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PERFORMANCE ANALYSIS OF A SINGLE-PHASE THERMOSYPHON IN SOLAR WATER HEATING

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ABSTRACT
A single-phase closed thermosyphon has been designed, fabricated and experimented to utilize solar energy for water heating. The working fluid of the closed thermosyphon heated at the flat-plate collector and the hot water goes to the water tank due to density gradient caused by temperature differences. This experimental work was done using insulated water tank and insulated connecting pipe between the tank and the flat-plate collector. From the collected data, performance parameters such as instantaneous collector efficiency and heat removal factor are calculated and analyzed. Effects of glazing were also observed in this study. The water temperature rise and the maximum instantaneous efficiency obtained from this experiment with glazing are 16^0C in a period of 5 hours and 59% respectively using insulated water tank and insulated connecting pipe. Whereas the water temperature rise and the maximum instantaneous efficiency obtained from this experiment with glazing are 13^0C in a period of 5 hours and 38% respectively using non-insulated water tank and non-insulated connecting pipe.

Keywords: Single-phase thermosyphon, Flat-plate collector, Insulated tank and pipe.

1. INTRODUCTION
It has become obvious that fossil fuels resources are fast depleting and are gradually coming to an end. Commercial energy has also created many problems. The most serious of these are they are finite, they cannot be regenerated and their harmful effect on the environment. Now man embarks on the search for alternative sources of energy. The primary sources of alternative energy that hold potential for future the solar energy is one of them. Solar energy is abundant and perpetually renewable. Unlike fossil fuels and nuclear power, it is an environmentally clean source of energy, free and available in adequate quantities in almost all parts of the world where people live. The solar energy is used in different types of field and many Engineers/ Scientists or Institutes have performed a number of experiments/projects regarding solar energy [1-17]. Using single-phase heat transfer technique, a lot of work has been done. These works are performed using non-insulated water tank and non-insulated connecting pipe. This project work has been conducted employing single-phase heat transfer process in a solar flat-plate collector using insulated water tank and insulated connecting pipe. In this study, a flat-plate solar collector acts as heater and a water tank store the hot water. There is a scope to reduce a huge amount of heat loss from the tank and also from the connecting pipe to the environment. The ultimate result is the amount of enhanced water temperature and the efficiency of the flat-plate collector will be increased. With a view to having benefits stated above a single-phase closed thermosyphon has been designed, fabricated and installed to utilize solar energy for water heating. Here the objectives are to design a low cost single-phase thermosyphon type solar water heater and to compare the performance between the flat-plate collector with insulated tank and pipe and the flat-plate collector with non-insulated tank and pipe.

2. EXPERIMENTAL SET UP
The general views of the assembled equipment are-Collector: The collector, which receives the sun's rays and heats the water, is composed of four parts. These parts include as followings:

(i) Absorber Plate: We have used 22 gauges G.I sheet as absorber plate.
(ii) Tubes or Channels: G.I pipe of 1.3 cm diameter is used to circulate the water. The tubes are bonded to the plate by lead brazing.
(iii) Thermal Insulation: Here we have used wooden chips, glass wool etc.
(iv) Glazing: Here we have used one transparent cover, which is made of low iron glass.

The Collector Housing: The exterior box, which integrates the other components that make up the collector. The box is made of gamier wood (thickness 3.80 cm).

Water Storage Tank: A common tank made of Cast Iron material is used for the purpose of supply and storing hot water in the closed loop thermosyphon system.

Variable Inclined Stand: This stand is made of M.S angle bar.

Schematic diagram of single-phase thermosyphon type flat–plate collector with insulated water tank and with non-insulated water tank are shown in the Fig. 1 & Fig. 2 respectively.

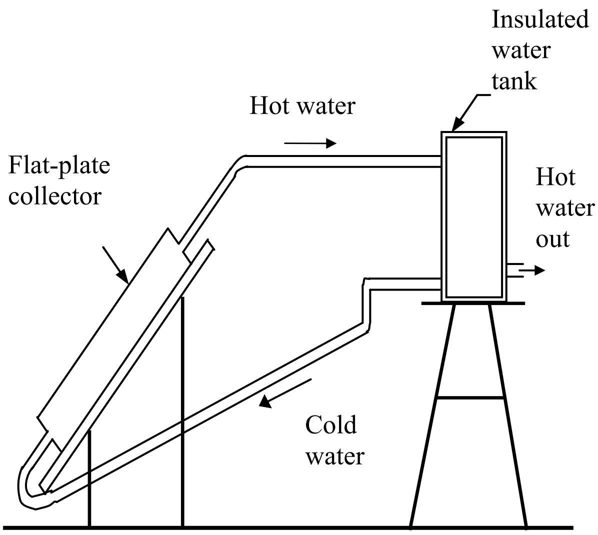

Fig 1. Schematic diagram of the experimental setup of single-phase thermosyphon type collector.

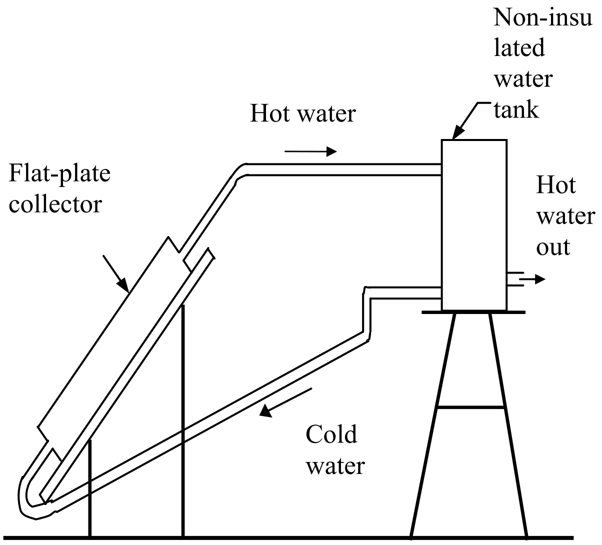

Fig 2. Schematic diagram of the experimental setup of single-phase thermosyphon type collector.

Figure 3 and 4 illustrate sectional view of the whole collector assembly.

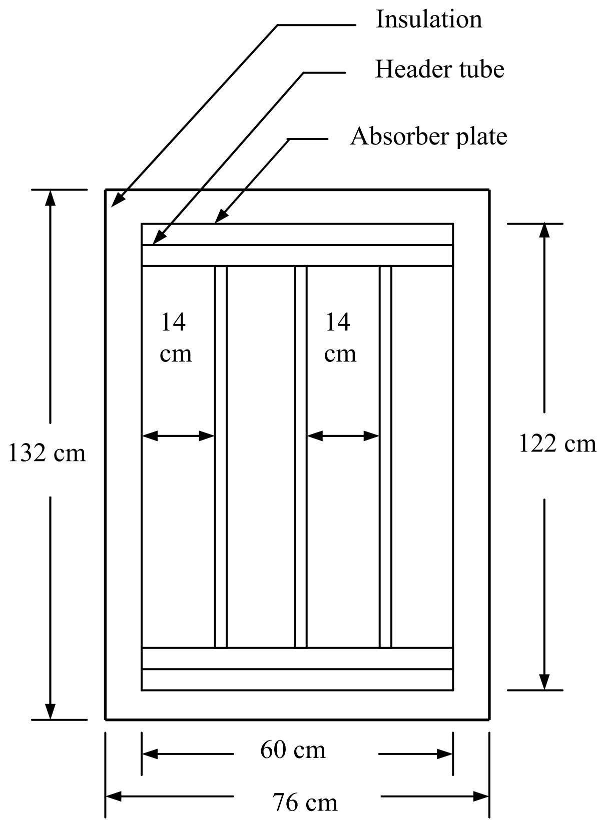

Fig 3. Top view of the flat-plate collector assembly.

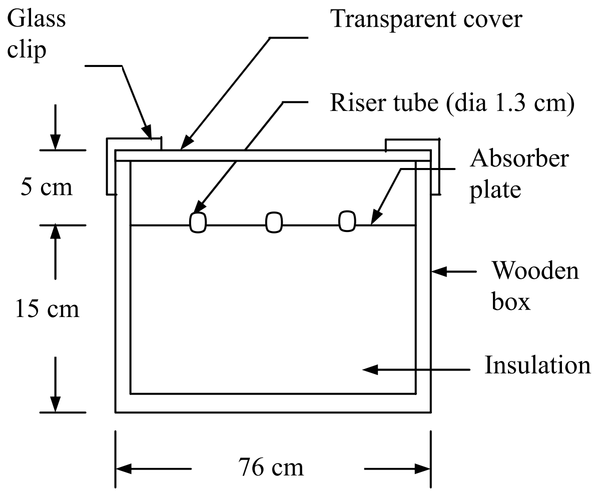

Fig 4. Side view of the flat-plate collector assembly.

3. WORKING PROCEDURE

The thermosyphon system is installed at BUET, Dhaka, Bangladesh (23.7° N) where the average solar radiation is in the range of 3.5-5 kWh/m^2 per day [6]. After construction the flat-plate collector held at a tilted angle of 22 degree and also 35 degree (on 13 December 2003) facing south on a supporting structure. To compare the performance parameters experiments also performed on the same collector with non-insulated water tank and non-insulated connecting pipe. During experiment instantaneous solar flux (global radiation) was measured by a Pyranometer. At about 15 minutes interval, solar insolation, absorber plate temperature at different locations, water temperature in the water tank are recorded carefully. To get a better comparison we have worked on several days of the year. Series of data have been recorded for water collector at several conditions. For temperature measurement of the set-up of the single-phase collector thermocouples are used in six locations. Of them, one at header tube inlet for measuring tank inlet temperature, one at header tube outlet for measuring temperature of the outlet fluid of the plate, two in the absorber plate at different positions for measuring the average plate temperature, one at riser tube and one at the water tank. The absorbed radiation is partly transferred to water flowing through tubes that are fixed to the absorbed plate. This energy transfer is the useful gain. The remaining part of the radiation absorbed in the absorber plate is lost by convection and radiation to the surroundings form the top surface and by conduction through the back and edges. To minimize these losses side and bottom insulations are used.

4. RESULTS AND DISSCUSSION

To analysis the performance of the flat-plate collector some graphs are plotted from the collected data and calculations for the following working conditions and these are shown in Figs. 5-8.

Working conditions:

(i) With glazing and with insulated tank & pipe on 12 December 2003

(ii) With glazing & with non-insulated tank & pipe on 02 June2003

(iii) Without glazing & with non-insulated tank & pipe on 01 June 2003.

Experiments with Insulated Tank and Insulated Connecting Pipe:

From Figs. 5-8 we get that the solar insolation varied from 265 W/m^2 to 810 W/m^2 and the ambient temperature was 28^{0}C on 12 December 2003. The plate temperature raised as high as 68^{0}C and the water temperature raised up to 48^{0}C and the collector instantaneous efficiency was as high as 59% with glazing.

Experiments with Non-Insulated Tank and Non-Insulated Connecting Pipe:

From Figs. 5-8, we get that the solar insolation varied from 600 W/m^2 to 824 W/m^2 and the ambient temperature was 36^{0}C on 02 June 2003. The plate temperature raised as high as 67^{0}C and the water temperature raised up to 49^{0}C and the collector instantaneous efficiency was as high as 38% with glazing.

From the analysis we get that the solar insolation was in the range of 640 W/m^2 to 815 W/m^2 and the ambient temperature was 36^{0}C on 01 June 2003. The plate temperature raised as high as 105^{0}C and the water temperature raised up to 47^{0}C and the collector instantaneous efficiency was as high as 39% without glazing.

It is worth mentioning that the enhanced water temperature and the instantaneous efficiency of the collector with insulated tank and insulated pipe are more than that of the collector with non-insulated tank and non-insulated pipe. It is also observed that the performance of the collector with glazing is better than that of the collector without glazing. The summery of the results obtained from this project work are shown in table1.

Table 1: Performance of the single-phase thermosyphon type flat-plate collector with glazing:

Date	**Working condition**	**Average solar insolation I (W/m^2)**	**T_{pm}**
06 Jan. 2003	With non-insulated tank and non-insulated pipe	674	41.00
31 May 2003	Do	576	74.35
01 June 2003	Do	733	86.00
10 Dec. 2003	With insulated tank and insulated pipe	522	60.72
11 Dec. 2003	Do	460	54.80
12 Dec. 2003	Do	636	62.50
13 Dec. 2003	Do	765	60.36

Table 1: (Contd.)

Date	**U_l (W/m^2 K)**	**Q_u (Watt)**	**F_R**	**$(\eta_i)_m$ (%)**
06 Jan. 2003	18.11	175	0.461	32
31 May 2003	4.69	195	0.622	48
01 June 2003	6.02	195	0.532	39
10 Dec. 2003	4.54	273	0.785	60
11 Dec. 2003	5.57	195	0.694	54
12 Dec. 2003	5.20	318	0.765	59
13 Dec. 2003	6.78	326	0.720	53

Here, T_{pm} = Average temperature of the absorber plate,
U_l = Overall loss coefficient,
Q_u = Useful heat gain,
F_R = Collector heat removal factor,
$(\eta_i)_m$ = Maximum instantaneous efficiency.

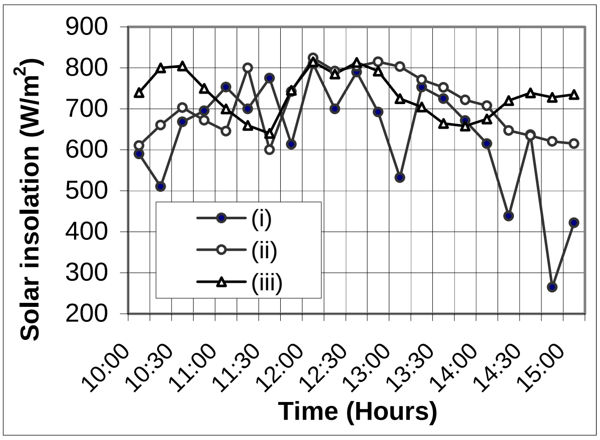

Fig 5. Hourly variation of solar insolation on the flat-plate collector.

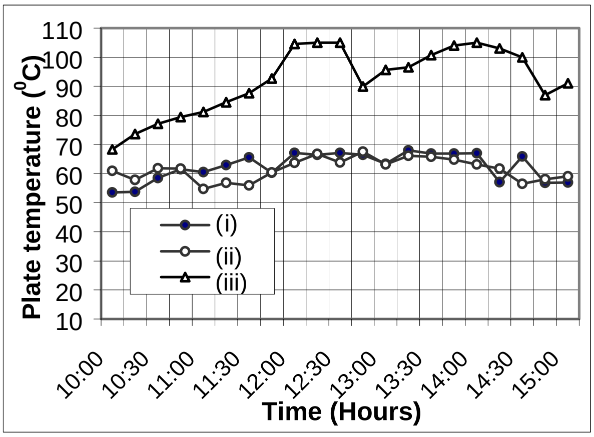

Fig 6. Hourly variation of plate temperature of the flat plate collector.

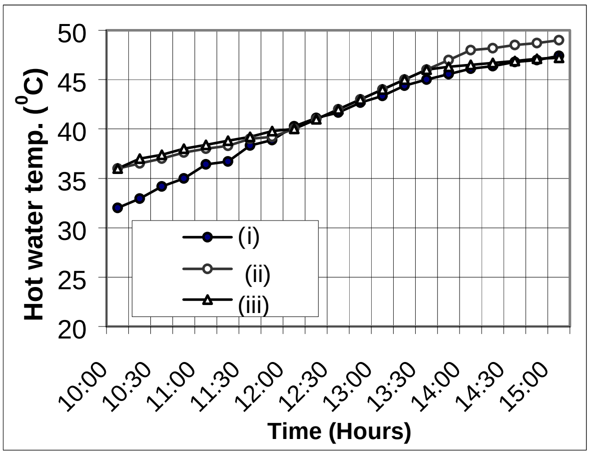

Fig 7. Hourly variation of hot water temperature of the collector.

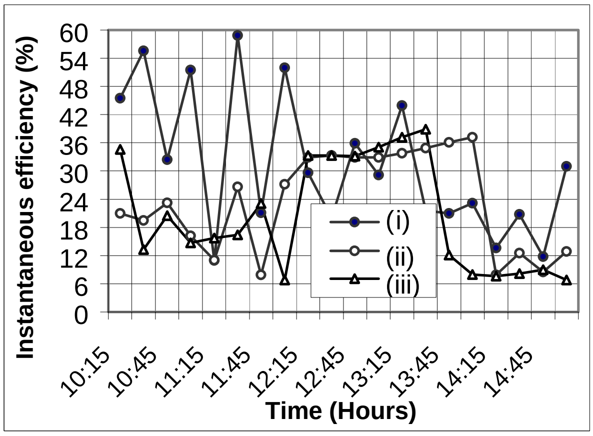

Fig 8. Hourly variation of instantaneous efficiency of the flat-plate collector.

5. CONCLUSIONS

The construction cost of the collector with insulated tank & pipe and the collector with non-insulated tank & pipe is almost same. The maximum rise in water temperature obtained by this setup is about 16^0C for the collector with insulated tank and pipe and 13^0C for the collector with non-insulated tank and pipe. The maximum instantaneous efficiencies have been found 60% for the collector having insulated tank & pipe and 48% for the collector having non-insulated tank & pipe. The maximum collector heat removal factors obtained from this experimental work are 0.785 for the collector having insulated tank and pipe and 0.622 for the collector having non-insulated tank and pipe. The main target of this work was to increase the efficiency and to retain the hot water temperature of the storage tank reducing the heat loss from the tank using insulation. And it is fulfilled from the experimental results. Here we have used nearly $1m^2$ collector with 3 riser tubes. But it is obvious that comparing with previous experimental works that to increase the amount of enhanced water temperature, collector with a face area about $2m^2$ and 4 riser tubes is needed.

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7. NOMENCLATURE

Symbol	Meaning	Unit
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	(^0C)
T_w	Water temperature	(^0C)
U_l	Overall heat loss coefficient	($W/m^2 K$)
η_i	Instantaneous solar collector efficiency	(-)