JOURNAL OF ADVANCEMENT IN
ENGINEERING AND TECHNOLOGY

Journal homepage: 1p

Research Article Open Access

Design, Construction and Performance Evaluation of Parabolic Dish Solar Collector (Pdsc)

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Received: June 29, 2018, Accepted: August 23, 2018, Published: August 23, 2018.

ABSTRACT

This paper presents the design, construction and performance evaluation of Parabolic Dish Solar Collector (PDSC) that can be used in different applications. It explores a design option for utilizing and managing the available local raw materials and using appropriate mathematical modeling to find the focal point of the dish. The construction was done in three stages: the dish which was fabricated from aluminium sheet and coated with high reflecting material for high efficiency, the receiver used to generate steam using the heat it absorbed from the dish, and the support which hold both the dish and the receiver. Heat from the sun is reflected by the coated dish onto the receiver in order to generate steam as well as served for cooking applications. The field work was conducted in three days and the results obtained at an interval of 30minutes during the test period revealed that the temperature generated is much higher than the ambient temperature during most hours of the day-light which can be use for heating or other different applications. The performance efficiency was found to be 32.47% while the cooking power was 63.54W.

Keywords: *Concentrated Solar Power, Parabolic dish, Direct Solar Irradiance, Solar Power.*

1. INTRODUCTION

Energy is an essential prerequisite to man's survival. It provides man's need in all aspects of life such as food, light, warming, education, health and sundry. Access to adequate or dependable sources of energy has become a major problem to Nigeria, it is always either as a result of the growing population, civilization, and increase in the number of industries/companies or due to environmental problems/green house effect, flooding, and drought. Moreover harnessing of energy resources in Nigeria ranging from the local method firewood to electricity are still undependable sources. The gasoline generators which could have been the only alternative to both domestic and large scale consumers are quite expensive and beyond the reach of low and medium consumers. These left the government and the entrepreneurs with no any alternative but to seek other energy sources having in mind the desire of a clean and environmental friendly source of energy.

Among the sources of renewable energy, energy from sun (solar energy) is considered the best and in fact, the most dependable in terms of pollution-free and viability. Solar energy is highly renowned alternative energy source; the intensity of the sun radiation that reaches the globe yearly is equivalent to 12 billion tons of petroleum [1].

MATERIALS AND METHODS

LOCATING THE FOCAL POINT OF THE DISH

In locating the focal point of the dish, two methods are often used: Manual construction which entails finding the focal point by placing the receiver on the approximate or assumption point till the right point of receiving the highest reflected sunlight is gotten or through the calculations (equation) method. In this work, the calculation (equation) method which entails using the parabola equation to calculate the required parameter was adopted.

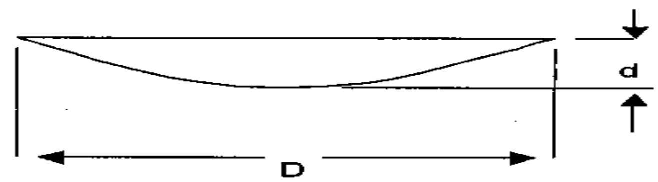

Fig 2: Schematic diagram for determining the focal point

Referring to Fig 1.0, the focal point can be calculated by the equation below:

$$f = \frac{D^2}{4d} \qquad (1)$$

where D is the longest width [2]

Step 1: The longest diameter (width) of the parabola up to its rim was measured to be 252m

Step 2: Divide the diameter by two i.e. $\frac{1}{2} \times 252$ to determine the radius y, we have y = 126m Step 3: Square the radius i.e. $y^2 = (126)^2 = 15,876$

Step 3: Measure the depth of the parabola (d) from its vertex .i.e.(42m) and multiply it by 4. i.e. $4d = (4 \times 42) = 168m$

Step 4: substituting into equation 23 gives the focal point i.e. $\frac{15,876}{168} = 94.5m$

CONSTRUCTION

The main components of a Parabolic Dish Solar Concentrator (PDSC) are: The Parabolic dish, the Support and the Receiver.

THE SOLAR DISH

It is coated with an aluminium foil reflector sheet in order to have a high efficiency of reflecting sun energy onto the receiver.

After finishing the coating, the six parts are brought together to be fixed into the parabolic dish shape as in Fig 3.4 and mounted on a rigid sand- rooted support.

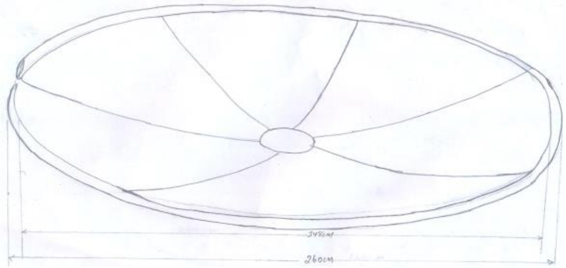

Fig 3: Schematic diagram of the assembled dish coated with aluminium foil.

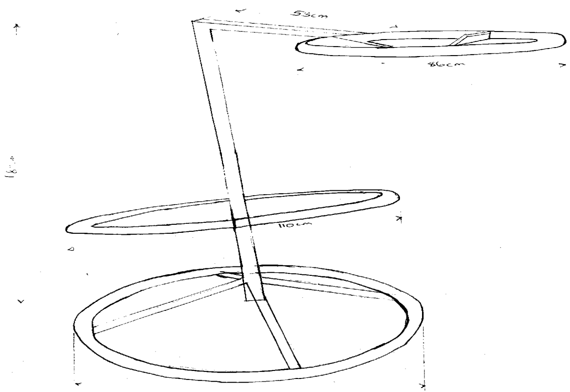

Fig 4: Schematic diagram of support for Dish and Receiver.

THE SUPPORT

The support is made up of a cylindrical shaped construction using cubed iron to be rooted to the ground or hold using heavy stones or any heavy objects in order to be strong and firm in case of wind or rain, it protrude through the middle of the dish upwards in order to hold the receiver at the determined focal point, see Fig 3 and Fig 4.

THE RECEIVER/HEAT EXCHANGER

The heat exchanger is an improvised receiver in the form of a kettle-like form with an internal coil made from a good conducting material e.g. copper. It shall be used in conducting the steam generation test, while pot shall be use for the cooking applications which shall be mounted on the head of the support.

EXPERIMENTAL/TEST

For the performance evaluation of the PDSC system, experiments were conducted for a given period of time on the performance of the receiver e.g. steam generation and as well as for cooking applications.

The following parameters are taken into account for the performance evaluation. First the availability of solar irradiation: this is measured using pyranometer instrument. Also ambient condition information like ambient temperature, ambient pressure/relative humidity, wind speed and its direction are essential for the performance calculation of PDSC.

Table 1 indicates the various material used in the construction

Table 1: List of material used for the construction

S/N	MATERIAL	SPECIFICATION	QUANTITY
01	Aluminum reflector	10.0m	6
02	Galvanized Pipes	0.4m	4
03	Connecting arms	0.35m	4
04	Mount round	0.56m	1
05	Cross bar	0.81m	1
06	Adjuster	0.30m by 0.23m	1
07	Receiver sitter	0.51m	1
08	Receiver adjuster	0.43m	1
09	Tank/Reservoir sitter	0.38m	2

Table 2: List of instrument used in the measurement

S/N	PARAMETER MEASURED	INSTRUMENT USED
01	Solar insolation	Pyranometer
02	Wind speed	Anemometer
03	Relative humidity	Max and min thermometer
04	Ambient & content temp	Mercury in glass
05	Weight of water and other food substance	Electronic Weighing balance

COOKING TEST

With the parabolic solar cooker placed under the sun, 10gm of mass of cooking pot containing 4 litres of water was placed at the focus of the dish which already has been oriented in the direction of the sun. The temperatures at intervals of 30 minutes were measured with a thermometer until the water started boiling. The readings for this part of the experiment were recorded and used for the heating test analysis. At the time the water had started boiling, the set-ups were immediately shaded for the cooling test. As the temperature of the water contained in the cooking pot falls, a record of the temperature were taken at an interval of 30 minutes until the temperature of the water approaches that of the ambient. The cooling and heating tests as suggested [3] were used to determine the heat loss factor FU_L and the optical efficiency factor $F\eta_o$:

$$F'U_L = \frac{(MC)_W}{\tau_O A_t} \tag{2}$$

where τo is the time constant determined as the temperature difference $(T_W - Ta)$ falls to 1/e of its initial value and A_t is the surface area of the cooking utensil. $(MC)_w$ is the combined heat capacities of water and the cooking utensil which is equivalent to:

$$(MC)_w = M_w C_w + M_p C_p \tag{3}$$

where:

M_W is the mass of water,

C_w is the specific heat capacity of water i.e. 4200 $Jkg^{-1}K^{-1}$,

M_p is the mass of pot,

and C_p is the specific heat capacity of the pot. Since the pot is made of Aluminum implies that C_p is the specific heat capacity of Aluminum.

The optical efficiency factor for the solar parabolic collector can be determined from:

$$F\eta_o = \frac{FU_L}{C} \frac{\{(\frac{T_{Wf} - T_a}{I_b} - (\frac{T_{wt} - T_a}{I_b})e^{-\tau/\tau o}}{1 - e^{-\tau/\tau o}} \quad (4)$$

where,

T_{wi} and T_{wf} are the initial and final water temperatures during the heating test respectively,

τ is the time required for the water temperature to increase from T_{wt} to T_{wf} ,

T_a is the average ambient temperature,

I_b is the direct solar radiation during time interval τ

and U_L is the overall heat loss coefficient.

Other test techniques as suggested by [4] were also used to evaluate the parabolic solar dish collector. In these techniques, the cooking power, standardized cooking power and the overall heat loss coefficient were determined subject to the conditions that the wind speed not greater than 2.5 m/s, air temperature in the range of 20 to 35°C and radiation range of 450 Wm^{-2} to 1100 Wm^{-2}, the average beam insolation of 608 Wm^{-2} the required conditions were duly satisfied. The average values of environmental condition parameters are presented with their variations with the local time of the day of experiment in the appendix.

The cooking power P of the parabolic solar cooker which is the rate of useful energy available during heating period is given as:

$$P = M_w C_w \frac{(T_{wb} - T_{wa})}{\tau} \quad (5)$$

P at each interval is corrected to a standard irradiance of 700 Wm^{-2} using:

$$P_s = M_w C_w \frac{(T_{wb} - T_{wa}) \times 700}{\tau I_b} \quad (6)$$

where,

M_w is the mass of the cooking utensil,

C_w is the specific heat capacity of water,

T_{wb} is the final temperature of the water,

T_{wa} is the initial temperature of the water,

τ is the time taken for the water to boil,

I_b is the intensity of direct solar irradiance on the parabolic concentrator.

RESULTS AND DISCUSSION

The performance efficiency of the receiver was calculated using equation 14 as indicated below:

Mass of water (M_w) = 2.45kg

Specific heat capacity of water (C_w) = 4200J/kg/k

Mass of pot-like receiver (M_{pr}) = 0.85kg

Specific heat capacity of pot-like-receiver (C_{pr}) = 452$JKg^{-1}K^{-1}$

Initial temperature of the water & pot-like receiver (T_{wi}) = 31.5^{0}C

Final temperature of the water and pot-like receiver (T_{wf}) = 100^{0}C

Solar insolation at 01:00pm = 854W/m^2

Volume of the kettle receiver (using $\pi r^2 h$) is 70.66m^3

Therefore, the magnitude of the efficiency of the receiver by 01:00pm can be calculated using this equation; $\eta = \frac{Q}{VIT} \times 100$

$$\eta = \frac{Q}{VIT} = \frac{M_{pr}C_{pr} + M_w \times C_w(T_{wf} - Twi)}{VIT} \times 100$$

$$\therefore \eta \approx 32.47\ \%$$

While the cooking power of the parabolic dish solar collector was calculated using equation (34), thus:

$$P = M_w C_w \frac{(T_{wb} - T_{wa})}{\tau}$$

$$\therefore P = 63.58W$$

WATER BOILING TEST

The result of the water boiling test for the parabolic dish solar collector which was conducted from 10am to 1pm on Friday, 24/07/2015 is shown in fig 5 and fig 6. The result shows the effect of the atmospheric parameters on water temperature. It was noticed that the water temperature rises highly and positively influenced by the solar insolation during the time of the day. As the solar insolation increases so the water temperature until it reaches boiling point of 95^{0}C during the hour. The atmospheric temperature was in constant fluctuation between 25.3^{0}C to 34.5^{0}C in between the hours of 10:00am to 12:00pm with the highest ambient temperature reached at that same time i.e.100^{0}C. The maximum solar insolation was found to be 851W/m^2.

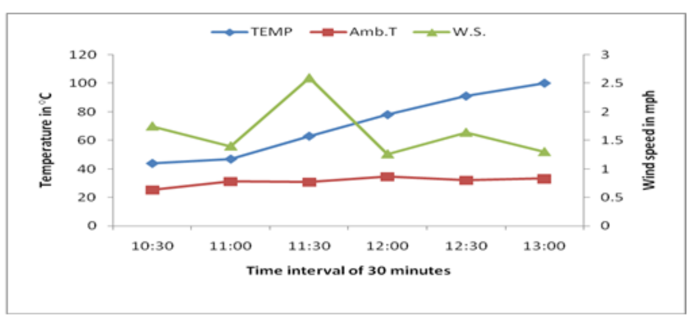

Fig 6: Effect of Wind speed and ambient temperature on Water temp on 24/07/ 2015.

The result shows the performance efficiency of 32.47% indicating a better performance when compared to the 17.86% as reported by [5] but much lower than the direct solar steam system (DSS) which has an efficiency of 75% as reported by [6] and also far less when compared to the peak efficiency of solar energy generation system plants (SEGS) [7].

STEAM GENERATION TEST

The steam generation test was conducted on the second day of the field work i.e. 25/07/15 and the result was interpreted by Fig 8. Comparison between the water boiling test data and the steam generation shows that, the later one was being favoured by clear sky which makes the boiling point to be reached with little delay compared to the previous one. The performance efficiency was found to be 32.47% that is less than the expected value of 75% of direct solar steam system (DSS) solar dish collector [6] which could be attributed to the month of the year the field work was conducted .i.e. July which is the raining season and obviously there was no clear sky.

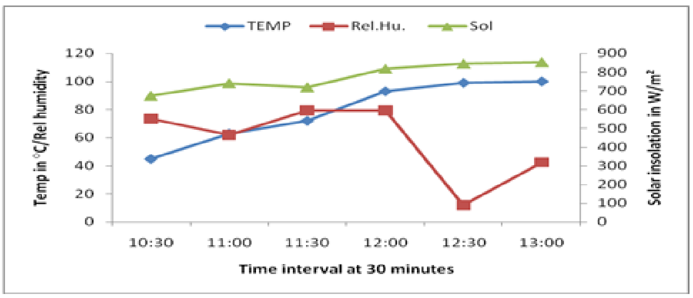

Fig 7: Variation of temperature (θ), Relative Humidity (RH) and Solar Insolation (W/m^2) for Saturday, 25/07/ 15.

THE COOKING TEST

Cooking test of rice was conducted on 24/07/2015. The time taken for the rice was from 12pm to 3pm. The effect of the solar insolation, relative humidity, wind speed and the ambient temperature are shown in Fig 9.

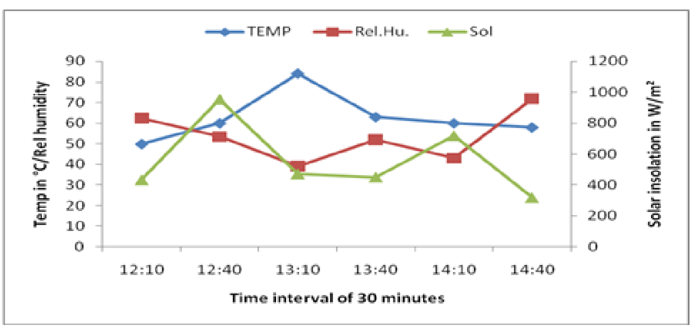

Fig 9: Variation of temperature (θ), Relative Humidity (RH) and Solar Insolation (W/m^2) for Sunday, 26/07/15.

The solar insolation falls from 433 to 318W/m^2 while the relative humidity rises from 62.5 to 72.0. This fall in temperature was obviously due to evidence of rain fall on that day. The cooking power at a temperature difference of 60^{0}C was estimated to be 63.58W during the period of the test slightly ahead of the LPG stove, kerosene wick stove and the kerosene pressure stove that have 53.6W, 50W and 47W respectively [8], though it was found to be less than 96.53W as compared to solar dish cooker [9].

CONCLUSION

Having conducted the development and evaluation of PDSC system that can be used for different applications, the following recommendations were found inevitable for the furtherance of study and improvement of the research area:

I. Need for an automatic tracking system integration to improve the system efficiency and also reduce the associate risk of contact with glare.
II. Heat losses are a major impediment to the process, most especially when the food is to be tasted or stir, therefore, effort should be made to have a better means of loading, offloading and steaming.
III. Modeling and optimization work should be conducted on the system for better efficiency.

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Citation: A. D. Adamu *et al*. (2018). Design, Construction and Performance Evaluation of Parabolic Dish Solar Collector (Pdsc), J. of Advancement in Engineering and Technology, V6I4.07. DOI: 10.5281/zenodo.1005180.