ISSN (Online): 2455-7838
SJIF Impact Factor (2016): 4.144
UGC Approved Journal No: 48844

EPRA International Journal of

Research & Development

(IJRD)

Monthly Peer Reviewed & Indexed
International Online Journal

Volume:2, Issue:6, June 2017

Published By :
EPRA Journals

UGC Approved Journal No: 48844 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
SJIF Impact Factor: 4.144 Volume: 2 | Issue: 6 | June | 2017

EXPERIMENTAL INVESTIGATION OF PERFORMANCE OF THERMOSIPHON CONCEPT OF SOLAR WATER HEATING SYSTEM TOWARDS SUSTAINABLE DEVELOPMENT

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ABSTRACT
The experimental study of performance of thermosiphon concept of solar water heating system is presented in this paper. A thermosiphon solar flat plate water heater is designed, constructed and instrumented for the experiment. Design analysis was carried out to determine the solar collector area and the storage tank volume that will allow optimum performance of the system. The location of the collector system is north-south direction upon which the sun is allowed to heat the water in the collector through various water tubes that absorb the heat from the plate by conduction and transfer it to the water passing through the tubes by convention. In the process, the water becomes warmer compared to the water in the tank. The parameters measured include water flow rate in M^3/hr *using industrial grade water flow meter. Five sets of temperature readings: Inlet temperature* (T_1)*, Plate temperature* (T_2)*, Outlet temperature* (T_3)*, lower tank temperature* (T_4) *and upper tank temperature* (T_5) *were taken. The results show that the maximum temperatures recorded were 83* ^{O}C *for outlet temperature, 74* ^{O}C *for plate temperature, 35* ^{O}C *for lower tank temperature and 48* ^{O}C *for upper tank temperature. The system was found to be highly efficient.*
KEYWORDS: *Temperatures, Solar Energy, Thermosiphon and Flat Plate Collectors*

1. INTRODUCTION

Due to the increasing harmful side effects and rising cost of fossil fuels (i.e gas, petrol and oil), solar energy is considered as the most capable of the alternative energy sources. In the present energy scenario, solar energy among other non-hydro modern renewable energy technologies is in the fastest rate of increase (Arunachala, 2011). Water heating for domestic, office and industrial purposes is a simple and effective way of utilizing solar energy.

Conventional Natural Circulation Solar Water Heating Systems (SWHS) are the most economical and large scale application of solar energy all over the world. The temperature levels required (40 - 60 ^{O}C), can be produced efficiently by simple, relatively inexpensive collection devices. The combination of moderate temperature requirements and uniform annual demand makes the production of hot water for domestic, commercial and industrial uses a particular attractive application for solar energy (Kreidar and Kreith, 1981).

One method of classifying solar water – heating systems is to divide them into direct and indirect designs. Direct system design are those in which the portable water is heated directly in the solar collector whereas the indirect systems are those in which a separate heat transfer medium is used in the solar collector loop and portable water is heated indirectly by a heat exchanger. Again, SWHS of direct or indirect design may be described as active or passive depending on the type of circulation adopted in the collector loop. Active systems adopt forced-circulation and require pump to drive water round the collector circuit whereas passive systems employ natural, convective circulation rather than pumps to force water through the solar collectors (Kreidar and Kreith, 1982).

Thermosiphon systems are passive water-heating systems, requiring no pumps or controls. Their operation is based on natural pressure circulation. Thermosiphon systems are fundamentally simpler to design and build than are active systems of either direct or indirect design. Their performance is equal to and in some cases better than that of the active systems. The only requirement for proper functioning is that relatively larger piping be used, since the pressure available to cause fluid flow is relatively small. Piping should have a minimum of tight elbows, and sweeping bends are preferred to reduce pressure drops (Kreidar and Kreith, 1982; Gupta and Garg, 1968).

Solar collectors are the key component of solar heating systems. Solar collectors gather the sun's energy transform its radiation into heat and then transfer the heat to water. Solar collectors may be grouped into four classes: flat-plate collectors, concentrating collectors, hybrid collectors and tubular collectors. Flat-plate collectors have the capability of collecting and using both the direct (or beam) and the diffuse radiation from the sun. Flat plate collectors with one or two cover plates and selective surface absorber are most commonly used for domestic water heating and space-heating applications due to their high efficiencies at low temperatures and low costs.

2. MATERIALS AND METHODOLOGY

Description of the Experimental set up and Test Procedure

A thermosiphon solar flat plate water heater is designed, constructed and instrumented for the experiments. It is made up of a single collector flat plate, a storage tank and connecting pipes.

The collector plate (absorber plate) that has 0.5mm thickness, 850mm width and 1820mm length was made of aluminum painted with black paint. The design of size of the collector was made 1.547m^2 for it to remain portable, allows for sufficient clearance in most doorways and would allow for safe transportation from storage to a testing environment.

Eight evenly spaced parallel, 12.5mm (1/2) ″, copper pipe (water flow tubes) were welded to the collector surface. These flow tubes are linked together through the supply and drain headers (18.1mm or ¾″ copper pipes). Thermometer sockets were installed on the collector plate, supply and drain headers for collector plate, water inlet and outlet temperatures respectively (see figure 2.1).

The collector assembly was encased in a rectangular galvanized metal box. The top of the box is covered with a transparent 3mm white glass while the sides and bottom of the absorber plate are lagged with glass wool to insulate it from having contact with the metal casing. This is done to prevent heat loss to the casing by conduction. Figure 2.2 shows the collector assembly with the cover glass, casing, insulation, water flow pipes and absorber plate

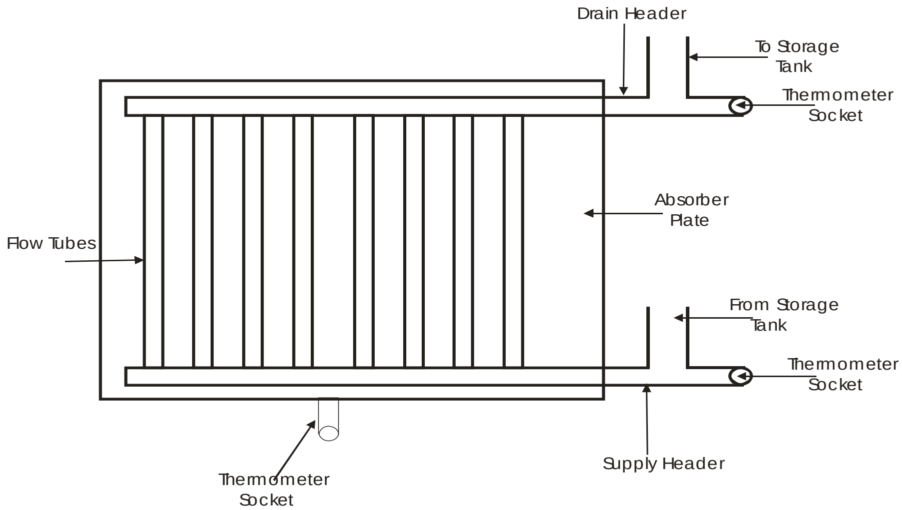

Fig 2.1: Collector plate showing water flow tubes, header pipes and thermometer sockets

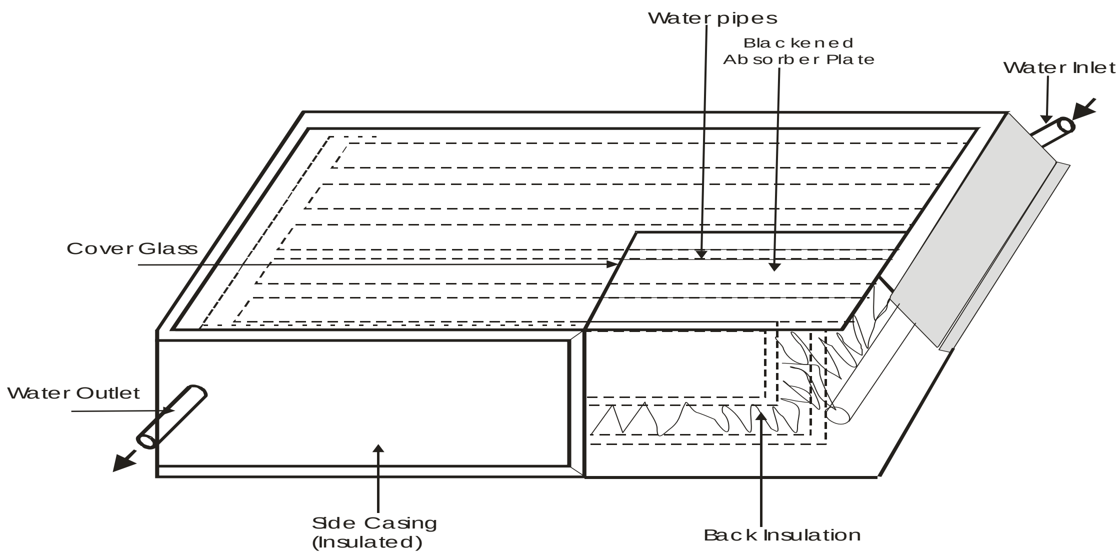

Fig 2.2: Solar Collector Showing cover plate, insulation, casing, water pipes and absorber plate.

The storage tank is cylindrical in shape with a storage capacity of 70.8liters. It is made from a 5mm galvanized steel plate. The tank was designed such that the water can enter and exit the tank and allows for the thermosiphon effect to take place. A cylindrical metal casing of the same material was made to house the storage tank. The metal casing has a lagging material in between to reduce or prevent heat loss to surrounding by the water. A pressure release valve is installed at the top tank to prevent excessive pressure build up in the tank. The storage tank is placed on a metal stand having a height of about 2m from the ground surface.

The connecting pipes supply water to the tank and collector inlet and also drain water from collector to the tank. Thermometer sockets are provided at the upper and lower parts of the tank for temperature measurement. A water flow meter is connected between the collector inlet and the water supply pipe from the tank to measure the water flow rate in M^3/hr. The collector assembly is placed in a north-south direction and inclined at an angle of 35 ^{O}C to the horizontal with the top of the collector having a distance of at least 35cm below the bottom of the storage tank to avoid reverse flow during the night. The general cross section of the experimental set-up is illustrated in figure 2.3

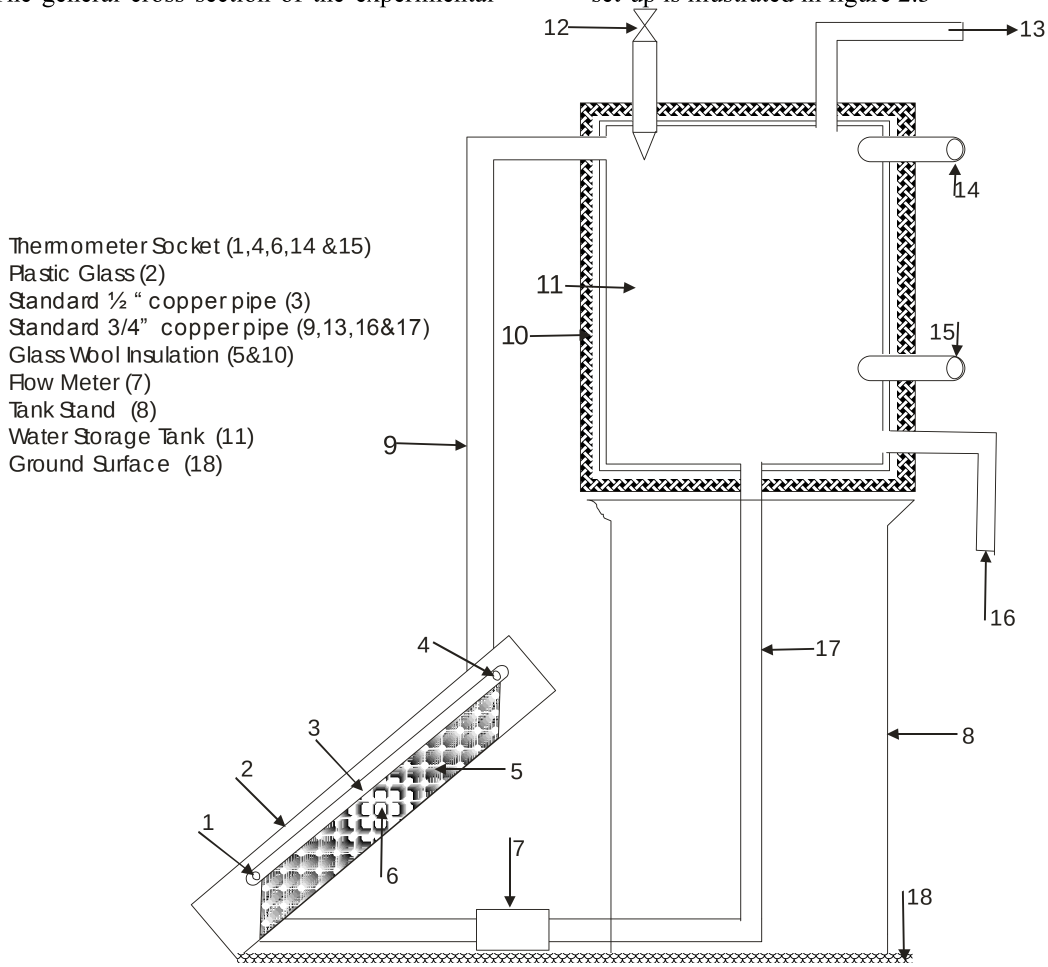

Fig 2.3 General View and cross-section of Experimental Set-up

Figure 2.4 illustrates in a block form the general setup of the designed thermoiphon solar water heater. The sun is the source of the solar radiation. This solar radiation is absorbed by the blackened absorber plate and converts it to heat. The heat is transferred to the flow tubes by conduction. The water in the flow tubes is in turn heated by convention process between the tubes and the water molecules. The heated water becomes warmer and less dense than the water in the storage tank. This density difference results in buoyancy forces, which create a continuous convective circulation of water from the bottom of the tank to the bottom of the collector, up through the collector flow tubes, and back into the top of the tank. This process is continuous until late afternoon when the plate temperature is highest.

The steady circulation of water in the collector loop results in the rise of water temperature in the tank. Mixing between the water at upper and lower parts of the tank results in a uniform water temperature in the tank at sunset. At sunset, the water supply line is locked to stop water circulation in the loop. This is to prevent further fall in temperature of the water in the tank since the absorber plate temperature is now the same as the ambient temperature and will increase heat loss if circulation is not discontinued at this time.

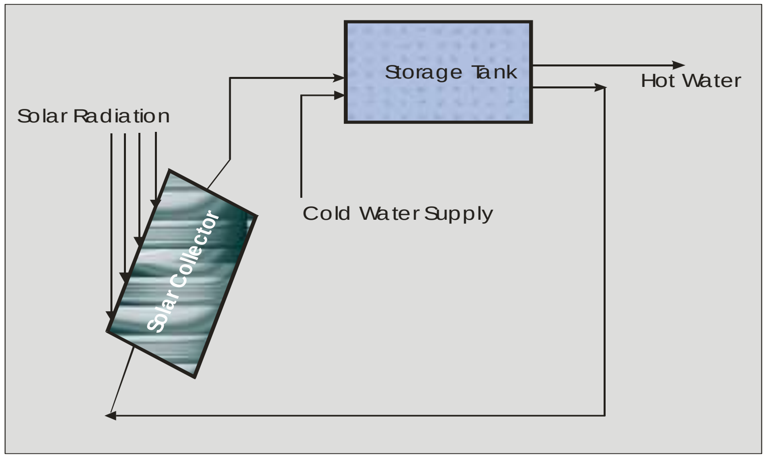

Fig 2.4 Block Diagram Representation of a Thermosiphon Solar Water Heating System

Materials of Construction

The various materials for this set-up were procured from the nearby market. Aluminium was used for the solar collector since it is comparatively cheaper and has a high thermal conductivity. it is lighter and good material for the solar absorber. It is painted with dull black paint for high abosorptivity. Black paint has the ability to absorb light of virtually all wavelengths (Ochuenwike, 2008). Copper tubes were selected for the piping because of its high thermal conductivity and anti corrosive properties.

Glass was used for the cover plates for its stability and high transmittance to visible light. It has low transmittance to infra-red radiations (Abraham and Daghigh, 2009). Glass wool was used for insulation. it is comparatively cheaper and readily available . It is widely used for its low thermal conductivity.

Design Analysis /Component Sizing of the Set Up

From performance prediction for water heating systems, it has been found that the size of all components in this solar water heating system can be related to collector area. Since performance is related to collector area, the optimal sizing procedure can be based on this index of system size alone. The sizing rule for domestic water heating systems as given by Kreidar and Kreith (1981) is applied here in determining the storage tank volume/collector area that will allow optimum performance of a single collector system. This rule gives collector area as being approximately equal to $1ft^2$ per gallon per day ($1ft^2$/gal.day). In locations with average available solar energy, flat plate collectors are sized approximately half to one-square foot per gallon of one day's hot water use.

From the collector dimensions given in table 1,

Collector area = $0.85m \times 1.82m$

Collector area = $1.55m^2 = 16.74ft^2$ (since $1m^2 = 10.8ft^2$)

From sizing rule [3], $1ft^2 \rightarrow 1$ gal/day

$\therefore 16.74ft^2 = 16.74$gal/day

but 1 gal = 3.8litres

$\therefore$ 16.74gal/day = 63.6 litres/day

To allow for tolerance, the volume of the storage tank is designed to be greater than 63.6 litres.

Thus, the height and diameter of the tank from table 1 are 780mm and 340mm respectively. Since it is cylindrical in shape, applying formular for the volume of a cylinder,

$V=\pi r^2 h$

where r and h are the radius and height of the tank respectively.

$\therefore$volume of the tank = $3.142 \times 170^{2} \times 780$

Volume of the tank = $70826964 \text{ mm}^3 = 70826 \text{ m}^2 =$ 70.8 liters

Other important technical details are shown in table 1

Table 1 technical data for the solar water heating system

S/N	Items	Details
1	Water flow pipes	8 parallel 12.5mm (1/2″) I.D , 1680mm long copper pipe
2	Supply and drain headers	18.1mm (3/4″) I.D, 1000 mm long copper pipe
3	Insulation	40mm Glass wool
4	Glass cover plate	3mm plastic glass
5	Collector plate	850mm ×1820mm×0.5mm Aluminium paited matt black
6	Casing	5mm galvanized steel
7	Water tank	Cylindrical , 5mm thick galvanized steel of holding capacity 70.8 liters (i.e 340mm I.D ×780mm long)

3. RESULT AND DISCUSSION

The experiments were performed at the department of Mechanical Engineering Technology, Federal Polytechnic, Oko, Anambra state, Nigeria. The experiment was started on the first day by charging the storage tank with fresh tap water. No water was drawn off from the system throughout the experiment. During the experiments, water flow rate, system and ambient temperatures were measured respectively and recorded every thirty minutes. Table 2-4 show the experimental data obtained for three days

Table 2: Experimental Data For September 26, 2015.

Time (Hour)	Ambient Temp. (^{0}C)	Inlet Temp. (^{0}C)	Plate Temp. (^{0}C)	Outlet temp. (^{0}C)	Lower Tank Temp. (^{0}C)	Upper Tank Temp (^{0}C)	Water Flow rate (cm^3/min)
7.00	20.0	19.0	18.0	17.0	28.0	28.0	331.4
7.30	20.0	20.0	19.0	17.0	28.0	28.0	331.4
8.00	22.0	20.0	19.0	17.0	28.0	28.0	331.4
8.30	24.0	21.0	21.0	19.0	28.0	28.0	331.4
9.00	26.0	24.0	25.0	22.0	28.0	28.0	331.4
9.30	29.0	30.0	31.0	26.0	28.0	29.0	331.4
10.00	32.0	36.0	36.0	33.0	28.0	30.0	331.4
10.30	35.0	43.0	44.0	41.0	28.0	32.0	331.4
11.00	38.0	49.0	51.0	50.0	29.0	33.0	331.4
11.30	40.0	55.0	57.5	57.0	29.5	34.0	331.4
12.00	42.0	61.0	61.0	65.5	30.0	35.0	331.4
12.30	40.0	64.0	69.0	69.0	30.5	35.0	331.4
13.00	40.0	61.0	64.0	68.0	31.0	35.0	331.4
13.30	42.0	63.0	68.0	74.0	31.0	37.0	334.0
14.00	44.0	65.0	69.0	83.0	31.0	39.0	335.2
14.30	38.0	58.0	59.0	66.0	32.0	36.0	336.8
15.00	40.0	53.0	53.0	59.0	32.0	36.0	339.6
15.30	42.0	54.0	60.0	60.0	32.0	36.0	343.7
16.00	40.0	53.0	55.0	60.0	32.0	32.0	333.7
16.30	40.0	52.0	53.0	57.0	32.0	36.0	321.8
17.00	38.0	50.0	52.5	56.0	32.0	36.0	321.8
17.30	37.0	46.0	48.5	51.0	32.0	35.0	321.8
18.00	35.0	41.0	43.0	45.0	32.0	34.0	321.8
18.30	33.0	36.0	36.0	37.0	32.0	32.0	321.8

Table 3: Experimental data for September 27, 2015

Time (Hour)	Ambient Temp. (^{0}C)	Inlet Temp. (^{0}C)	Plate Temp. (^{0}C)	Outlet temp. (^{0}C)	Lower Tank Temp. (^{0}C)	Upper Tank Temp (^{0}C)
13.00	44.0	61.0	74.0	69.0	28.0	35.0
13.30	42.0	60.0	70.0	77.0	29.0	35.0
14.00	42.0	62.0	72.5	81.0	29.0	36.0
14.30	42.0	64.0	67.0	72.0	29.0	36.0
15.00	42.0	62.0	67.0	71.0	29.0	36.0
15.30	42.0	59.0	70.0	69.0	30.0	37.0
16.00	40.0	56.0	65.0	65.5	30.0	36.0
16.30	40.0	51.0	56.0	60.0	30.0	35.0
17.00	38.0	47.5	52.5	54.0	30.0	34.0
17.30	37.0	43.0	48.5	48.0	30.0	33.5
18.00	36.0	39.0	43.0	43.0	30.0	32.5
18.30	32.0	35.0	38.0	38.0	30.0	31.5
19.00	30.0	31.0	33.0	33.0	30.0	30.0

Table 4 Experimental Data for September 28, 2015

Time (Hour)	Ambient Temp. (^{0}C)	Inlet Temp. (^{0}C)	Plate Temp. (^{0}C)	Outlet temp. (^{0}C)	Lower Tank Temp. (^{0}C)	Upper Tank Temp (^{0}C)
14.45	40.0	35.0	70.0	65.0	28.0	35.0
15.15	39.5	50.0	64.0	60.0	30.0	37.0
15.45	39.0	56.0	62.0	62.0	31.0	36.0
16.15	38.0	56.0	59.0	59.0	31.0	36.0
16.45	38.0	53.0	54.0	54.0	30.5	35.0
17.15	37.0	49.0	49.0	49.0	30.0	35.0
17.45	35.0	43.0	43.0	43.0	30.0	33.0
18.15	34.0	39.0	39.0	39.0	30.0	33.0

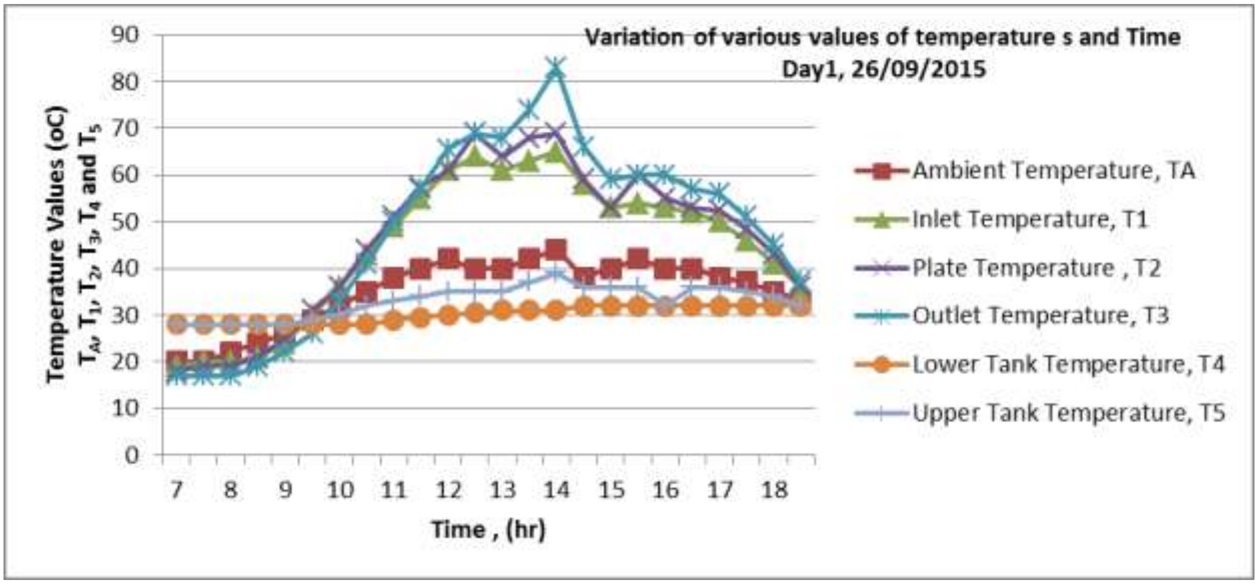

Fig 3.1: Variation of Various values of temperatures and Time, Day1, 26/09/2016

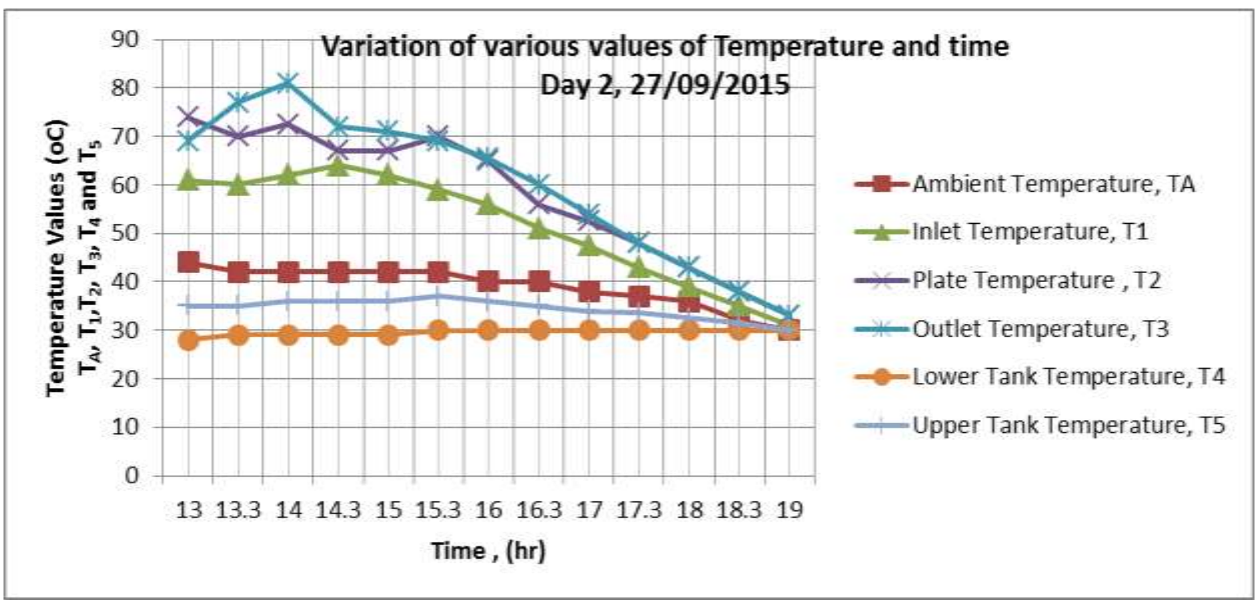

Fig 3.2 : Variation of various values of temperature and time, Day 2, 27/09/2016

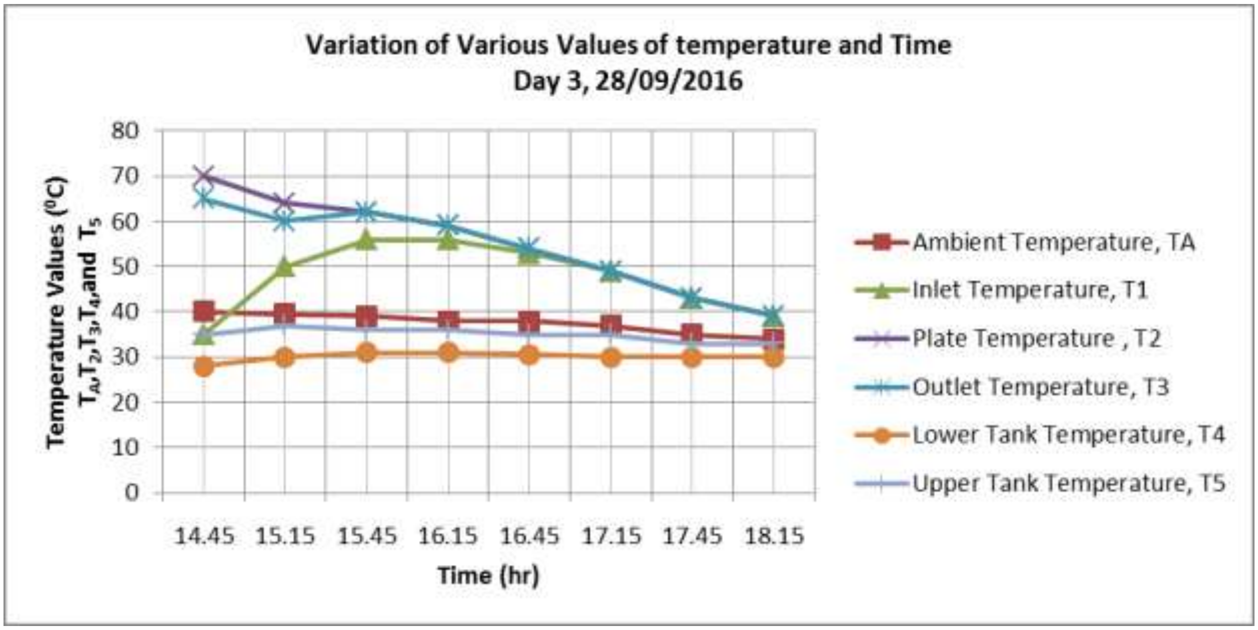

Fig 3.3: Variation of various values of temperature and time, Day 3, 28/09/2015

Figure 3.1 shows ambient, water inlet, water outlet, plate, lower tank and upper tank temperatures. For this particular date, measured on a clear day, the ambient temperature varied from 20 ^{O}C to 44 ^{O}C between 17.00 and 14.00 hours and the water temperatures continues to change through the day. It is noted that water inlet temperature remained almost constant for the first three hours of the experiment indicating an essentially unmixed supply of water coming from the storage tank.

Concurrently, outlet temperature from the collector is gradually increasing as is also indicated by the increasing temperature of the collector plate. This plate temperature reaches its maximum at 14.00hr when the outlets temperature attains a maximum of 83 ^{O}C . After about 2 -3 hours from the beginning of the experiment , both inlet and outlet collector temperatures increases up until sometimes in the afternoon (about 14.30 local time) when a decline in both these temperatures is observed.

The variation patterns of the measured values of water inlet, water outlet, plate, lower tank and upper tank temperatures compare very well with the works carried out by Farringtoon, Murphy and Noreen (1980) and, Gupta and Garg (1968) on thermosiphon solar water systems.

The decline of collector water inlet and outlet temperatures in the late afternoon hours is indicating enhanced energy losses form the system to the surroundings. Outlet temperature drop is a compounded, result of a lower ambient temperature and much lower solar insulation. This loss of energy could be reduced significantly by installing an automatic valve in the system that will stop water circulation as soon as such a phenomenon occurs.

The drop in collector inlet temperature however, is due to the fact that the feed pipe , was not insulated . This fact, combined with the smaller flow rate and consequently the greater residence time of water in this pipe, enhanced energy losses to the environment.

It is also shown that at the beginning of the experiment, water temperature is uniform throughout the tank. As the experiment progresses, the temperature at the upper part of the storage tank increases, with no apparent changes in temperature at the lower part. This trend continues until about 4-5 hours from the beginning of the experiment when the temperatures throughout the tank are changed.

The measurements inside the storage tank lead to the conclusion that little or no mixing of water is present inside the tank. The stratification which is quite an important factor, is maintained due to the very slow water flow. It should be noted, however, that the above observation would probably hold in cases without any hot water consumption during the experiment. A greater mixing effect is to be expected with water extracted from the tank, depending on the consumption pattern.

The same pattern is depicted in figure 3.2 and 3.3 with a slight variation which is accounted for by the time of commencement of the experiment and the ambient temperature variation pattern for these dates.

Figure 3.4 shows the measured values of the water flow rate and the collector plate temperatures.

Water flow rate in the system was found to generally follow the pattern of variation of the solar insolation as expected. Accordingly the flow rate increases during the morning hours , reaches a maximum of about 343.7cm^3/mm , and then starts to decline in the late afternoon hours. Based on these measured values, it was estimated that the flow in the collector was laminar throughout the day. In the connecting pipes, the flow was also laminar for most of the day, becoming transitional around noon time only.

4. CONCLUSION

It has been shown through the experimental investigation that a thermosiphon concept of solar water heater has yielded very promising result. The experimental measurements indicate that the water in the tank was heated by the solar energy being absorbed by the solar collector. Moreover, the water temperature measurements at the lower and upper parts of the storage tank show the thermosipon effect. It has shown that it is possible to use the system to have heated water supply at the required time in homes, hospitals, industries among others. Results indicate that the experiment performed was a success.

5. RECOMMENDATIONS

This study points to the need to perform more detailed and in-depth studies of thermosiphon solar water heating systems. Specifically, there is need to develop a software to ascertain the level of effect of impurities present in water which form deposits in the flow passages (scaling) of the system . This will call for high efficiency of thermosiphon solar water heating system in the future.

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