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Performance of a Two-Phase Solar Collector in Water Heating

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Abstract

Experiments have been conducted with a two-phase solar collector in which a flat-plate collector acts as an evaporator and a water tank acts as condenser. Each of the working fluids (Acetone and Methanol) boils in the flat-plate collector, condenses in the water tank by releasing heat to water, and goes back to the flat-plate collector to be boiled again in order to repeat the cycle. The solar collector has been installed at BUET, Dhaka, Bangladesh (23.7 degree N latitude) where the average solar radiation is in the range of 3.5-5 kWh/m^2 per day. For each of the experiments during May-June 2003, absorber plate temperatures at different locations, coolant tube temperature, inlet /outlet temperatures of working fluid, water temperature in the water tank and solar insolation at a regular interval were recorded, and compared with those obtained using a conventional flat-plate collector. From the collected data the performance parameters such as instantaneous collector efficiency and heat removal factors have been calculated and analyzed.

Nomenclature

A_C	collector area [m^2]
F_R	collector heat removal factor [-]
I_T	global or total solar radiation incident on the collector per unit area per unit time, [W/m^2]
Q_u	rate of useful heat collected from the collector, [W]
T_{pm}	average temperature of the absorber plate, [^{0}C]
T_p	instantaneous plate temperature, [^{0}C]
U_l	overall heat loss coefficient, [W/m^2 K]
η_i	instantaneous solar collector efficiency [-] = $Q_u/I_T A_C$

Introduction

The solar energy is indispensable for the survival of lives on earth. Efficient use of it has been sought since the dawn of the history and a great many technologies have been developed until today. A flat-plate solar water heater absorbs solar radiation and transfers it to cold water thereby raising its temperature. Solar water heaters are in use for the last couple of decades in various countries and are commercially as well as technically viable. The solar water heaters, depending on the temperature requirement and the amount of water to be heated, can be of either in-built-storage type or natural circulation type or forced circulation type. Most of the solar water heaters employ tube-in-plate type of flat-plate collectors having an optimized configuration to use solar energy at the maximum efficiency at the minimum cost.

A number of studies [1-10] on solar collector have been performed in Bangladesh and elsewhere in the world. Almost all the works done so far are of single-phase type. From the studies on the conventional single-phase solar collector it is found that the major heat loss occurs from the top surface of the collector even though glazing is installed. It may be possible to use a two-phase solar collector to reduce top loss keeping the temperature of the absorber plate lower because of phase-change process, and to increase the efficiency of the flat-plate collector.

With a view to having the benefits stated above a two-phase solar collector has been designed, fabricated, installed and experimented in this work to utilize solar energy for water heating. This employs a two-phase heat transfer process in a solar flat-plate collector where a flat-plate collector acts as an evaporator and a water tank acts as condenser. The working fluid passing through coolant channel boils at the flat-plate collector, condenses at the condenser transferring latent heat to water, and goes back to the flat-plate collector to be boiled again in order to repeat the cycle.

Experiment

Set-up

The schematic diagram of the two-phase solar collector is shown in Fig. 1 which consists of (i) the flat-plate collector assembly, (ii) water tank containing condenser, (iii) working fluid storage tank, and (iv) connecting tubing. A conventional single-phase flat-plate solar collector is as shown in Fig. 2. A brief description is given below; a more detail of which is available in the work [11]. The flat-plate collector assembly is basically composed of four parts as described below.

(a) *Absorber Plate*: Its purpose is to absorb the solar radiation as much as possible and to transfer the heat to the coolant. In this study, the absorber plate is of length: 122 cm, width 60 cm and is made of 22 gauge GI sheet. The plate is coated by a non-selective coating with a view to improve its absorptivity. Several thermocouples are attached to the plate from the bottom to get spatial temperature distributions.

(b) *Tubes or Coolant Channels*: Three equally spaced G.I tubes of 1.3cm diameter are brazed to the plate in pre-machined semicircular troughs and gap between troughs and tubes are filled with molten lead. Thermocouple locations are also machined in the tubes to measure the coolant temperature during the experiment.

(c) *Thermal Insulation*: The absorber plate-and-tubes assembly is housed in a wooden box (132 cm by 76 cm by 20 cm) having adequate clearance for adding insulation necessary to prevent the side and bottom heat losses from the collector. Wooden chips and glass wool are used in this study for this purpose.

(d) *Glazing*: Two 3-mm thick glass sheets are used as glazing for both the collectors. These are provided to reduce top losses from the collectors.

Water tank having capacity of 50 liter contains the condenser where vapor of working fluid/hot water releases heat and make the tank water hot. The tank is also insulated to prevent heat gain/loss from/to the environment. A thermometer is fitted there to measure the temperature of tank water after a regular interval. For the case of two-phase collector, a storage tank is used to store the working fluid temporarily in order to ensure enough supply of liquid to the flat plate collector.

GI tubes and/flexible tubing are connected with the water tank and/or storage tank to complete circulation of the working fluid in the thermosyphon. The exit tubing for vapor/hot water from the collector is also insulated to prevent heat losses. The vapor tube has provisions to visualize the flow of vapor.

The wooden box containing flat-plate collector is supported in a frame that can be tilted from 20^o to 40^o. In this study, south facing 22 ^{o} inclination of the system is set as latitude of Dhaka is about 23.7^o. The water and storage tanks are also supported on separate frames as shown in Figs. 1and 2.

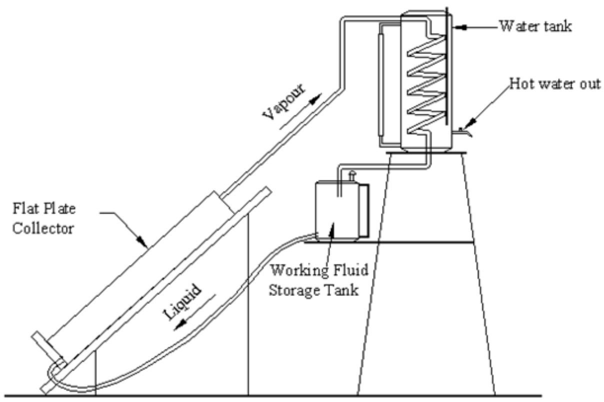

Fig. 1 Two-phase solar collector

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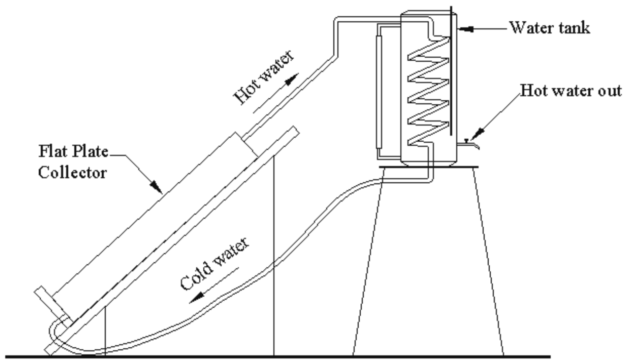

Fig. 2 Single-phase solar collector

Procedure

During all experiments (as shown in Table 1) the flat plate collector was tilted at an angle of 22^{o} and working fluids were charged with special care so that there was no trapped air in the coolant channel. Instantaneous solar flux on the tilted collector was measured by a pyranometer at an interval of 15 minutes from 10 am to 5 pm. At the same time, steady temperatures of absorber plate, coolant tube inlet-outlet and water were measured by thermocouples. Data were collected for Water-Acetone and Water-Methanol combination as mentioned in Table 1. Collected data were then used to calculate loss coefficient, useful heat gain, instantaneous collector efficiency and heat removal factor of the collector.

Table 1 Experimental ranges and conditions

Date of Experiment	Glazing	Working Fluid
31 May 2003	Yes	Water and Methanol
01 June 2003	Yes	Water and Acetone

Results and Discussions

For the experimental conditions mentioned in Table 1, solar insolation, absorber plate temperatures at different locations and hot water temperature are measured and recorded at 15 minutes interval as mentioned in the procedure section. The variations of the above parameters are displayed and analyzed here. From the collected data instantaneous collector efficiencies are calculated using relation given in the nomenclature and analyzed under above mentioned conditions.

Experiment in 31 May 2003

Figs. 3-5 exhibit the variations of plate temperature, hot water temperature and instantaneous collector efficiency over the hours of 31 May 2003 where average ambient temperature was 34^{o}C. The variation of solar insolation is also shown in these Figs. on the secondary axis. From Figs. 3-5, we observe that the solar insolation varied from 300 W/m^2 to 707 W/m^2, the average of which was 576 W/m^2. For water collector, the maximum plate temperature was 81^{0}C and the maximum water temperature was 47^{0}C. The collector instantaneous efficiency of the single-phase collector was as high as 48%. On the other hand, the maximum plate temperature was 87^{0}C and the maximum water temperature was 46^{0}C for Methanol collector. The collector instantaneous efficiency of the two-phase collector was as high as 63%.

It is worth mentioning that for the same solar flux the enhanced water temperature and the instantaneous efficiency of the Methanol (two-phase) collector are more than that of Water (single-phase) collector.

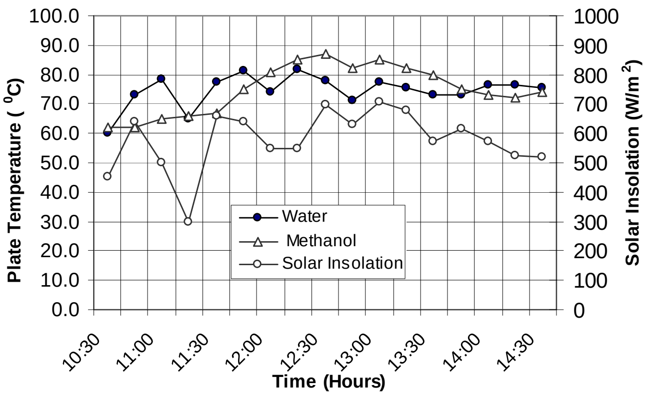

Fig. 3 Variation of plate temperature

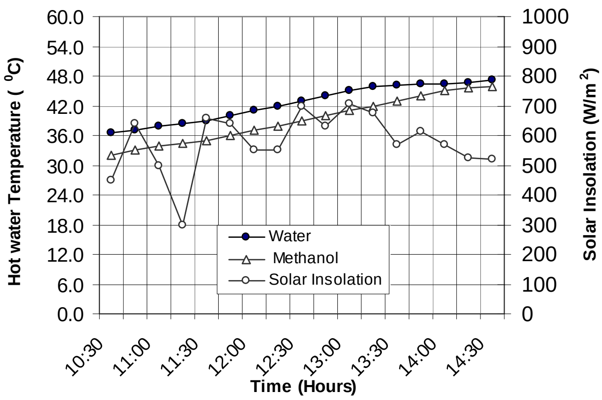

Fig. 4 Variation of hot water temperature

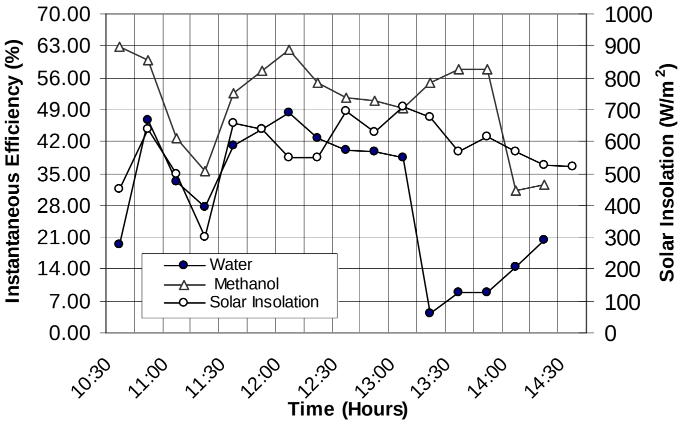

Fig. 5 Variation of instantaneous efficiency

Experiment in 1 June 2003

Figs. 6-8 exhibit the variations of plate temperature, hot water temperature and instantaneous collector efficiency over the hours of 1 June 2003 where average ambient temperature was 36^{o}C. The variation of solar insolation is also shown in these Figs. on the secondary axis. From Figs. 6-8, we observe that the solar insolation varied from 640 W/m^2 to 815 W/m^2, the average of which was 733 W/m^2. For Water collector the maximum plate temperature was 105^{0}C and the maximum water temperature was 49^{0}C. The collector instantaneous efficiency of the single-phase collector was as high as 39%. For Acetone collector the maximum plate temperature was 102^{0}C and the maximum water temperature was 47^{0}C. The collector instantaneous efficiency of the two-phase collector was as high as 50%.

It is worth mentioning that for the same solar flux the enhanced water temperature of the acetone (two-phase) collector is less than that of water collector, but the instantaneous efficiency of the two-phase collector is more than that of water (single-phase) collector. The lower latent heat of vaporization of acetone may be in part responsible for giving less amount of heat to water after condensation of its vapor as also mentioned for acetone-water collector without glazing.

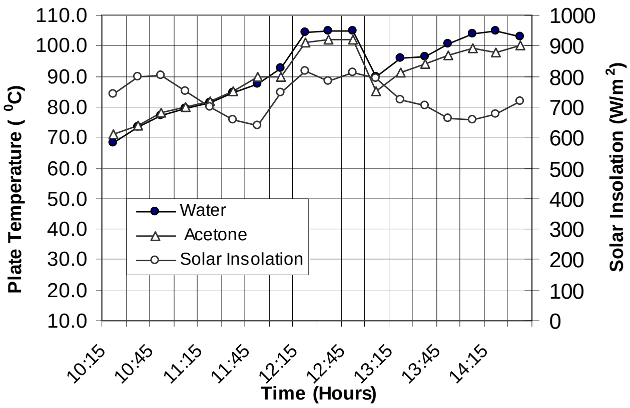

Fig. 6 Variation of plate temperature

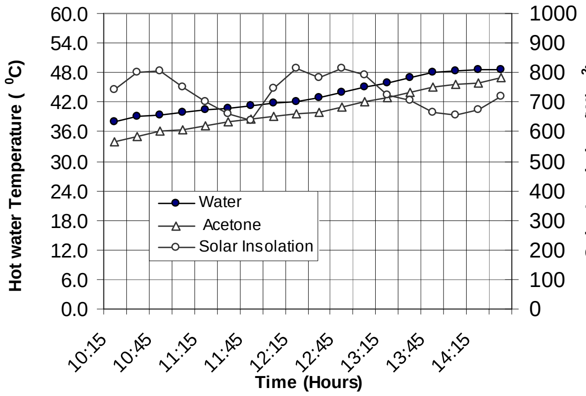

Fig. 7 Variation of hot water temperature

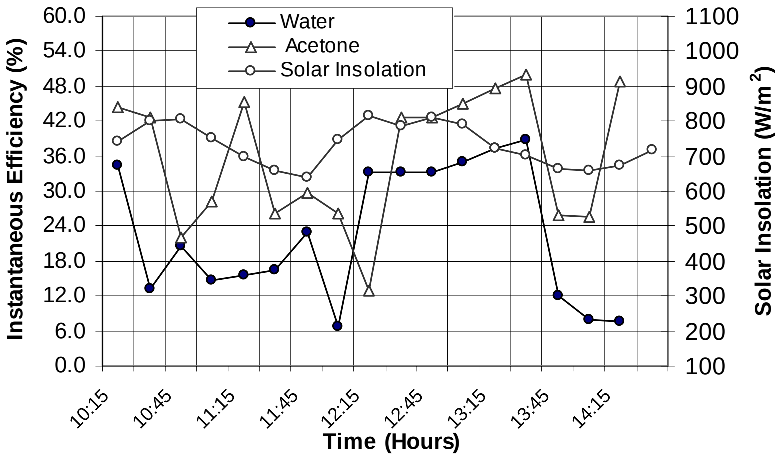

Fig. 8 Variation of instantaneous efficiency

In addition to instantaneous efficiency, overall heat loss coefficient and collected heat removal factors are calculated. The summery of the results obtained from this investigation are given in Table 2.

Table 2 Performance of the collectors

Date	Working fluid	Solar insolation I_T (W/m^2)	T_{pm}	U_l (W/m^2 K)	Q_u (Watt)	F_R	$(\eta_i)_m$ (%)
31 May 2003	Water	576	74.35	4.69	195	0.622	48
	Methanol	576	70.60	3.04	250	0.745	63
01 June 2003	Water	733	86.00	6.02	195	0.530	39
	Acetone	733	87.80	4.34	251	0.642	50

From the performance Table 2, it is clear that two-phase solar collector working with methanol possesses good performance parameters. It has lower top loss coefficient, higher heat recovery factor and higher instantaneous efficiency. Properly engineered two-phase solar collector working with methanol may be experimented in order to evaluate the performance parameters more precisely and may be recommended to exploit solar energy.

Conclusion

Experiments are carried out on a two-phase solar collector in order to find out suitable working fluid for this. The obtained data have been presented and analyzed leading to the following inferences.

i) The maximum rise in water temperature obtained is about 15^0C, 14^0C, and 15^0C for the collector working with Water, Methanol and Acetone, respectively.

ii) The respective maximum instantaneous efficiencies have been found to be 60%, 63%, and 55%.

iii) The respective maximum collector heat removal factors are 0.785, 0.745 and 0.660.

iv) Among the liquids that have been experimented with, Methanol is the best. It has the lowest top loss coefficient, and the highest heat recovery factor and instantaneous efficiency.

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