

Original Research Article

PERFORMANCE OF A SOLAR WATER FLAT PLATE COLLECTOR MADE FROM LOCALLY AVAILABLE MATERIALS.

Abstract:

A solar water heater constructed from a locally available materials is made and tested at university of Maiduguri campus. The sunlight energy is absorbed by the collector made up of an aluminum absorber plate enclosed within a transparent cover to prevent the emitted radiation from escaping (greenhouse effects). The absorber is made with fluid carrying tubes to absorb heat and increases the temperature of the water in the tank through theromsyphon principle. Maximum fluid output temperature and the collector temperature of 59°C and 70°C respectively were obtained on a sunny day. This solar water heating system finds useful application and acts as a renewable energy resources in regions where there is abundant sunlight.

1.0 INTRODUCTION

Solar water heating is the conversion of renewable sunlight energy into heat energy for domestic and industrial use, renewable energy resources of which sunlight is a good example are those resources which undergoes faster replenishment rate within a relatively shorter period of time at which they are utilized. The energy of the sun is generated from the nuclear fusion of the of its hydrogen into helium, with its resulting mass depletion rate of approximately of 4.7×10^6 tons per seconds and a tremendous release of heat and light (Ogie *et. al.*, 2016).

Solar energy being transmitted from the sun to through space to earth by electromagnetic radiation must be converted to heat before it can be used for practical heating or cooling (Veis and Vehebi, 2012). This energy is relatively dilutes, therefore the size of a system used to convert it on a practical scale must be relatively large. Solar collectors usually consists of a surface that efficiently absorbs radiations, and convert the incident flux to heat which raises the temperature of the absorbing material. A part of this energy is then removed from the absorbing surface by a means of heat transfer fluid that may either be liquid or gaseous. One of the simple forms of a solar energy collector built is the flat plate collector. The later usually accomplish a fluid-to-fluid exchange with more conventional heat transfer rates but with emitted radiation as an unimportant factor (Dobriyal *et. al.*, 2013). Flat-plate collectors unlike focusing systems are designed for applications requiring energy delivery at moderate temperature up to perhaps 80%

above ambient temperature (Prakash *et.al.*, (2016). They have the advantage of using beam and diffused solar radiations, not requiring orientation toward the sun, no any significant optical terms and requiring little maintenance.

The domestic solar water heater under review is a passive system and has been divided into the following components namely: storage tank, absorber plate and fluid passage. Some countries like Nigeria have abundant available solar energy from which useful energy can be harnessed for several purposes (despite the drawback of night losses). The aim of this research work is to test the performance a solar water heater from locally available materials and in the process design, constructs and test the performance of a solar water heater in Maiduguri.

2.0 THEORETICAL BACKGROUND

2.1 Passive solar water heating system

A passive solar water heating system is a device that converts solar energy to heat energy using natural convection process. Passive solar water heater heating system but they are usually not as efficient as other types. Passive systems are more efficient and may last long, passive system are of two types, they are the integral collector passive systems, which works best in areas where temperature rarely fall below freezing and thermosyphon system which utilizes water density difference between hot and cold water (Prado *et.al.*, 2016). Thermosyphon system works best in warmer climate.

2.2 Flat plate collector

A simple flat plate collector is a rectangular or square metal box with dark colored absorber at the bottom and a transparent glass cover and insulated from all sides to prevent heat loss. Sunlight passes through the glass and is absorbed by the dark colored metallic collector and thereby increasing the temperature of the collector. Heat energy from the collector is transferred to the fluid through the absorber pipes (Dobriyal *et. al.*, 2019). The variation in density between the hot water in the absorber pipes and the cold water in the storage tank(slightly elevated in height than the collector casing) cause a movement(circulation) of the hot water (less dense) into the storage tank and flow of the cold water into the absorber tubes (Nemec & Malcho, 2015).

2.3 Storage Tank

Is a water tank, that is used for storing hot water for space heating or domestic use, a heavily insulated tank can retain heat for days, water has high specific heat capacity and therefore a convenient heat storage medium (Yang and Zeng 2017). Water can store more heat per unit weight when compared with other substances. Water is cheap or even free in most countries and non-toxic. In order to heat the water using solar power, run the water through the hot collector. Solar water heater has the following disadvantages of No hot water when the sun isn't shining and the collector might get cold enough to freeze which can be very dangerous. The storage tank can store enough water and made hot water available even in cold or cloudy atmosphere.

2.4 Greenhouse Effects

The Green house effects refers to a circumstance where the short wavelengths of visible light from the sun pass through a transparent medium are absorbed , but the longer wavelengths of the infrared re-radiation from the heated objects are unable to pass through that medium. The trapping of the longer wavelengths radiation leads to more heating and a higher resultant temperature. In greenhouse, energy from the sun passes through the glass as rays of light, it is absorbed by the metallic collector and it is removed by the circulating fluid. In our design, a glass act like a greenhouse; allowing sunlight most of low wavelength from the flat plate collector from escaping, the resultant energy within the collector is therefore more than that outside (Vox *et.al.*, 2008).

2.5 Blackbody Radiation

A blackbody is a perfect absorber of light. It absorbs sunlight at all temperature, wavelength and angle of incidence. Therefore a blackbody is used for comparison with real bodies that emits and absorbs solar radiation. The color of any objects is the color of the spectrum of light it reflects, blue objects are blue because they reflects blue light while absorbing the other spectra of white light (sunlight), red objects are red because reflect only the red spectrum of solar radiation,

therefore the best absorber is black. This is why a flat plate solar collector need to be black, so that it absorbs much energy (Tian *et.al.*, 2020).

3.0 MATERIALS AND METHOD

Tables 1: List of Materials Used In Solar Water Heater.

S/NO:	Name of Materials
1	1mm Aluminum sheet
2	3mm transparent glass
3	Copper pipe
4	22 mm water storage tank
5	Fibre insulator
6	plywood
7	Angle iron
8	Metal sheet
9	valve

An already built solar water heater was considered and a similar solar water heater was built with focus on simplicity, installation and maintenance cost as well as durability(Ogie *et. al.*, 2016).. The solar water was specifically made from a locally available materials. A flat plate collector is used as the absorbers made with a coils of fluid carrying tubes and covered with a transparent glass cover. The water get heat and flows through the absorber pipes into the storage tank. The efficiency of the solar heater rely on the capacity and insulation of the storage tank and the thermal capacity of the absorber plate. All components were designed for and constructed in line with the design values obtained (Ogie *et. al.*, 2016).

3.1 Working principle

Principle of operation of a flat-plate solar water heater, the solar radiation passes through the glass in front of the absorber plate and strikes the flat black surface of the absorber plate where the solar energy is absorbed as heat (i.e by increasing the internal energy).

The collector becomes very hot and the water in the absorber fluid carrying tube attached to the collector becomes very hot by conduction. The water in the fluid carrying tubes becomes very hot and less dense than the cold water in the storage tank (Dervinis, 2018).

On the thermosyphon principle hot water in the pipes rises by natural convection and cold water in the tank descend by gravity pull into the fluid carrying tubes.

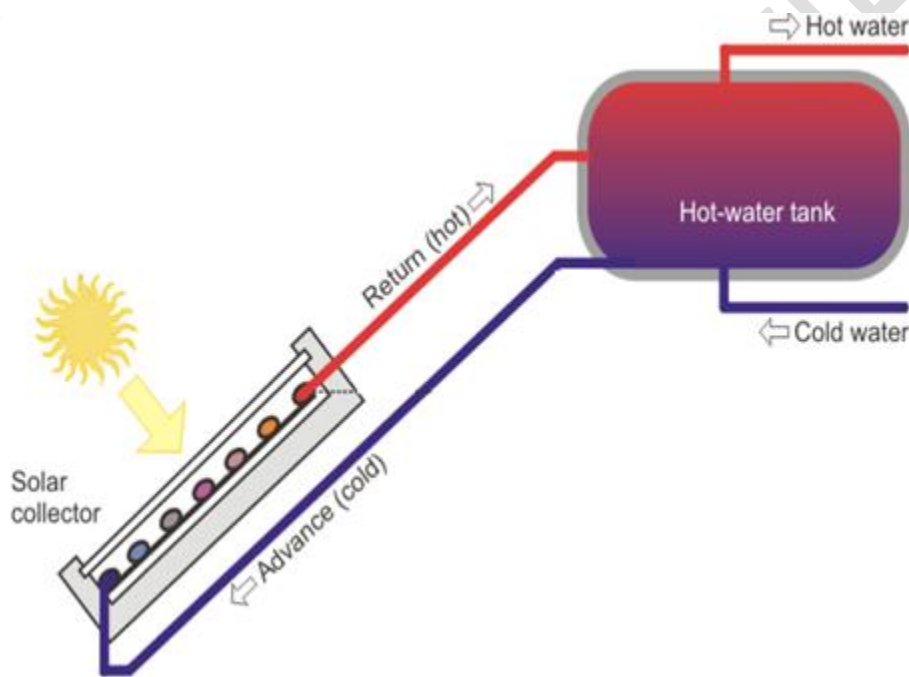


Figure 1. The working principle of solar water heater (Eschenbach, 2015)

3.2 Design Analysis/Method of Analysis

Efficiency is the ration of the input energy to the output energy, for the solar water heater; (Ogie *et. al.*, 2016).

$$\text{Efficiency } (\eta) = \frac{\text{useful energy collected by the collector } (Q_u)}{\text{solar incident illumination upon the collector } (I) \times \text{collector area } (A_c)} \quad (3.1)$$

$$Q_u = IA_c - Q_{loss} \quad (3.2)$$

$$Qu = IA_c\tau\alpha - Q_{loss} \quad (3.3)$$

Where Q_{loss} = heat loss by the collector

τ = transmittivity of the glass & α = absorbtivity of the collector

Q_{loss} is related to the overall heat loss coefficient (UL) by

$$Q_{loss} = U_L A_c (T_p - T_a) \quad (3.4)$$

therefore

$$Qu = IA_c\tau\alpha - U_L A_c (T_p - T_a) \quad (3.5)$$

$$Qu = A_c [I\tau\alpha - U_L (T_p - T_a)] \quad (3.6)$$

The average global solar insolation constant (I), is 1367W/m^2

3.3 Design of Collector Area

Collector area is the ratio of the quantity of heat (Q_w) required to raise the temperature of water from T_{in} to T_{out} to the energy absorbed by the collector over a specified period of time.

$$\text{Collector area } (A_c) = \frac{Q_w}{\mu l} = \frac{MwCw\Delta T}{\mu l} = \text{useful energy absorbed by the water.} \quad (3.7)$$

$$Q_w = MwCw(T_{out} - T_{in}) = \rho V C w (T_{out} - T_{in}) \quad (3.8)$$

volume of water on the collector plane is given by :

$$V = \frac{\mu \times Re}{\rho \times D} \quad (3.9)$$

Where Re = Reynolds number for lamina flow,

ρ = density of water,

μ = viscosity at temperature of 70°C ,

v = volume of water obtained after 30sec. D = Diameter of pipe.

desired volume of water to be obtained from

the system is 3.1 litres, therefore useful absorbed by the water for

Therefore useful energy absorbed by the water for 1 hr (3600 sec.)

$$= \frac{Q_w}{t} = \frac{\rho V C w (T_{out} - T_{in})}{3600}$$

$$Q_w = 163.75W$$

But $I = 1367W/m^2$

Average efficiency for flat-plate collector (η) = 40% and viscosity of water at 70°C, $\mu = 0.4$

$$\text{area of collector } (A_c) = \frac{Q_w}{\mu I} = \frac{162.75}{1367 \times 0.4} = 0.297m^2$$

This is the minimum requirement; hence we choose $1m^2$ as the area of collector A_c .

Mass flow rate of water within the collector is given by $Mf = \frac{Mass}{Time}$

Where $t = 30sec.$ = time to drain 3.1 litres of water within the collector.

Mass = Density (ρ) \times volume (v),

where $\rho = 10^3kg/m^3$ and $v = 3.1$ litres = $3.1 \times 10^{-3}m^3$

mass = $10^3kg/m^3 \times 3.1 \times 10^{-3} m^3 = 3.1$ kg

$$\text{massflow rate } (Mf) = \frac{3.1}{30} = 0.1kg/sec.$$

3.3 Heat Loss Coefficient

The heat lost coefficient is given as follows.

Total thermal resistance (RT) = $R_1 + R_2 + R_3$

Where $R = \frac{T_2 - T_1}{Q}$

Where $Q = I A_c \tau \alpha$

$$R = \frac{T_2 - T_1}{I A_c \tau \alpha} \tag{3.10}$$

Since all heat losses are approximately through conduction on both edges and bottom only.

The nusselt number calculated using the formular givig by (Ogie *et. al.*, 2016):

$$Nu = 1 + 1.44 \left\{ \frac{1 - 708(\sin 1.88\beta)16}{Rac\cos\beta} \right\} \left[\frac{1 - 1708}{Rac\cos\beta} \right] + \left(\frac{Rac\cos\beta}{5830} \right)^{\frac{1}{3}} - 1 \tag{3.11}$$

Where $\beta =$ the thermal expansion coefficient .

Overall heat loss coefficient obtained is $6W/m^2\text{ }^\circ C$

Recall equation (4)

$$Q_u = A_c [I \tau \alpha - U_L (T_p - T_a)] = 1 [1367 \times 0.88 \times 0.95 - 6(60 - 25)]$$

$$Qu = 1018.92\text{W/m}^2$$

3.4 Design of the Water Storage Tank

The water storage tank is single thin-walled cylinder of 40 litres capacity with a height (length of 480mm) and since 1 litre = 1000m³

$$40\text{litres} = 40 \times 1000 = 40,000\text{m}^3$$

Therefore;

Volume (V_T) = Area (A_T)* Height (H_T).

But $A_T = \frac{\pi D^2 H_T}{4}$, Therefore

$$V_T = \frac{\pi D^2 H_T}{4}$$

$$DT = \sqrt{\frac{4V_T}{H_T\pi}} = \sqrt{\frac{4 \times 40 \times 10^6 \text{ mm}}{480 \times 3.142}} = 325\text{mm} \quad (3.12)$$

Therefore, diameter of the cold water tank (D_T) IS 325mm. the pressure at the cold water tank at full capacity is given by

$$P_T = \rho w_1 g H_T$$

Where P_T = pressure at the cold water exit of the storage tank

g = acceleration due to gravity m/s^2

ρ = density of cold water (kg/m^3)

$$P_T = 1000 * 9.81 * 0.56 = 5493.6\text{Pa} \text{ or } 5.5\text{KPa.}$$

It means that as H_T increases. This increase in the pressure in the tank results in an increase in the flow rate of water through the flat-plate collector, hence, efficiency is improved because

transfer of the entrapped heat in the collector to the water inside will be faster, thereby minimizing convection and other losses from collector.

The coefficient of cubic expansions of water at 40-60°C is give as $4.58K^{-1} \times 10^{-4}$

Pressure of hot water in the storage tank at full capacity is given by

$$P^1 = \rho W_2 g H_T^1$$

ρW_2 is the density of hot water

$$\rho W_2 = \rho W_2 [1 + \gamma \Delta T]^{-1}$$

$$1000 [1 + 4.58 \times 10^{-4} K^{-1} \times 45^\circ C]^{-1}$$

Where γ is the coefficient of cubic expansion of water at

$$70^\circ C = 4.58 \times 10^{-4} K^{-1}$$

$$\rho W_2 = 978.81 Kg/m^3$$

$$P_T = 978.81 * 9.81 * 0.56 = 5493.6Pa \text{ or } 5.5KPa.$$

4.0 RESULTS AND DISCUSSION

4.1 Testing



Figure 2 : The Constructed Solar Water Heater

The tank was filled with water after proper filtration. The water flow to the circulating pipes, which are made of riser and header pipes. Through the carriage pipe (i.e the inlet pipe). The water is heated up from the heat supplied by the absorber plate to the tubes integrated underneath the absorber plate; hence, by virtue of density difference the cold and hot water (i.e the cold water goes down, while the hot water comes up), a flow is initiated (thermosyphon or natural convection). The water flows to the water storage tank, and the circulation continues until the temperature is evenly distributed.

4.2 Result

Table 2: give test results of the system on a normal sunny day.

TIME (hr)	AMBIENT TEMPERATURE (°C)	COLLECTOR TEMPERATURE (°C)	FINAL (FLUID) TEMPERATURE (°C)
08:00	32	41	30
09:00	33	51	34

10:00	38	60	38
11:00	39	63	44
12:00	38	65	52
13:00	39	63	53
14:00	39	70	56
15:00	44	69	58
16:00	40	68	59
17:00	38	60	55
18:00	30	50	53

4.3 Discussion

The collector and final fluid temperature of the fluid have massively increased as shown by figures 3, figures 4 and figures 5

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \times 100 \quad (4.1)$$

Thus,

$$\text{The collector efficiency} = \frac{\text{sum of collector temp.}}{\text{insum of ambient temp.}} \times 100 = \frac{660}{370} \times 100 = 160.97\% \quad (4.2)$$

$$\text{Also the overall solar heat efficiency} = \frac{\text{sum of fluid temp.}}{\text{sum of collector temp.}} \times 100 \quad (4.3)$$

$$= \frac{479}{660} \times 100 = 72.57\%$$

The system has a collector efficiency of 160.97% and overall solar efficiency of 72.57%.

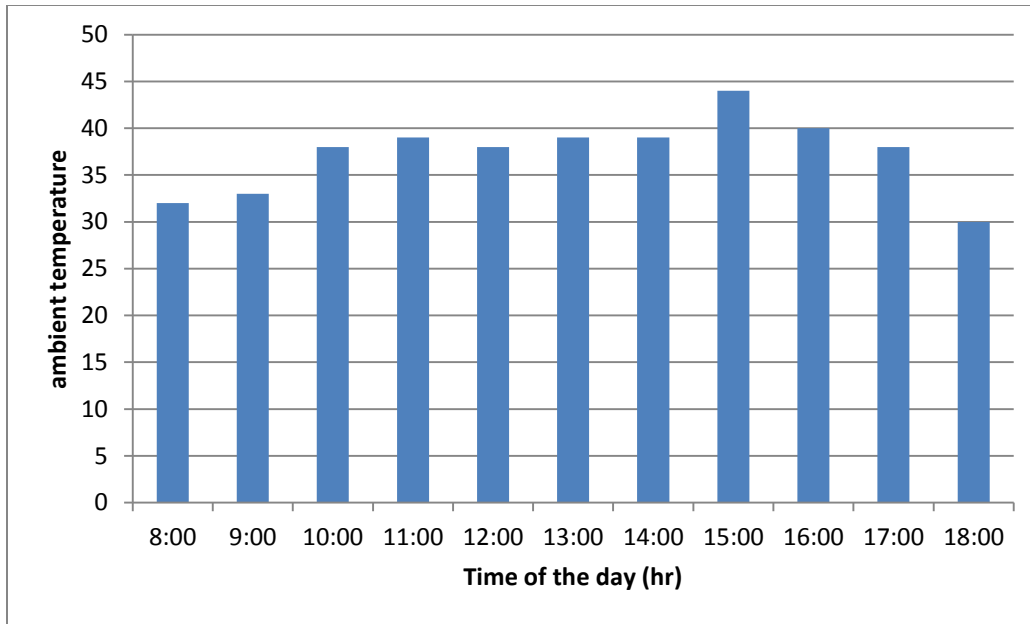


Figure 3. variation of ambient temperature with time

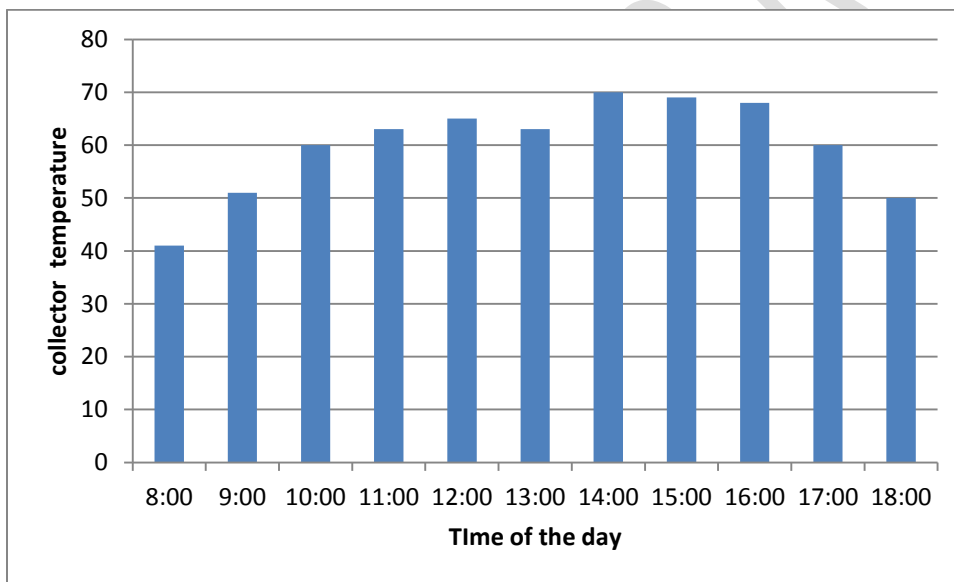


Figure 4. variaton of collector temperature with time

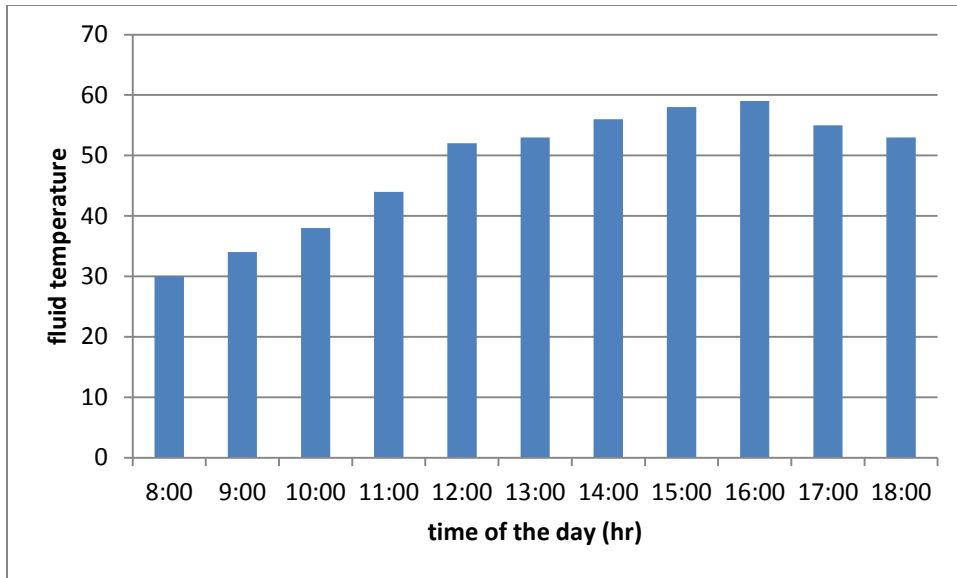


Figure 5 variation of final (fluid) temperature with time

From the results, ambient temperature varied between 38 and 40 on average. Maximum fluid(water) output temperature and the collector temperature was obtained between noon and 4:00pm. The fluid temperature increased from a low 8:00 AM to a peak between noon and 4:00PM. The fluid temperature increased from a low value 8:00 AM got to a peak between noon and 4:00 PM and then fell back to a low value. The collector temperature averagely above the ambient temperature by a value of about 160.73%, this is a significant increase in temperature with shows that the green house effects is at work.

The cold water temperature increase averagely by about 72.57%, this mean that any cold water heated by this solar water heater, will have it temperature increased by more than half of its original temperature. A cold water will be heated and have its temperature increases by more than half of its original temperature. This shows that thermosyphon principle is at work.

5.0 CONCLUSION

The water get heated and flows into a storage tank through thermosyphon principle. The system was tested and maximum fluid output temperature and the collector temperature of 59°C and 70°C respectively, were obtained on a sunny day. This solar water heating system finds useful application and acts as a renewable energy resources in regions where there is abundant and consistent sunlight.

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