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# DEVELOPMENT AND PRELIMINARY TESTING OF A PARABOLIC TROUGH SOLAR WATER HEATER

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## ABSTRACT

Solar energy is a high-temperature, high-energy radiant energy source, with tremendous advantages over other alternative energy sources. It is a reliable, robust renewable resource which is largely undeveloped. The design and fabrication of parabolic trough solar water heater for water heating was executed. The procedure employed includes the design, construction and testing stages. The equipment which is made up of the reflector surface (curved mirror), reflector support, absorber pipe and a stand was fabricated using locally sourced materials. The results obtained compared favourably with other research works in the literature. It depicts that employing a suitable design, selection of time of heating and proper focusing of the reflected rays to the focal spot region, solar radiation can efficiently be utilized for water heating in a tropical environment. This work presents a parabolic trough solar water heater as a suitable renewable energy technology for reducing water-heating costs.

**Keywords:** Solar radiation, parabolic trough, water heater, focal spot, thermal efficiency

## 1.0 INTRODUCTION

The energy consumption in residential sector is substantial as it accounts for approximately one-third of overall delivered-energy use and carbon-dioxide emissions (Sambo, 2005; BERR, 2008a). Of this delivered-energy use, approximately a quarter is for water heating (Allen *et al.*, 2010). Water heating is generally provided by burning non-commercial fuels, namely, firewood as in the rural areas and commercial fuels such as kerosene oil, liquefied petroleum gas (LPG), coal; through either their direct combustion or through the use of electricity in urban areas (BERR, 2008a, Lee and Sharma, 2007; Gunerhan and Hepbasli, 2007). In this regard, the need to decarbonize heat was acknowledged as an important means of reducing carbon-dioxide emissions (Allen *et al.*, 2010; BERR, 2008b) and this search has led to different forms of research into the use of solar energy, which is a free gift of nature, is renewable, sustainable and pollution free.

Solar radiation has a high-temperature, high-exergy energy source at its origin, the Sun, whose irradiance is about 63 MW/m$^2$ and travels to the earth in the form of electromagnetic radiation (Ilenikhena, 2007). However, Sun-Earth separation geometry dramatically decreases the solar energy arriving the Earth's surface to around 1 kW/m$^2$. This disadvantage can be overcome by using optical concentrating solar systems which transformed concentrated radiation usually into thermal energy (Romero *et al.*, 2004; Fernandez-Garcýa *et al.*, 2010).

$$= m_p c_p (T_1 - T_0) + m_w c_w (T_1 - T_0) \quad (1)$$

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In a tropical continent like Africa, solar energy is available in abundance. Nigeria is a geographically favoured region lying approximately between $4^0$ N and $14^0$ N of the Equator and $15^0$ E of the Greenwich Meridian (McVeigh, 1977), where abundance of sunshine or solar energy can be received (Kenneth, 1976). The tropical station under consideration, Ilorin, lies on latitude $8.462^0$ N and has solar radiation of 550-1075Wh/m$^2$ or about 17-25MJ/m$^2$ per day (Alonge *et al.*, 1999). This is quite an enormous amount of energy that should be put to best use (Lasode and Ajimotokan, 2010).

The solar irradiation available to a solar collector device varies with its azimuth, pitch and geographical location (Allen *et al.*, 2010); and the relative amount of solar irradiation at a given geographical location plays an important role on the type of solar collector device that may be applied. The different devices available for harnessing solar energy include systems with flat plate collector, concentrators, vacuum tube collectors are employed among others for heating of building and crop drying (Pelemo *et al.*; 2002). Non-focusing solar collectors like glass and flat plate collectors make use of both diffuse and direct solar radiation with a greater geographical range of application. Focusing solar collectors mainly operates with direct solar radiation (Goswami *et al.*, 2000; Krieder, 1979). The solar radiation is converted into thermal energy in the focus of solar thermal concentrating systems. These systems are classified by their focus geometry as either point-focus concentrators (central receiver systems and parabolic dishes) or line-focus concentrators (parabolic trough collectors (PTCs) and linear Fresnel collectors) (Fernandez-Garcia *et al.*, 2010).

Solar Water Heating (SWH) system is a well-proven and readily available technology that directly substitutes renewable energy for conventional energy in water heating (DOE, 1998). However, parabolic-trough SWH is a renewable energy technology with considerable potential for application in building facilities (DOE, 2000).

Thus, this paper presents a reproducible solar water heater as a suitable way to directly utilize solar energy for water-heating purposes. Thus, research has enabled the employment of SWH systems with optical concentrating technologies as an important entrants needed for providing bulk solar energy.

## 2.0 THEORETICAL CONSIDERATIONS

Generally, solar water heater performance is measured by its thermal efficiency. For a parabolic trough solar water heater, the thermal efficiency is greatly dependent on the direct solar irradiation intensity, ambient temperature and wind speeds.

However, the efficiency using calorimetric method as presented by Pelemo *et al.* (2002) can be calculated as the ratio of thermal energy gained by water and absorber pipe, $Q_h$, to the radiant solar energy supplied, $Q_r$.

For a rise in temperature from $T_0$ to $T_1$, thermal energy gained, $Q_h$ is given as:

$Q_h$ = Heat gained by absorber + Heat gained by water

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Where: $m_p$, $m_w$ are the weights of container and water (in kg) respectively; $c_p$, $c_w$ are the specific heats of container and water (in kJ/kg$^0$K) respectively; and $T_1$, $T_0$ are final and initial temperatures (in $^0$K) of water, respectively.
This implies that:

$$Q_h = (m_p c_p + m_w c_w)(T_1 - T_0) \tag{2}$$

The radiant solar energy, $Q_s = HA$ (3)
And (4)
where $H$ is the amount of accumulated direct solar radiation per unit area (in kJ/m$^2$), $A$ is the aperture or focal spot area (in m$^2$), is optical efficiency of the collector and $I$ is the amount of direct solar radiation per unit area (in kJ/m$^2$).

The optical efficiency of a collector is the ratio of the sunlight energy absorbed by the absorber component of the collector to that intercepted by the collector aperture directly facing the sun.
Thus, thermal efficiency of the water heater is given as:

$$\eta_{wh} = Q_h / Q_s \tag{5}$$

## 3.0 EXPERIMENTAL PROCEDURE

In the development of this device, engineering practice that involved utilizing scientific principles to design components and systems that performed reliably, satisfactorily and cost effectively was employed. However, the materials for the fabrication of the device were studied considering strength, suitability and local availability.

The available solar energy is 972 W/m$^2$ while the amount of energy needed to heat 0.5 kg of water from room temperature to 100$^0$C in 10 minutes is 315W. The area of collector is 0.934m$^2$, aperture length is 0.94m, aperture width is 1m, focal length is 0.433m and the rim angle is 60$^0$. A parabolic trough solar water heater was designed and fabricated. The procedure employed includes the design, construction and testing stages. The solar device was fabricated using locally sourced materials.

The equipment is made up of the reflector surface (curved mirror), reflector support, absorber pipe, absorber stand and a stand. The reflector surface an optical concentrator is a parabolic trough (curved) segmented mirror designed to concentrate radiant energy from the sun. The support is made with plywood; absorber pipe, a black painted Aluminum material for the thermal fluid and wooden stand as depicted in Figure 1..

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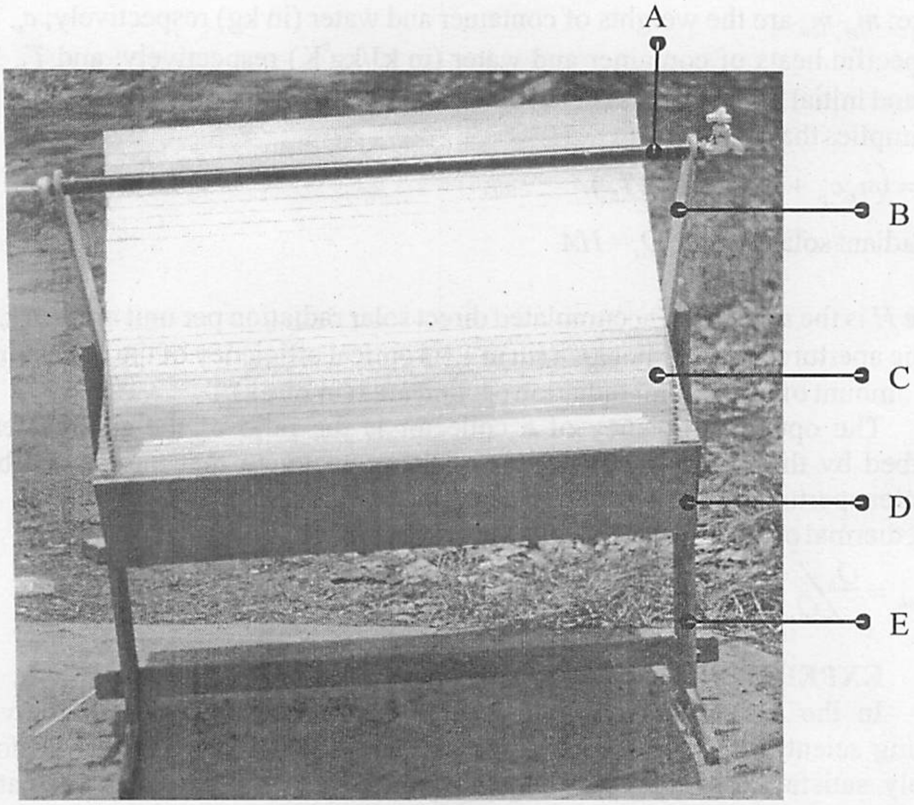


**Figure 1: Parabolic Trough Solar Water Heater**
*Legend: A-Absorber Pipe, B-Absorber Stand, C-Reflector Surface (Curved Mirror), D-Reflector Support and E- Stand.*

### 3.1 Experimental Description

The parabolic trough solar water heater was placed outside with no shading effect in a manner that allows the tracking of the sun from east to west. The device was placed in the sun for a period of 30 minutes to 60 minutes to attain thermal equilibrium and the absorber pipe was then filled with water. The collector surface is rotated manually continuously to get a good focus on the absorber pipe such that when this is properly done there would be a bright reflection on the lower part of the absorber and the procedure was repeated thereafter. A thermometer was fixed inside the absorber with the help of a cork and another thermometer was hung on the collector stand to read the ambient temperature, the initial temperature was taken and recorded. Measurements were taken and recorded every 10 minutes.

## 4.0 RESULTS AND DISCUSSION

The observed results of the solar water-heating experiment carried out on April 16 and 18 are presented in Tables 1 and 2, while their corresponding graphs are depicted by Figures 2 and 3 respectively.

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**Table 1:** Experimental Data of the Parabolic Trough Solar Water Heater (16 th April)

| Run No. | Time of the Day | Ambient Temperature (°C) | Initial Water Temperature (°C) | Final Water Temperature (°C) |
|---|---|---|---|---|
| 1 | 10:00-10:10 | 31 | 27 | 60 |
| 2 | 10:20-10:30 | 31 | 27 | 65 |
| 3 | 10:40-10:50 | 32 | 27 | 65 |
| 4 | 11:00-11:10 | 32 | 27 | 70 |
| 5 | 11:20-11:30 | 32 | 27 | 70 |
| 6 | 11:40-11:50 | 32 | 27 | 70 |
| 7 | 12:00-12:10 | 32 | 27 | 71 |
| 8 | 12:20-12:30 | 32 | 27 | 71 |
| 9 | 12:40-12:50 | 32 | 27 | 71 |
| 10 | 1:00-1:10 | 32 | 27 | 71 |
| 11 | 1:20-1:30 | 32 | 27 | 71 |
| 12 | 1:40-1:50 | 32 | 27 | 71 |

**Table 2:** Experimental Data of the Parabolic Trough Solar Water Heater (18 th April)

| Run No. | Time of the Day | Ambient Temperature (°C) | Initial Water Temperature (°C) | Final Water Temperature (°C) |
|---|---|---|---|---|
| 1 | 10:00-10:10 | 31 | 25 | 65 |
| 2 | 10:20-10:30 | 31 | 25 | 70 |
| 3 | 10:40-10:50 | 31 | 25 | 76 |
| 4 | 11:00-11:10 | 31 | 25 | 78 |
| 5 | 11:20-11:30 | 31 | 25 | 86 |
| 6 | 11:40-11:50 | 31 | 25 | 90 |
| 7 | 12:00-12:10 | 32 | 25 | 96 |
| 8 | 12:20-12:30 | 34 | 25 | 100 |
| 9 | 12:40-12:50 | 34 | 25 | 100 |
| 10 | 1:00-1:10 | 36 | 25 | 92 |
| 11 | 1:20-1:30 | 36 | 25 | 90 |
| 12 | 1:40-1:50 | 37 | 25 | 90 |

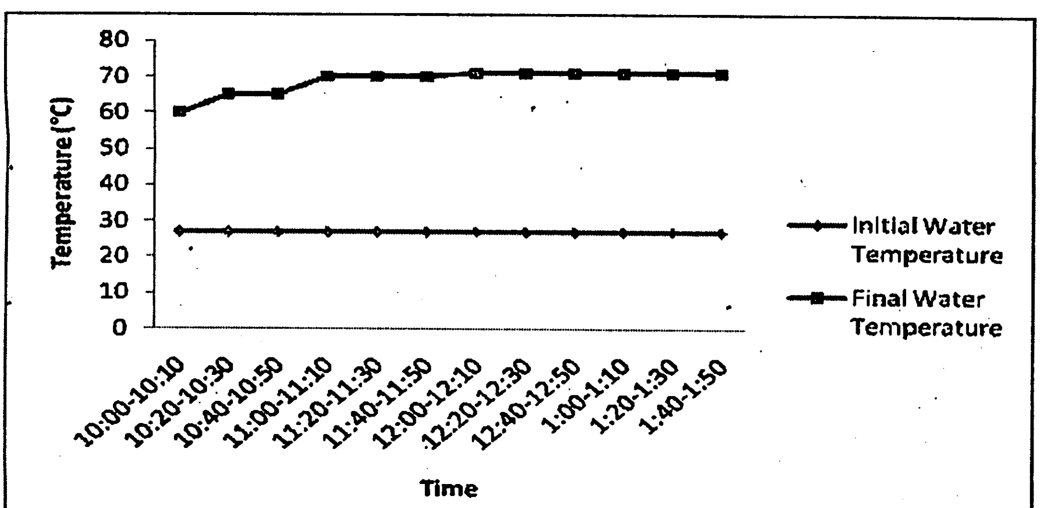


**Figure 2:** Variation of Temperature with Time of the Day

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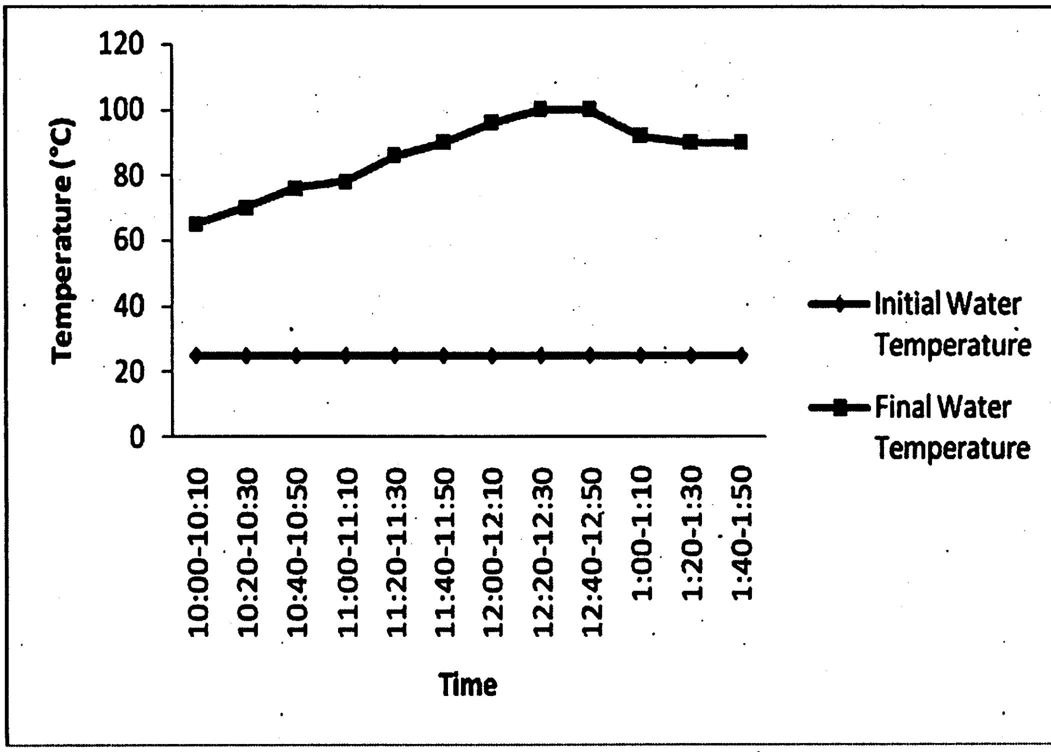


**Figure 3:** Variation of Temperature with Time of the Day

The 16th day of April was characterized with cloudy weather condition and the 18th day of April was a clear day and hence, the high optical efficiency. The solar radiation that reaches the earth surface is dependent on the direct radiation intensity, ambient temperature and wind speed. Diffused radiation is high during cloudy raining season (April-August) and also during the dust-laden harmattan (November-February). Apart from the cloudiness during the wet days, the dust-laden north-eastern wind during the harmattan days and the associated high value of diffuse radiation affect optical efficiency (Pelemo *et al.*, 2002) and hence, the performance of the solar heater. Bamiro (1993) reported that the diffused component of the solar radiation accounts for 65% of the average monthly radiation. Consequently, the high component of diffuse radiation could be responsible for the considerably low performance presented in Table 1.

Table 3 depicts the hourly thermal energy gained $Q_h$, hourly direct solar radiation $Q_s$, and the thermal efficiency of the solar heater.

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**Table 3:** Hourly Thermal Energy Gained, Hourly Direct Solar Radiation, and the Thermal Efficiency of the Solar Heater

| Time of the Day | Hourly Thermal Energy Gained, $Q_h$ (kJ) | Hourly Direct Solar Radiation, $Q_s$ (kJ) | Thermal Efficiency, |
|---|---|---|---|
| 10:00-11:00 | 309.23 | 343.59 | 90.0 |
| 11:00-12:00 | 501.13 | 552.43 | 90.7 |
| 12:00-1:00 | 596.58 | 670.33 | 89.0 |

Thus, the average thermal efficiency of the solar water heater, = **89.9% and a SWH** system is considered efficient if the efficiency is greater than or equal to 40% (Pelemo *et al.*, 2002).

## 5.0 CONCLUSIONS

Nigeria as a country is blessed with abundant supply of solar energy. It has been relatively limited to traditional technological use of solar drying of agricultural crops and other products. Solar energy can be harnessed by converting solar radiation to heat employing solar energy technologies. A parabolic trough solar water heater was designed and constructed as a suitable way to directly utilize solar energy for water-heating purposes. Results obtained compared favourably with other research works in the literature (Adedokun *et al.*, 1994; Okogbue, 1997; Qi, 1997). Thus, solar radiation can effectively and efficiently be utilized for water heating in the tropical environment by employing a suitable design, selection of time of heating and proper focusing of the reflected rays to the focal spot region.

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