

Performance Analysis of Domestic Thermosyphon Solar Water Heater at Mautech, Yola Nigeria

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Abstract
This paper present the performance profile of a thermosyphon flat plate solar water heater developed at the Modibbo Adama University of Technology (MAUTECH), Yola. The major components of the heater include; solar collector, storage tank and circulating pipes. The solar collector has a surface area of 1.5 m^2 mounted on an angled-iron frame tilted to an angle of 14 degrees. Data were collected for three days (clear and cloudy days). The dynamic performance of the system to variations in solar insolation was studied and analized. The maximum output water temperature recorded was 79.5 ^oC, 71.5 ^oC and 76.5 ^oC respectively at 13:00 hr for both the three days while the maximum recorded ambient temperature was 40.63 ^oC, 36.60 ^oC and 37.54 ^oC at 16:00 hr respectively. The maximum collector efficiency occurred at 17:00 hr for all the three days with values 80.84 %, 78.96 % and 73.46 % respectively. Thermosyphon solar water heating system finds useful application and acts as cost effective renewable energy resource in region with abundant and consistent solar insolation.
Keywords: Thermosyphon, solar water heater, insolation, collector efficiency, overall heat loss coefficient

Introduction

In communities throughout the developing world, poor households struggle to meet their hot water needs. Some households rely on biomass to heat water while others rely on electricity or liquid fuels such as propane to heat their water. These fuel options are not sustainable as they are costly and contribute to the build-up of greenhouse gases in the atmosphere. Many communities face limited or intermittent access to fuel and/or electricity which limiting their ability to access hot water for hygienic and domestic uses. In many countries demand for fuel wood is one of the principal contributors to deforestation (Rasheed and Sajjadur, 1995).

Health and social communities in developing countries are institutes that make daily use of large quantities of hot water. When such communities are situated in areas that are hardly accessible to electricity, they mainly use fuel wood for water heating. These sources have adverse health, economic as well as environmental impact on the populace. Given the fact that solar radiation is present in abundance, it is justifiable to build locally-made hot water systems.

The efficiency of a solar water heating system can be optimized if the peculiarities of the location are considered in adopting an optimum design and operating parameters (Garg, 1987). Solar water heater designs and performance studies carried out in different parts of the globe such as China (Wang, 1979), Australia (Morrison and Trans, 1992), Israel (Faiman, et al., 1997) and the USA (Farber, 1959) reflect the climatic conditions of the location among other parameters.

Experimental set-up

The tests were conducted at the school of pure and applied sciences Modibbo Adama University of Technology, Yola (9^{o}13″ North) Nigeria. The schematic diagram of the thermosyphon flat plate solar water heating system is shown in Fig 1. The closed view of the thermosyphon flat plate solar water heating system is shown in Fig. 2. The system consists of flat plate collector, storage thank and connecting pipes. The flat plate collector is oriented facing south direction in order to receive maximum solar radiation. The detailed specifications of solar water heating system are given in table 1.

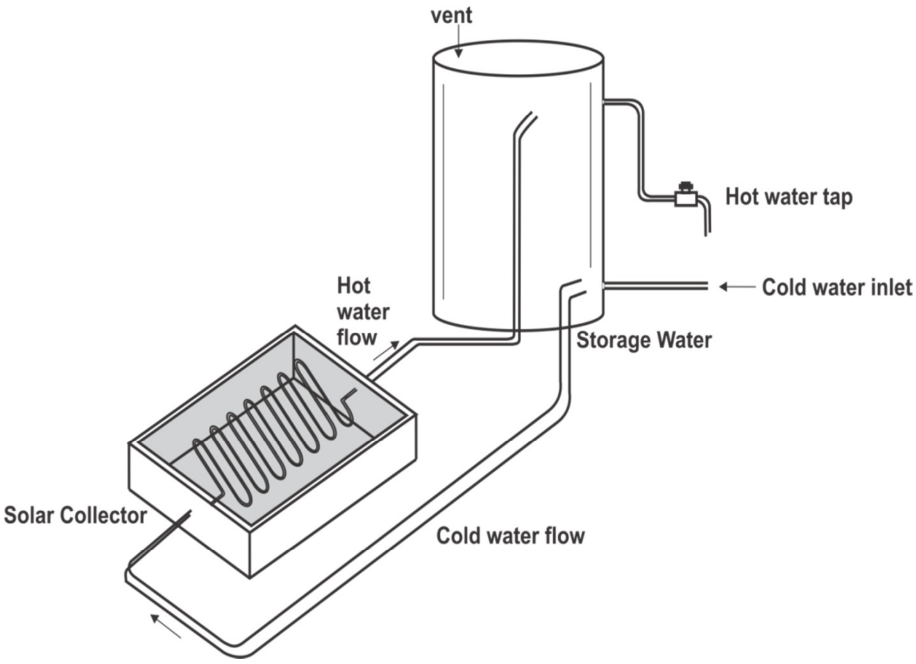

Figure 1. schematic diagram of thermosyphon solar water heating system.

Figure 2. Closed view of thermosyphon solar water heating system.

Tablbe 1. Specification of the tested system in the study.

System parts	Specification
1. Collector	
Type	flat plate
Tilt angle	14^o facing south
Collector area	1.5 m^2
Absorber plate thickness	0.5 mm
Glass cover thickness	0.4 cm
Number of risers	15
Frame	angle iron
2. Storage thank	
Type	cylindrical
Material	galvanized
Length	1 m
Diameter	0.275 m
Capacity	60 liters
Insulation material	saw dust
3. Inlet & outlet pipe	
Material	copper pipe
Diameter	1.5 cm
Insulation material	Styrofoam
4. Working fluid	water
Capacity	60 liters

Performance evaluation

The system was tested for the period of three days (clear and cloudy) in the month of May, 2015 at an interval of one hour between 9:00 am and 17:00 pm every day. The experiment was carried out in an open space where the set up was directly exposed to the sunshine free from shade of trees and buildings.

The incident solar radiation intensity and ambient temperature was collected from Nigerian Environmental Climatic Observation Programme (NECOP) instrument installed at MAUTECH) Yola. The temperature of the glass surface, absorber, air between absorber and glass, inlet and outlet water temperatures of the collector were measured using thermometer with a precision of 0.5°C.

Collector efficiency

The collector efficiency as a performance parameter is expressed as the ratio of the useful energy gained over any time period to the incident solar energy over the same time period (duffie and Beckman, 1994).

$$\eta = \frac{Q_U}{A_c I_o} \quad 1$$

The relationship between the temperature and the collector overall heat loss coefficient U_L is given by the equation for the useful heat energy (Q_u), as (Ogie *et al.,* 2013)

$$Q_U = A_c\left[I\alpha\tau - U_L\left(T_{out} - T_a\right)\right] \quad 2$$

The collector overall loss coefficient U_L is the sum of the heat losses from top and back given by

$$U_L = U_t + U_b \quad 3$$

Table 2. Performance Parameters of the Thermosyphon Solar Water Heater

Performance parameters	Calculated values
Useful energy absorbed by water per unit time Q_w	264.4444 W
Collector area A_c	1.5 m^2
Number of parallel pipe N_p	15
Transmittance –absorbtance product (τα)	0.88
Bottom loss coefficient U_b	1.3 $Wm^{-2}K^{-1}$
Top- loss coefficient U_T	3.31 $Wm^{-2}K^{-1}$
Overall heat loss coefficient U_L	4.61 $Wm^{-2}K^{-1}$
Pressure in the storage tank P_T	9800 Nm^{-2}
Tangential stress in the storage tank σ_t	4900 Nm^{-2}

Results and discursion

Figure 3 shows the hourly solar intensity from 9:00 hr to 13:00 hr for the test days. It was observe that the solar intensity increases from 9:00 hr to 13:00 hr, on day one and two and up to 14:00 hr on day three, reaching a maximum value of 774.78 Wm^{-2}, 818.55 Wm^{-2} and 778.68 Wm^{-2} respectively. For day two and three, the solar intensity decreases to 392.55 Wm^{-2} and 497.06 Wm^{-2} respectively at 15:00 hr. This occurred due to cloud cover and other atmospheric conditions. From there on, the solar intensity drops sharply towards the noon for both the three days to a value of 289.28 Wm^{-2}, 303.98 Wm^{-2} and 307.13 Wm^{-2} at 17:00 hr.

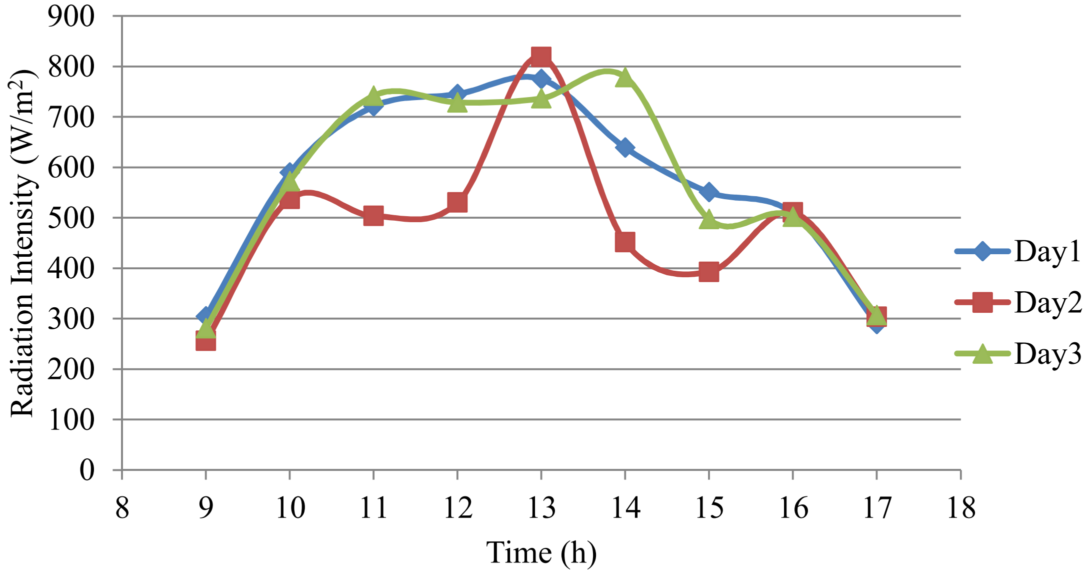

Figure 3 Hourly time variation of solar insolation for day one, two and three.

Figure 4, 5 and 6 shows the temperature profile of the solar water heater from 9:00 hr to 13:00 hr. The ambient temperature is nearly a plat bell shaped and reaches a highest peak at 16:00 hr. The inlet temperature increases slightly during the day except on day one and two where there is a sharp increase in temperature from 11:00 hr to 12:00 hr. This happened due to the increase in solar insolation. From there on, the inlet water temperature follows nearly a straight line and reaches maximum value of 61.5 ^oC, 61.0 ^oC and 61.5 ^oC at 17:00 hr for both the three days. The outlet water temperature rises significantly and attained a maximum peak at 13:00 hr on the one and three, and 14:00 hr on day two with an average temperature of 79.5 ^oC, 71.5 ^oC and 76.5 ^oC respectively. In fact, the outlet temperature follows the radiation intensity pattern in figure 3 very closely.

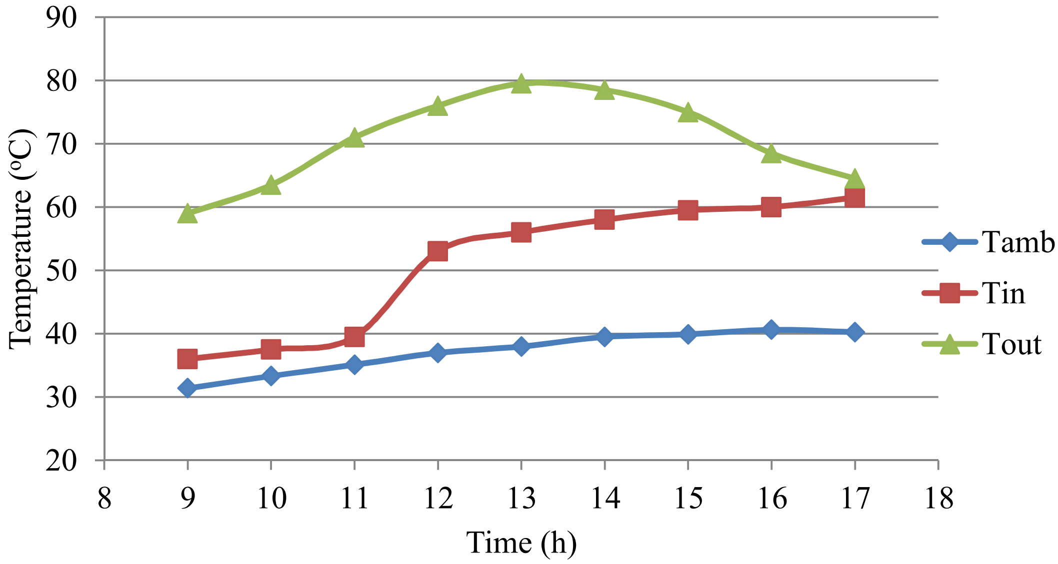

Figure 4. Time variation of Ambient, inlet and outlet temperature for day one.

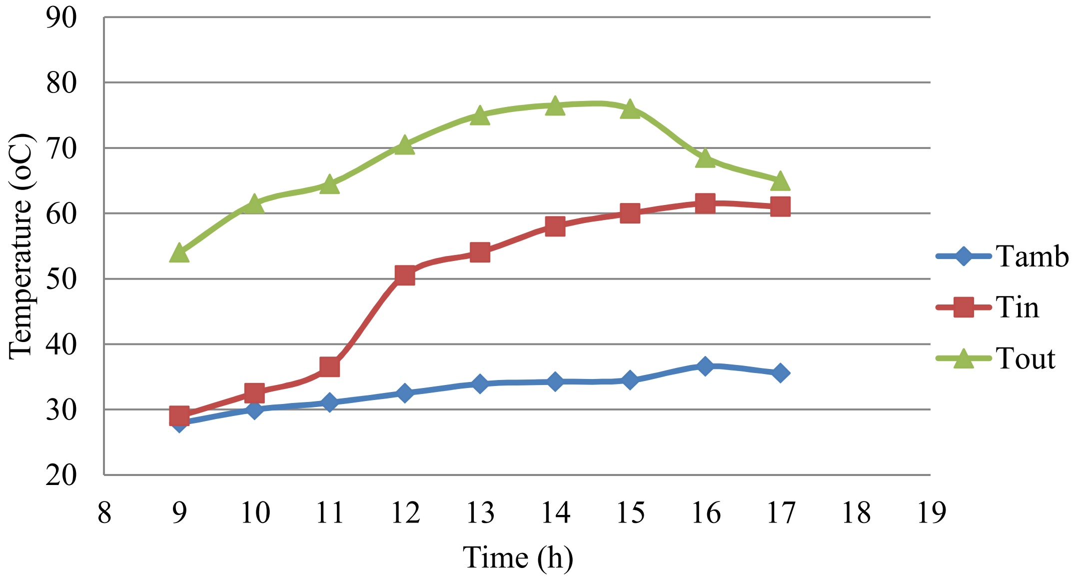

Figure 5. Time variation of Ambient, inlet and outlet temperature for day two.

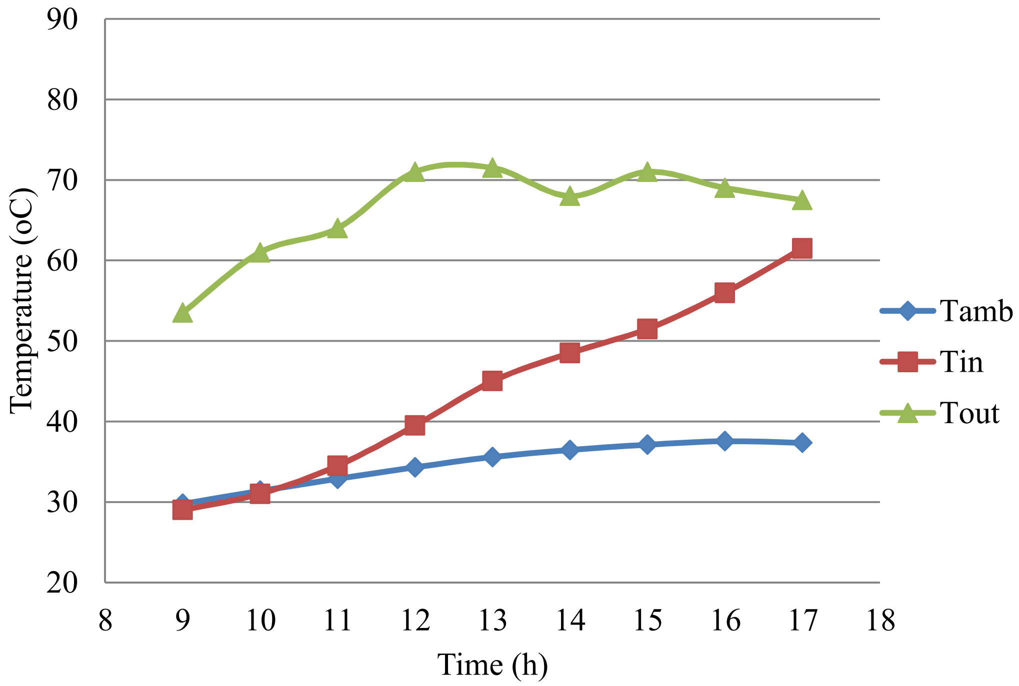

Figure 6. Time variation of Ambient, inlet and outlet temperature for day three.

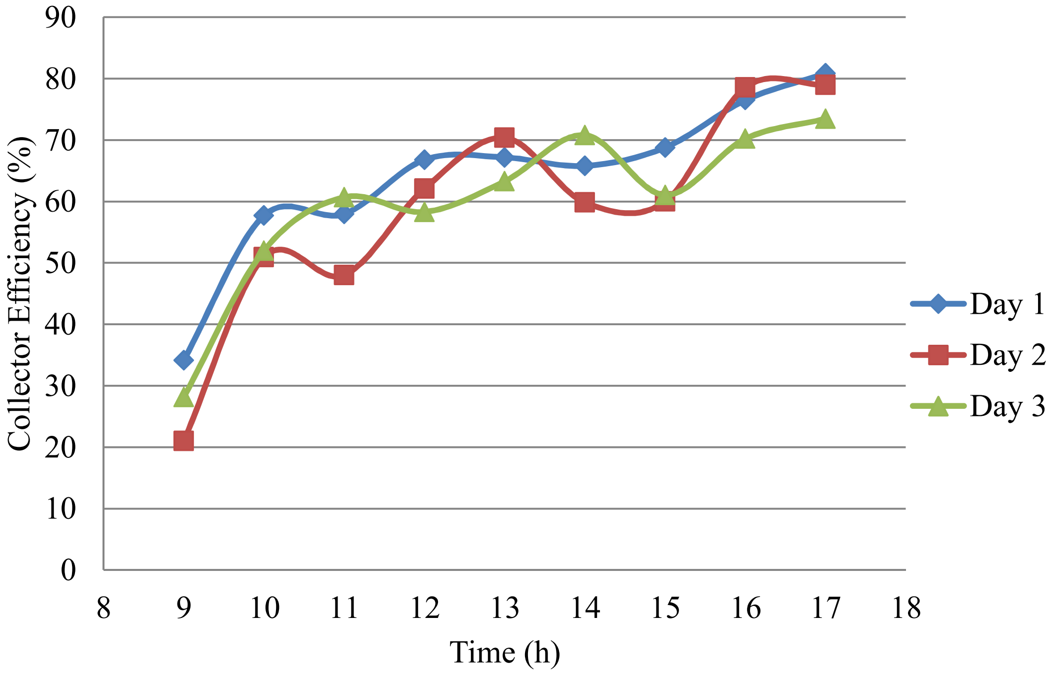

Figure 7. The curve for collector efficiency against time for the three days.

The collector efficiency at 9:00 hr for day one, two and three is 34.16%, 20.99% and 28.13% respectively. The maximum efficiency is observed at 17:00 hr in all the three days as 80.84 %, 78.96 % and 73.46 % respectively.

Conclusion

The performance of thermosyphon solar water heater has been evaluated for three days (clear and cloudy days) in the month of May 2015. The solar water heater has the capacity of 60 liters with a total collector area of 1.5 m^2. The result shows that the collector outlet temperature is a function of solar irradiance and time. The output water temperature attained a maximum at 13:00 hr for both the three days with values 79.5 ^oC, 71.5 ^oC and 76.5 ^oC respectively. The maximum collector efficiency occurred at 17:00 hr for all the three days with values 80.84 %, 78.96 % and 73.46 % respectively.

Finally, the performance of thermosyphon solar water heater in MAUTECH, North East, Nigeria, has shown that, solar water heating is feasible in Nigeria especially in the northern part of the country where the solar insolation is very high and in all other regions with similar solar insolation.

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