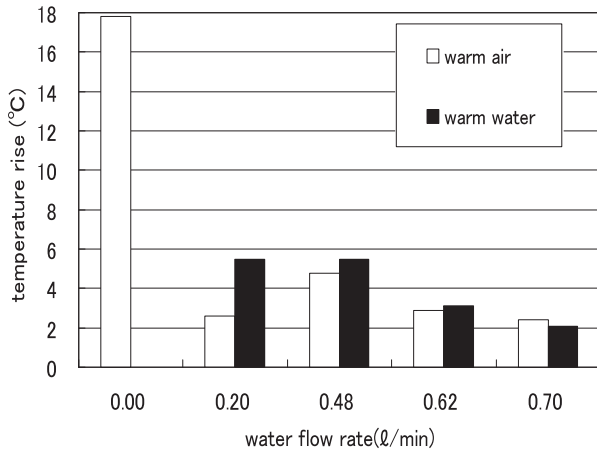


Fig. 7 Temperature rise of warm water and air

equal to about 16 °C, thus indicating the possibility of practical application.

3.4 Examination of the practical application

However, when this collector is actually installed outdoors, there are a few instances in which the inlet temperature of the warm air and the warm water is equal, as in this experiment. It is assumed that the entry temperature of the warm water rises and that heat characteristics of the solar collector change as

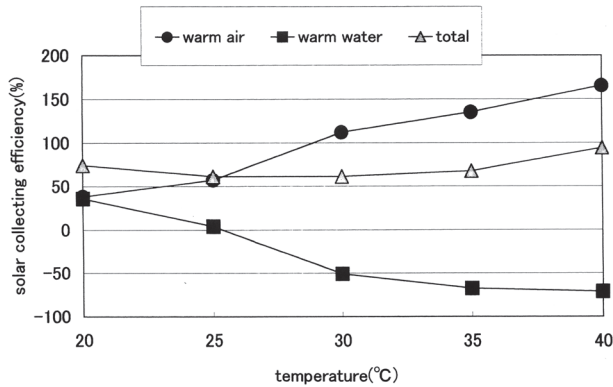


Fig. 8 Variation in solar collecting efficiency under conditions involving changes in the inlet temperature of the warm water

the warm water continues to circulate. Therefore, the variation in solar collecting efficiency under conditions involving changes in the inlet temperature of the warm water with a fixed air flow rate and warm water rate is shown in Fig. 8.

Contrary to results in which the solar collecting efficiency of warm water decreases as the inlet temperature of hot water rises, the solar collecting

efficiency of warm air increases, but the total solar collecting efficiency does not change significantly. These results show that the air flow recovers heat radiation from the warm water to produce the temperature rise as the warm water circulates.

For the solar collector that is in the market, the radiation produced by the circulation of warm water results in lower solar collecting efficiency. However, it may be that the hybrid solar collector can prevent the decline in solar collecting efficiency through the use of a method to recover heat radiation with an air flow.

The hybrid solar collector that was developed has the following features:

- 1) In winter, this collector produces warm air to use for heating by running only air; water cannot be supplied due to the fear of freezing when the atmospheric temperature is below 0 °C.
- 2) In spring and autumn, this collector simultaneously produces warm water and air by flowing both water and air, so the total solar collecting efficiency increases.
- 3) In summer, when heating is unnecessary, this collector can produce warm water to the fullest extent by flowing water alone.
- 4) As mentioned before, the year-round operability of the apparatus can be improved by changing the medium for washing depending on the season.

4. Conclusion

When comparing the results obtained in the laboratory, which has an artificial solar light source, and those obtained using direct sunlight, the solar collecting efficiency of the hybrid solar collector produced similar values. The maximum overall solar collection efficiency was 74–79%. The solar collecting efficiency of the forced circulation-type and the natural circulation-type solar collectors used for producing the usual hot-water supply are 40–55% ⁽⁶⁾, so this hybrid solar collector would be a suitable water heating and supply device for general public use.

Nomenclature

A	area	[m ²]
Cp	heat capacity of water	[J/kg K]
I	solar intensity	[W/m ²]
Q	rate of heat collection	[W]
W	volume flow rate	[m ³ /s]
ρ	density	[kg /m ³]

ΔT temperature difference [K]
 η solar collection efficiency [-]

Subscript

a air
 w water

References

- 1) Garg, H.P, R.K. Agarwal and J.C. Joshi, Experimental Study on a Hybrid Photovoltaic Solar Water Heater and Its Performance Predictions, *Energy Conversion and Management*, **35**, 621-633 (1994)
- 2) Agarwal, R.K and H.P. Garg, Study of a Photovoltaic -Thermal System—Thermosyphonic Solar Water Heater Combined with Solar Cells, *Energy Conversion and Management*, **35** 605-620 (1994)
- 3) Sopian, K, H.T. Liu and S. Kakac, Performance of a Double Photovoltaic Thermal Solar Collector Suitable for Solar Drying Systems, *Energy Conversion and Management*, **41** 353-365 (2000)
- 4) Hamada, Y., M. Nakamura, K. Ochifuji, R. Narita, K. Nagakura, H. Saitoh, S. Yokoyama and K. Nagano, Experimental and Analyses on a Hybrid Solar Collector, "Transactions of Society of Heating, Air-Conditioning and Sanitary Engineers of Japan", **83**, 21-30 (2001)
- 5) Harada, T., Grass as building materials (part 1) , *SHASE of Japan*, **69**, 63 (1995)
- 6) Aoki, H., N. Meng and K. Nakaya, Heat Collecting Efficiency of Solar Collectors placed in a Line, *The Bulletin of Hachinohe Institute of Technology*, **13**, 95-101 (1994)