Performance Analysis of a Single-Phase Thermosyphon Solar Water Heating System

S. Sadhishkumar, T. Balusamy

***Abstract*—**A single-phase closed thermosyphon has been fabricated and experimented to utilize solar energy for water heating. The working fluid of the closed thermosyphon is 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. In this study, the effects of glazing were also observed. The water temperature rise and the maximum instantaneous efficiency obtained from this experiment with glazing using insulated water tank and insulated connecting pipe are 17°C in a period of 5 hours and 60% respectively. Whereas the water temperature rise and the maximum instantaneous efficiency obtained from this experiment with glazing using non-insulated water tank and non-insulated connecting pipe are 14°C in a period of 5 hours and 39% respectively.

***Keywords*—**Solar water heating systems, Single-phase thermosyphon, Flat-plate collector, Insulated tank and pipe.

I. Introduction

THE increment in global energy demands due to population growth and 20th century industrial revolution leads fossil fuel through a transitional phase. It is being widely realised that for sustainable development presently used energy mediums such as fossil fuel and nuclear power have to be quickly replaced by renewable energy sources. The latter are sustainable and have the potential to meet present and future projected global energy demands without inflicting any environmental impacts. Renewable energy sources such as solar, wind, hydropower and biogas are potential candidates to meet global energy requirements in a sustainable way.

Solar energy is the best alternative to fulfil the increasing energy demand and to overcome the drawbacks of conventional sources like environment pollution. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat. Flat plate solar collector is the device used to convert solar energy into heat energy. Flat plate liquid solar collectors are the most commonly used collectors today all over the world in commercial and domestic water heating applications.

Hence way that the domestic sector can lessen its impact on the environment is by the installation of solar flat plate collectors for heating water. Although it should be said that some of these collectors have been in service for the last 40-50 years without any real significant changes in their design and operational principles.

Solar collectors for hot water domestic applications are flat plate, evacuated tube or concentrating collectors. The single-glazed, flat-plate type is the most commonly used type for low temperature applications. The main component of a solar water heater is the flat plate collector. The absorber plate serves as the central component of a collector. The thermal performance of a solar collector depends on the optical and thermal properties as well as on the design of the absorber plate.

A typical flat-plate collector consists of an absorber in an insulated box together with transparent cover sheets (glazing). The absorber is usually made of a metal sheet of high thermal conductivity, such as copper or aluminium, with integrated or attached tubes. Its surface is coated with a special selective material to maximise radiant energy absorption while minimising radiant energy emission. The insulated box reduces heat losses from the back and sides of the collector [1].

Thermosyphon or natural circulation solar water heating systems (SWHS) are the simplest and most widely used solar energy collection and utilization devices (Fig. 1). It consists of a collector, storage tank and connecting pipes. The collector is made up of an absorber plate, riser and header tubes, glass cover, casing and insulation. Water in the riser tubes get heated and flows to the storage tank due to density difference. This flow depends on the thermosyphon head due to the buoyancy force, which is due to the change in density of water caused by water temperature rise in the solar collector.

The solar energy is used in different types of fields for many applications. Many experiments have been performed regarding conversion of solar energy into heat [2]-[5]. Using single-phase heat transfer technique, lots of works have been done. In this study, the experiments are performed in a solar flat-plate collector, employing single-phase heat transfer process, by using non-insulated water tank and non-insulated connecting pipe and also by insulated water tank and insulated connecting pipe [6]-[8]. For this purpose, a flat plate solar collector acts as heater and a water tank stores the hot water. There is a scope to reduce a huge amount of heat loss from the tank and also from the connecting pipe. 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

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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.

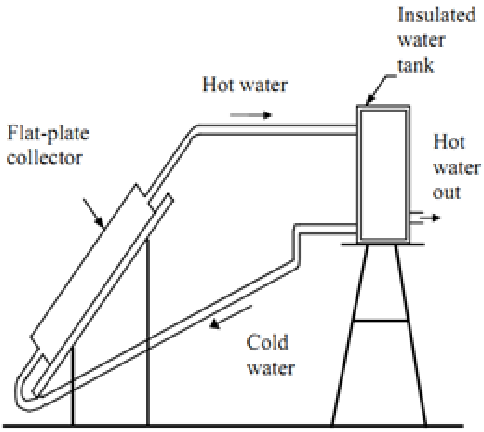

Fig. 1 Experimental setup of a single phase thermosyphon solar water heater with insulated water tank

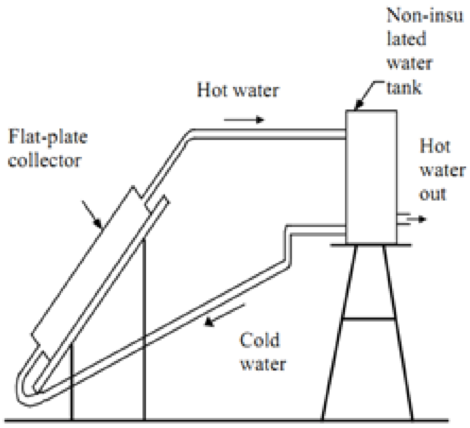

Fig. 2 Experimental setup of a single phase thermosyphon solar water heater with non insulated water tank

II. Experimental Set Up

Thermosyphon or natural circulation solar water heating systems (SWHS) are the simplest and most widely used solar energy collection and utilization devices (Fig. 1). It consists of a collector, storage tank and connecting pipes.

A. Solar Collector

It is the central part of the solar water heating system. The collector, which receives the sun's rays and heats the water, is made up of four parts.

These parts include as followings:

(i) Absorber Plate: For this experiment 22 gauges G.I sheet absorber plate is used.

(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: Wooden chips, glass wool etc. are used.

(iv) Glazing: One transparent cover which is made of low iron glass.

B. The Collector Housing

The exterior box which integrates the other components that makes up the collector. The box is made of gamier wood (thickness 3.80 cm).

C. 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.

D. Variable Inclined Stand

This stand is made of M.S angle bar.

Knowledge of the temperature distribution in the collector (absorber plate, cover and water in the riser tubes) and the flow of water in the riser tubes and connecting pipe of a solar water heating system are necessary to understand the performance of a SWHS. Water in the riser tubes get heated and flows to the storage tank due to density difference. This flow depends on the thermosyphon head due to the buoyancy force, which is due to the change in density of water caused by water temperature rise in the solar collector [9-10]. Schematic diagram of single-phase thermosyphon type flat–plate collector with insulated water tank and with non-insulated water tank are shown in Figs. 1 & 2 respectively.

III. Working Procedure

The thermosyphon system is installed at Government College of Engineering, Salem, Tamilnadu, India (23.7° N) where the average solar radiation is in the range of 5-5.5 kWh/ m^2/day [6]. After construction, the flat-plate collector held at a tilted angle of 22 degree and also 35 degree (on 18 April 2014) facing south on a supporting structure. To compare the performance parameters, the experiments are performed on the same collector with insulated water tank and insulated connecting pipe and with non-insulated water tank and non-insulated connecting pipe. During the 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 the experiments have been conducted on several days. 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 the 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.

IV. 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 have been made and these are shown in Figs. 3–5.

Working conditions:

(i) With glazing and with insulated tank & pipe on 16 April 2014

(ii) With glazing & with non-insulated tank & pipe on 17 April 2014

(iii) Without glazing & with non-insulated tank & pipe on 18 April 2014.

B. Experiments with Insulated Tank and Insulated Connecting Pipe

From Figs. 3–5, we get that the solar insolation varied from 265 W/m^2 to 810 W/m^2 and the ambient temperature was 28°C. The plate temperature raised as high as 68°C and the water temperature raised up to 48°C and the collector instantaneous efficiency was as high as 60% with glazing.

C. Experiments with Non-Insulated Tank and Non-Insulated Connecting Pipe

From Figs. 3–5, we get that the solar insolation varied from 600 W/m^2 to 824 W/m^2 and the ambient temperature was 36°C. The plate temperature raised as high as 67°C and the water temperature raised up to 49°C and the collector instantaneous efficiency was as high as 39% with glazing.

D. Experiments without Glazing and with Non-Insulated Tank and Non-Insulated Connecting Pipe

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°C. The plate temperature raised as high as 105°C and the water temperature raised up to 47°C and the collector instantaneous efficiency was as high as 40% 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 Table I.

TABLE I
Performance of the Single Phase Thermosyphon Type Flat – Plate Collector with Glazing

Date	**Working condition**	**Average solar insolation I (W/m^2)**	**T_{pm}**	**U_l (W/m^{2}K)**	**Q_u (Watt)**	**F_R**	**(η_i) m (%)**
16 April 2014	With non insulated tank and non insulated pipe	674	41.00	18.11	175	0.461	32
17 April 2014	Do	576	74.35	4.69	195	0.622	48
18 April 2014	With insulated tank and insulated pipe	522	60.72	4.54	273	0.785	60
	Do	460	54.80	5.57	195	0.694	54

Here, T pm = Average temperature of the absorber plate,
U_l = Overall loss coefficient,
Q_U = Useful heat gain,
FR = Collector heat removal factor,
(η_i) m = Maximum instantaneous efficiency.

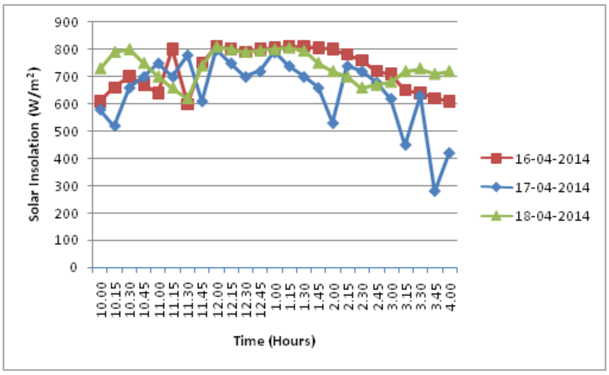

Fig. 3 Hourly variation of solar insolation on the flat plate collector

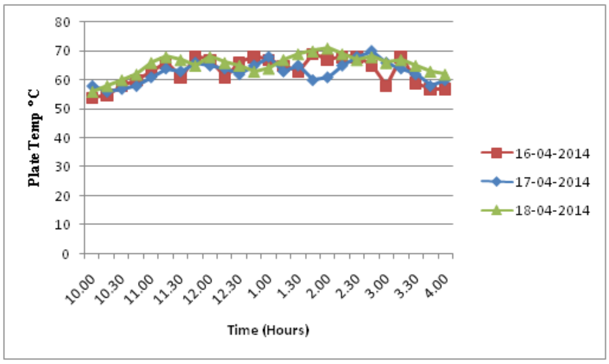

Fig. 4 Hourly variation of plate temperature of flat plate collector

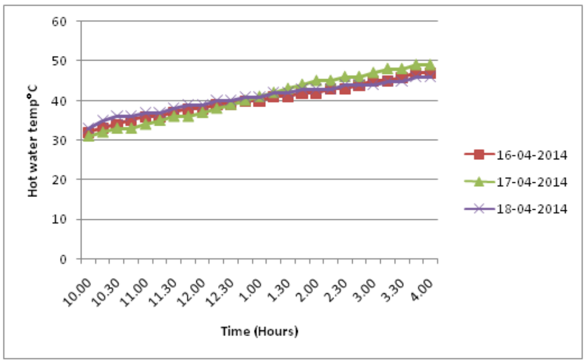

Fig. 5 Hourly variation of hot water temperature of the collector

V. 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°C for the collector with insulated tank and pipe and 13°C 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 $1m^2$ collectors 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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