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SOLAR TRACKING CONCENTRATING COLLECTORS' UTILIZATION FOR WATER HEATING IN MAIDUGURI, NIGERIA.

***Abdulrahim, A T[1]., Diso, I. S[2]. And Ngala, G. M[1].**

1. **DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF MAIDUGURI, MAIDUGURI, NIGERIA.** engrabdulrahimat@yahoo.com, garba.ngala68@gmail.com

2. **DEPARTMENT OF MECHANICAL ENGINEERING, BAYERO UNIVERSITY, KANO , NIGERIA.** isdiso@hotmail.com

*** CORRESPONDING AUTHOR**

ABSTRACT

Concentrating collectors utilize optical system reflectors or refractors to increase the intensity of solar radiation on the energy absorbing surface. This study carried out the performance evaluation of Solar tracking concentrating collectors for water heating in Maiduguri, a semi-arid zone of Nigeria. The Solar concentrating collector system has three distinct units, namely the solar collectors, the rotating shaft and framework supports, and the mechanical clockwork pendulum tracking system. The heat energy produced at the focal zone was utilized in heating the water inside the absorber. The device was used for heating 8 litres of water during the harmattan period, and the results of water heating carried out revealed that the highest water temperature measured during operation period was 87 ^{0}C at 13:00 hours with a maximum water temperature rise of 51 ^{o}C. The present work has demonstrated the potential of utilizing solar energy resource in a better and more efficient way. This was achieved by the introduction of more than one collector with options of concentrating the solar radiation in a common focal zone in order to increase available energy on the focal zone. The solar concentrating collector system is quite appropriate for water heating application in rural areas of developing countries because of it simple way of operation and the appropriate technology used in its development.

KEY WORDS: Solar collector, Tracking, Water, Heating, Temperature

INTRODUCTION

A device is generally called a concentrator if it increases the flux at the absorber of a solar collector. Concentrating collectors utilize optical system reflectors or refractors to increase the intensity of solar radiation on the energy absorbing surface. The optics for solar concentrating collectors is generally classified as either point focus or line focus systems. Three major solar - thermal technologies have been developed, the shape of reflecting surface on which sunlight is collected and concentrated characterizes each. These are the central receiver system, the parabolic trough, and the parabolic dish system (Cooper, 1972; Sayigh,1977; Magal, 1993; NREL, 2004). Paraboloidal concentrators have the ability to raise various absorbers and working fluid to high temperatures. The maximum concentrator factor and temperature attainable in practice depends on the aperture size, reflectivity and accuracy of the surface contour, and the degree to which the concentrator approximate a true paraboloidal geometry (Srinivasan et al., 1978). The tracking mode adopted also determined the accuracy of the collector following the sun, hence the amount of solar radiation concentrated at the focal zone.

In many solar energy applications where temperature of several hundred degrees Celsius and higher concentrating ratio is required, solar parabolic dish concentrators are found suitable. Solar parabolic dishes are applicable in the areas of bread baking, electricity production and solar cookers among others (Sayigh, 1977; Broman and Broman, 1996; Light Concentrated From Below, 2004). In Nigeria, various ways of utilization of renewable energy resources and development of various solar energy collectors are available in literature (Garba et al., 1999; Energetic Solution, 2004). Solar concentrators' development in Nigeria has also been reported by Abdulrahim et al. (2010). The present study is aimed at the performance evaluation of Solar tracking concentrating collectors for water

heating in Maiduguri, a semi-arid zone of Nigeria.

MATERIALS AND METHODS

Description of the Solar Tracking Concentrating Collector System

The solar tracking concentrating collector system is shown in figure 1 and plate 1. The system has three distinct units, namely the solar collectors, the rotating shaft and framework supports, and the mechanical clockwork pendulum tracking system. The solar collectors are made-up of the solar concentrators and the receivers with their supports. In this unit, solar radiation is been concentrated on focal zones where the receivers are positioned. The receiver (container for heating water) was made from mild steel to form a water tank having a total capacity of 8 litres and a mass of 3.2 kg when empty. The tank has only two openings. One of the openings was fitted with a thermocouple (Model E, 43593, Coley England) to measure the water temperature while the second opening serves as a point for refilling water. The second opening can be fitted with a plug after filling and made water tight during operation. Support stands connect the receiver to the rotating support shaft and the reflectors' shells. The receiver was adjusted to stay at the focal zone of the collectors. The heat energy produced is utilized in heating the water inside the absorber. The rotating support shaft and its axillaries such as the hinge supports, collectors' connectors, counter weight, driving weight, semi-circle iron bearing chain and pipe's support provide the necessary support for the solar collectors, and also give the collectors opportunity to move about the axis of the rotating support and for other adjustment in relation to tracking operation.

The mechanical clockwork pendulum arrangement consists of sprockets, chains, shafts, support frame, pinion, escapement gear, anchor and the pendulum. The unit regulates the speed of the collectors via the semi-circle iron bearing chain connected to the rotating support shaft so that they can follow the sun as it moves from east to west during the day. The system structural support unit, made-up of frameworks and moveable wheels on base shafts, provides the necessary rigid support for the whole component parts of the system. It also provides room for easy movement of the whole system from one place to another.

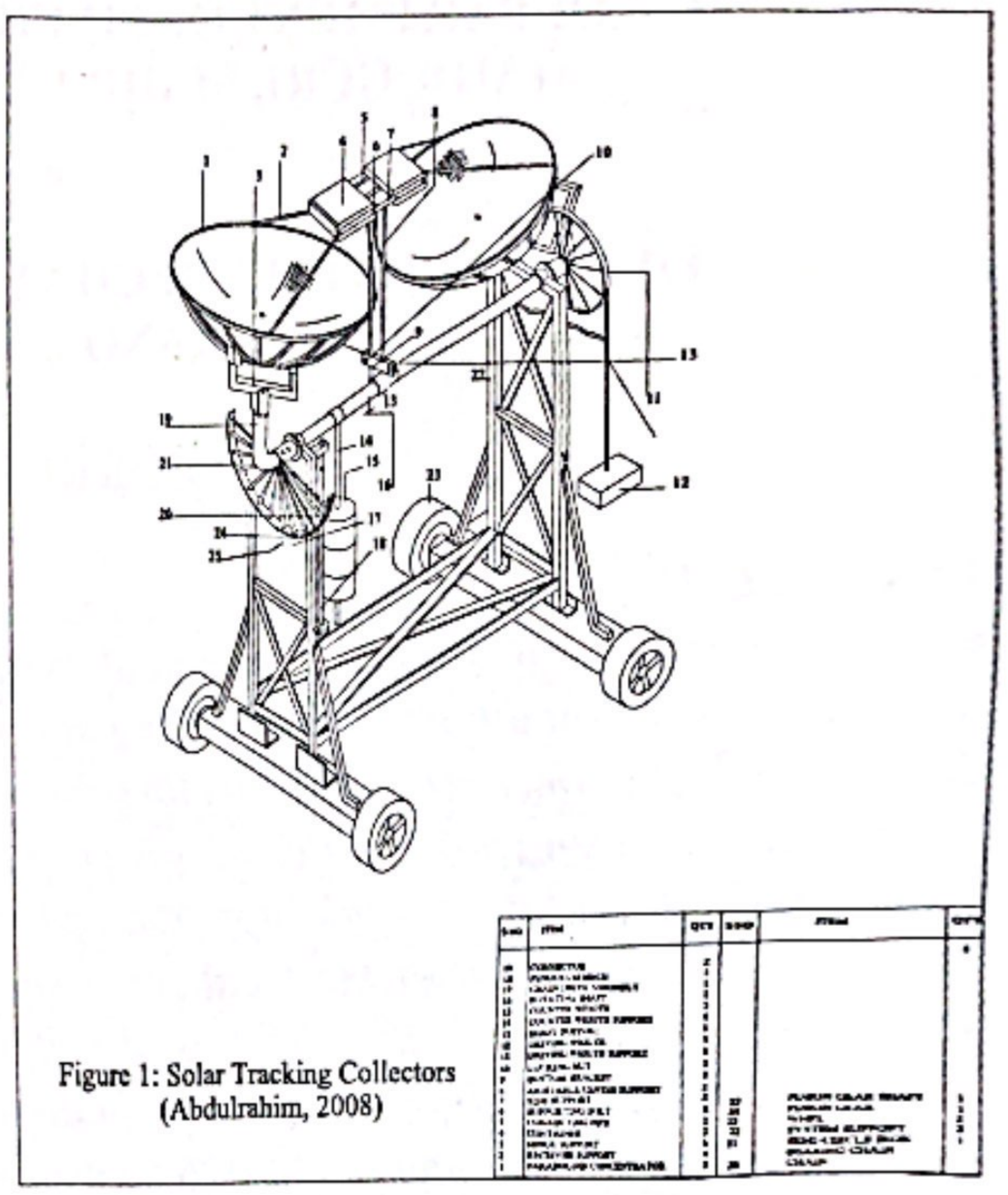


Figure 1: Solar Tracking Collectors (Abdulrahim, 2008)



Plate 1: Experimental Configuration of Solar Tracking Concentrating Collectors

EXPERIMENTATION

The performance of a solar tracking concentrating collector system was assessed through water heating/boiling measurement during operation. The system after proper assembly on test site was put into operation. Performance parameter such as temperatures of water was measured using thermocouple fixed at

appropriate positions on the receiver tank at 30 minutes interval and recorded accordingly. Measured values of some ambient parameters that affect the performance of the system such as ambient temperature and solar insolation were also recorded on 30 minute interval during the test period.

The solar tracking concentrating collector system was placed in the sun in Maiduguri (latitude 11.85 °) on the days of the experiments. The absorber tank was filled with 8 liters of water. The water temperatures in the absorber was measured using Thermocouples (Copper-Constantan Type with rigid stem: Model E43593, Coley England), while the ambient temperature was measured using mercury in glass Thermometer (Fisherbrand, England). The direct beam radiation during the period of the experiment was found by using two Pyranometers (Model CM21, Kipp and Zonen Group, Holland). One of the pyranometers was fixed with a shadow ring in order to measure the diffuse solar radiation component while the second one measured the global solar radiation. The difference of the two values gives the value for direct beam radiation. The pyranometers were connected to digital multi-meters (ALDA. Model: DT830B, 8300 series) that serve as the read out equipments for the pyranometers. The readings of measured values were taken on 30 minutes interval basis.

For the day of the experimentation, the day of the year, the sun's declination, the zenith angle, the sunrise (sunset) and the day length were found using standard expressions in literature and detailed in Abdulrahim (2008). The thermal efficiency of the solar collector was calculated using the method described by Ren et al. (1997) and detailed in Abdulrahim (2008).

RESULTS AND DISCUSSION

The Test Day Parameters are presented in Table 1 and measured values while using the solar tracking concentrating collectors to heat 8 liters of water inside a receiver position at the focal zone under the prevailing atmospheric conditions on a test day in March are shown in Table 2. The variation of the Ambient Temperature, Direct Beam Radiation and Absorber Water Temperature with the Time of the Day are presented in figures 2, 3 and 4 respectively.

Table 1: Computed Day Parameters on 11th March, 2007

Parameter	Value
Day of the Year [Day]	70
Sun Declination Angle, δ	-4.41^0
Zenith Angle	16.20^0
Sunrise (Sunset) Time (hour)	5.94
Sunrise (Sunset) Angle	89.07^0
Day Length (hours)	11.88

Table 2: Measured Parameters during Solar concentrating collectors' operation for Heating 8 Liters of Water on 11th March, 2007

Time [hour]	Water Temperature T_w(°C)	Ambient Temperature T_{amb} (°C)	Direct Beam Radiation I (W/m^2)
9:00	36	26	453.60
9:30	45	28	567.00
10:00	57	30	597.24
10:30	64	32	657.20
11:00	70	36	710.64
11:30	73	35	763.56
12:00	80	36	778.68
12:30	84	35	786.24
13:00	87	36	771.12
13:30	87	37	756.00
14:00	84	36	627.48
14:30	81	36	627.48
15:00	84	36	491.40
15:30	85	36	430.92
16:00	84	35	317.52

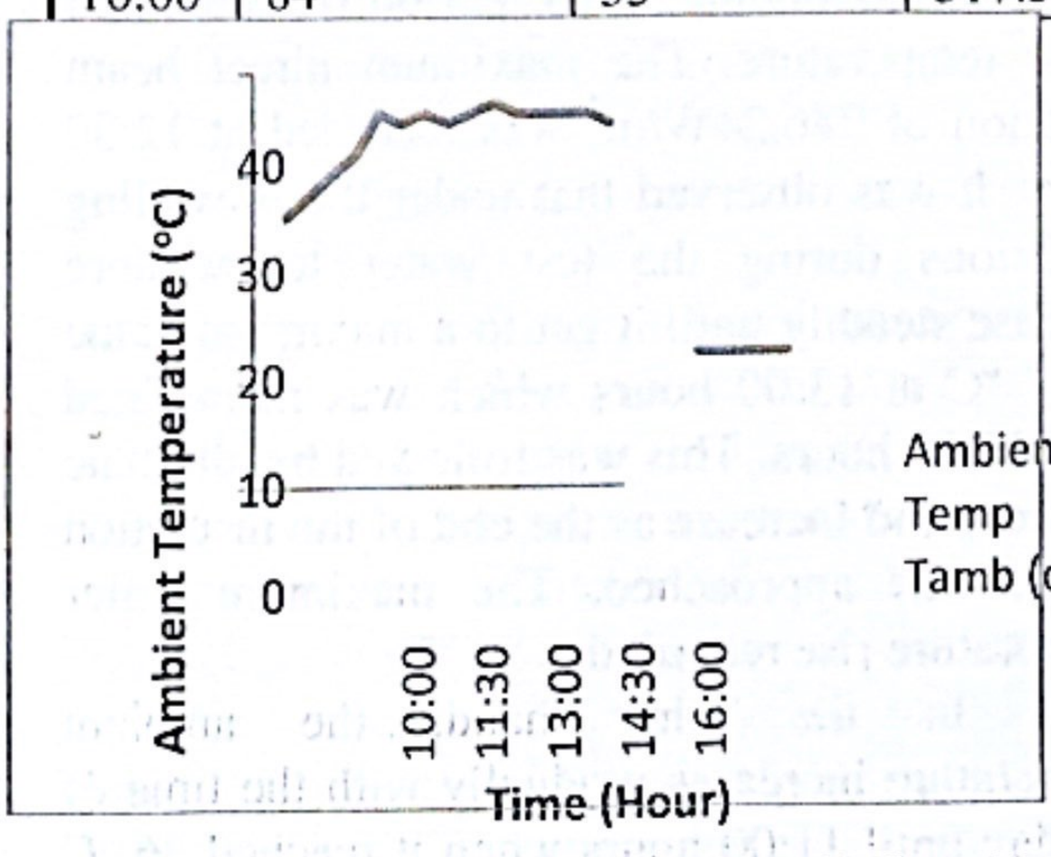


Fig. 2: Variation of Ambient Temperature with Time of the Day

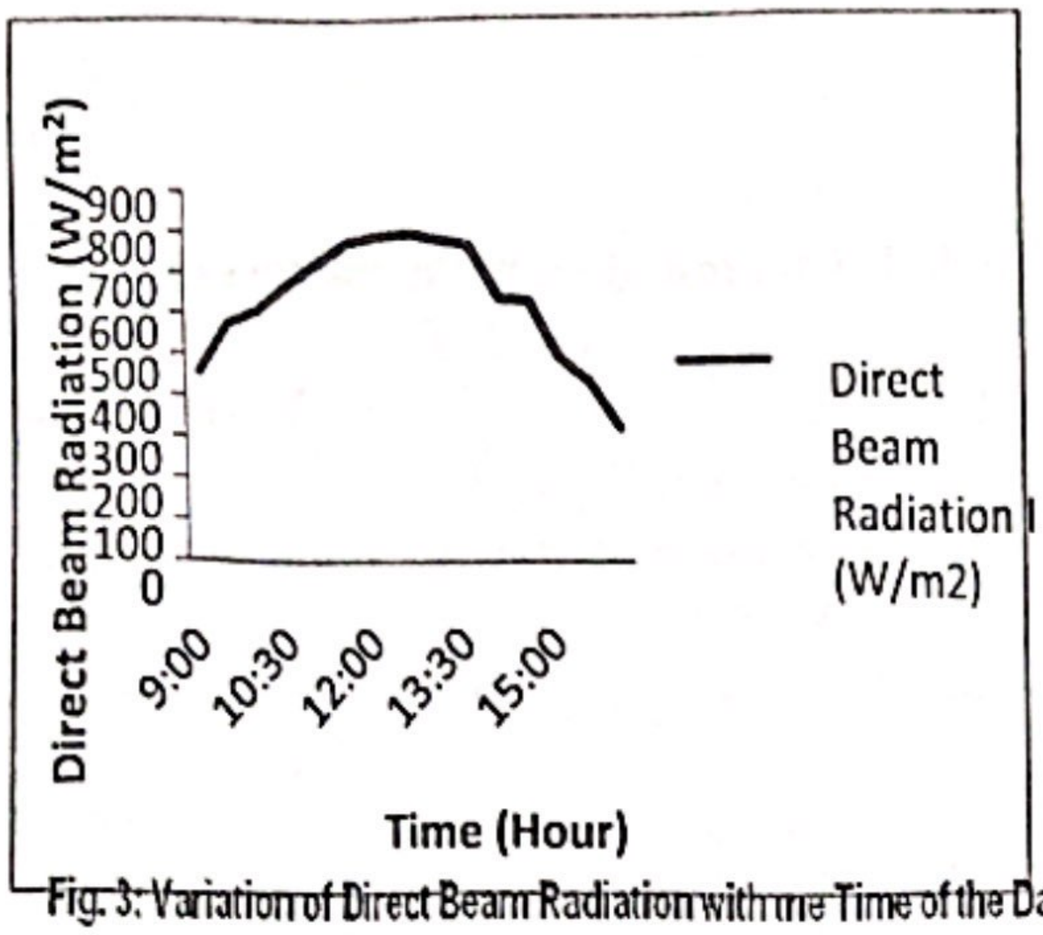


Fig. 3: Variation of Direct Beam Radiation with the Time of the Day

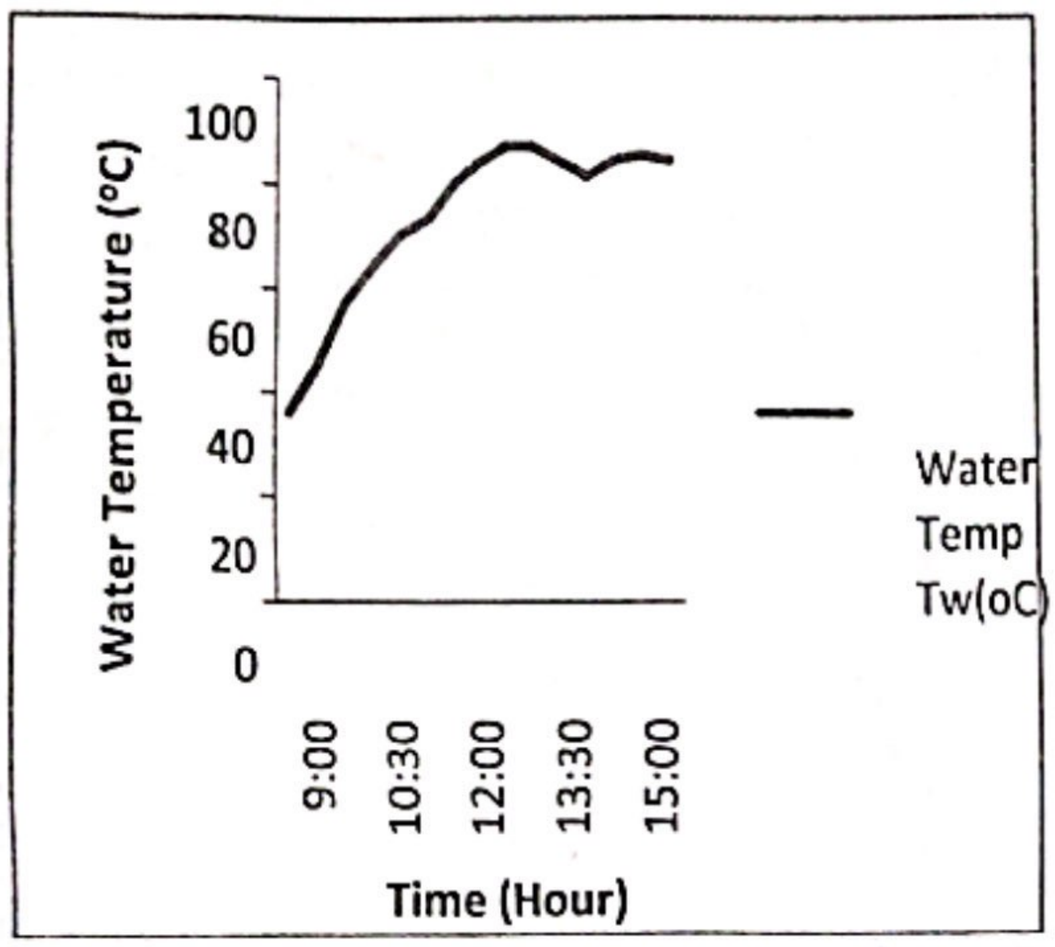


Fig. 4: Variation of Water Temperature with the Time of the Day

The results showed that maximum water temperature attainable during the test period was 87 °C, occurring at 13:00 hours and 13:30 hours while the direct beam radiation were 771.12 W/m^2 and 756.00 W/m^2 respectively. Ambient temperature was at maximum of 37 °C at 13:30 hours, corresponding to the period of maximum water temperature. The maximum direct beam radiation of 786.24W/m^2 was recorded at 12:30 hours. It was observed that under the prevailing conditions during the test water temperature increase steadily until it get to a maximum value of 87 °C at 13:00 hours which was maintained until 13:30 hours. This was followed by alternate decrease and increase as the end of the insulation period was approached. The maximum water temperature rise recorded is 51 °C.

In the other hand, the ambient temperature increases gradually with the time of the day until 11:00 hours when it reached 36 °C after which it decrease and increase again till a the maximum of 37°C was attained at 13:30. It started dropping till the end of the experiment.

The thermal efficiency of the solar collectors based on the maximum rise in temperature of 51 °C during this period was found to be 86%.

The results obtained suggest that the performance of the solar tracking concentrating collectors will greatly improve during a clear sunning day. This is because the conditions under which the experiments were carried out are some time characterized by dust and haze in the sky during the harmattan period that included the months of December, February and March (Gisilanbe, 1995). The results of the present study are indications that the solar collector system performance will greatly improve during the period of bright sunshine and clear day, and when heat losses are significantly reduced. The system looks promising given a clear weather and during hot season period of the year.

CONCLUSION

The highest water temperature measured during operation period was 87 °C at 13:00 hours with a maximum water temperature rise of 51 °C despite the prevailing harmattam weather conditions. The present work has demonstrated the potential of utilizing solar energy resource in a better and more efficient way. This was achieved by the introduction of more than one collector with options of concentrating the solar radiation in a common focal zone in order to increase available energy on the focal zone. This is quite appropriate for water heating application in rural areas of developing countries because of it simple way of operation and the appropriate technology used in its development. Hence, from the above performance, this device can be regarded as a renewable energy application for saving conventional energy cost to a great extent in rural area

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