ISSN No:-2456-2165

Thermal Energy Application and Evaluation of Parabolic Dish Solar Collector

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Abstract:- A parabolic dish solar cooker was constructed, and its performance were evaluated in katsina ($Lat\ 12^{o}\ 59'\ 52''\ N$, $Long\ 7^{o}\ 35'\ 5''\ E$) climatic condition. Solar energy has been harnessed using a parabolic concentrator for cooking, water heating, and cooling. The collector's optical efficiency was discovered to be 67.35%, the overall heat loss factor of $8.60 WK^{-1}m^{-2}$ and the average cooking power has been found to be $95.55W$.

Keywords:- *parabolic dish, manual bi-axial tracking, focus concentrator, thermal performance, Checking the Overall heat loss factor and factor of optical efficiency.*

I. INTRODUCTION

Solar concentrator cookers convert sunlight into heat, which can then be used to cook food. Because they rely on a free, abundant, and renewable energy source, solar concentrator cookers have very cheap operating expenses. Solar energy has taken precedence over other sources due to its ability to meet human energy needs; additionally, it has a large active contribution in the future due to its lack of pollution and ability to transform into other types or forms of energy such as electrical, mechanical, and thermal energy.

Recently, solar system energy research has seen a tremendous rise in applications in most world regions, including African countries, with a focus on strategies to improve and develop the efficiency of solar system applications [1]. There is no doubt that locations with a suitable moderate climate and high temperatures have benefited from numerous chances and the ability to obtain maximum solar energy with great efficiency. The mean annual average of total solar radiation in Nigeria ranges from around 3.5 kWh/m2/day in coastal parts to about 7 kWh/m2/day in semi-arid areas along the northern border region. The country receives approximately 19.8MJ/m2/day of solar energy on average. The average daily sunshine hours are predicted to be 6 hours. The distribution of solar radiation is pretty even. During the month of January, the minimal average is around 3.55kWh/m2/day at Katsina in the extreme north [2].

II. EXPERIMENTAL SET-UP

As indicated in Figure 1, the parabolic setup comprises of a concentrator and a coated black pot as an absorber in the form of a cooker. The diameter is chosen so that the heat input at the focal point is in the region of 600 watts [3]. The focus point is a white brilliant pinpoint that measures 0.045m in diameter. To achieve the shape of a parabola, a silver polymer reflector with a reflectivity of 82 percent is used.

During the morning hours, the paraboloid cooker was turned east and the reflector was angled to match the sun's angle.

Fig 1:- Experimental Set up of PDSC

III. TESTING METHODOLOGY

The functioning state of a parabolic solar concentrator cooker demonstrates its thermal precision. For this solar cooker, some work was done on designing a thermal test process. To assess the work's thermal performance and cooking abilities, the following tests [4] were carried out.

➢ *Tests On the Heating and Cooling of Water*

The optical efficiency factor and overall heat loss factor were determined using water heating and cooling testing, respectively. A paraboloidal concentrating cooker with an aperture area of 1.267 m^2 was used to conduct the water heating and cooling tests. The pot was made of aluminum and had a surface area of 0.096 m^2 on the outside. The ratio of the aperture to the surface area of the pot, C, was 13.196. The pot's heat capacity was 1100J/kgk.

The concentrator was shaded when the water temperature reached the required level. During the test, the water temperature and ambient temperature were both recorded. In addition, the insolation of the sun was computed.

➢ *Load Test*

This was done to determine how long it took to cook a given amount of rice, beans, potato, and spaghetti. On a solar cooker, equal quantities of these products were cooked separately and the time taken to cook was recorded.

➢ *Optical Efficiency Factor And Performance Evaluation Of The Pdsc For Load And Heating And Cooling Test*

After examining the sensible heating curve depicted in figure, optical efficiencies $F'\eta_0$ were calculated (2). The equation was used to calculate the values (1). The values of the overall optical efficiency factors were calculated and found to be virtually identical. As a result, solar insolation has only a little impact on the optical efficiency factor values. The reflectance of the reflector and the absorptance of the cooking pot are the two key elements that influence these numbers. If the insolation and ambient temperatures remain constant over time, and the water temperature rises from T_{wf} to T_{wi}, then in the optical efficiency factor:

$$F'\eta_O = \frac{\frac{F'UL \times A_{POT}}{A_a}\left[\left(\frac{T_{wf}-T_a}{I_b}\right)-\left(\frac{T_{wi}-T_a}{I_b}\right)\times e^{-\frac{\tau}{\tau_0}}\right]}{1-e^{-\frac{\tau}{\tau_0}}} \quad \text{.........} \ (1)$$

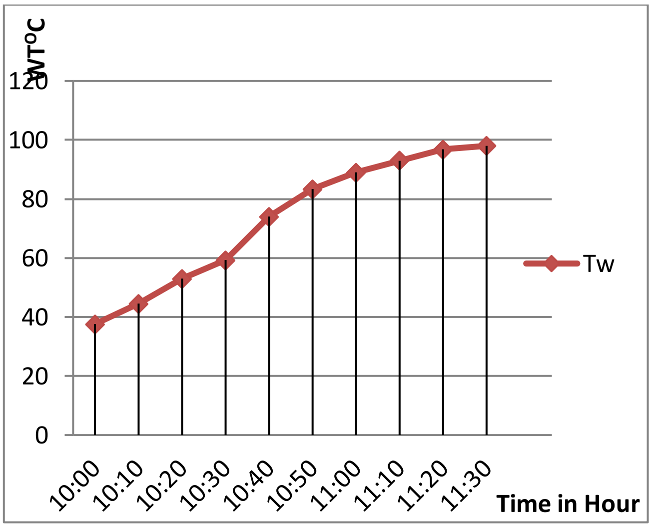

Fig 2:- Curve of Heating

➢ *Checking The Overall Heat Loss Factor*

The overall heat loss factor F'UL was calculated using the cooling curve (see figure) (3). The value of the cooling time constant, F'UL, is needed to calculate the overall heat loss factor F'UL, which may be found by computing the slope of the cooling curve. The measured value was 25.32 when using equation (2).

The heat loss factor is a function of the mass of the pot and the mass of the water, as well as the specific heat capacities of the water and the pot, the pot's area, and the cooling time constant [3].

$$F'UL = \frac{(M_{POT} \times C_{POT} + M_w \times C_w)}{A_{POT} \times \tau_0} \quad \text{......................} \ (2)$$

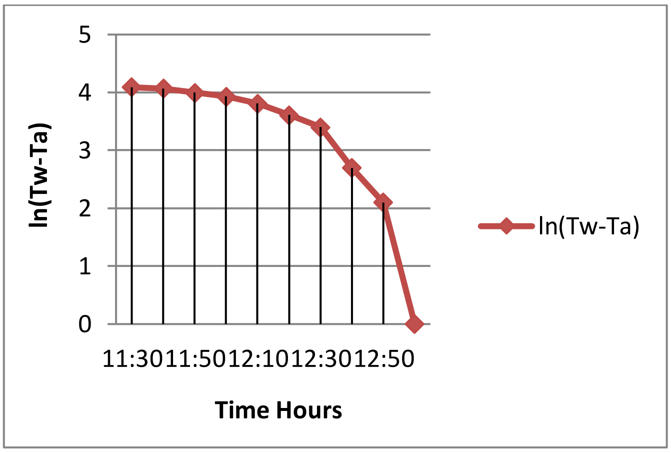

Fig 3:- cooling curve

➢ *Load Test*

The tests were carried *out*, and a set of measurements were taken. The purpose of these tests was to determine the thermal efficiency curve, which is depicted in Figure 4.

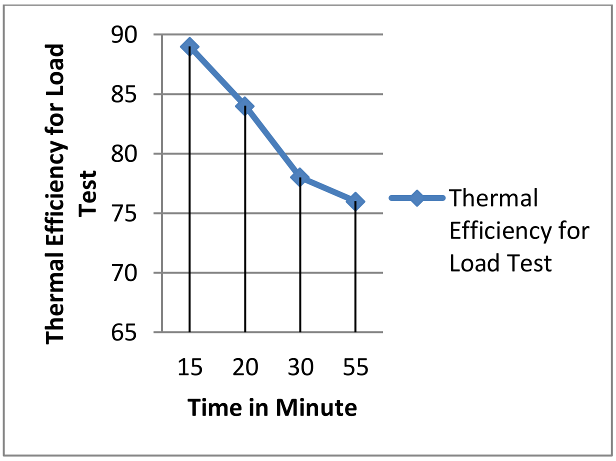

Fig 4:- Thermal efficiency curve with load test

Equation (3) shows the performance equation for the collector with load:

$$\eta_{th} = 0.9145 - 0.1523\left(\frac{T_f - T_{amb}}{I_b}\right) \quad \text{................} \ (3)$$

From equation (3), $(A_r U_L F_R / A_a) = 0.1523\, W/^0cm^2$ and for a concentration ratio13.196. The presence of load test increases η_0 from 0.8502 to 0.9950. The overall heat loss coefficient (U_L) of $1302.396\, W/^0cm^2$.

➢ *Test For Heating And Cooling Test*

Figure 5 depicts the PDSC's performance curve with heating and cooling tests, as generated from a series of tests.

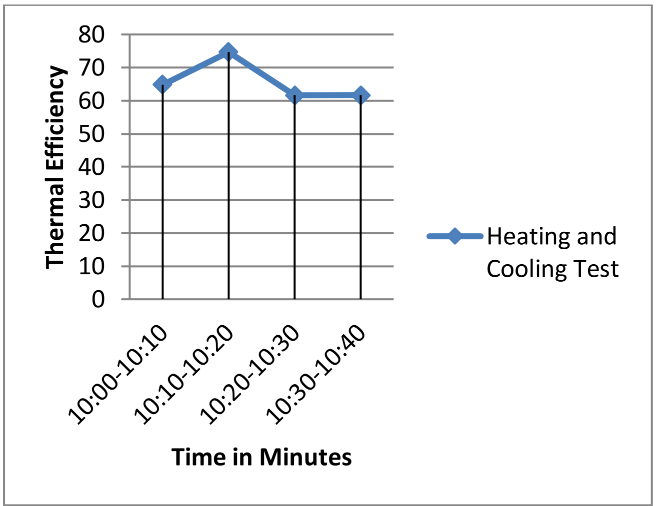

Fig 5:- Thermal efficiency curve with heating and cooling tests

An equation for the curve is obtained using standard technique of the best fit. The intercept is equal 0.6647 and the slope is 0.50715. This result has overall heat loss coefficient (U_L) of $310.21\, W/^0cm^2$. Therefore, for PDSC with heating and cooling tests, the collector thermal efficiency equation is:

$$\eta_{th} = 0.6647 - 0.040934 \left(\frac{T_f - T_{amb}}{I_b}\right) \quad \ldots\ldots\ldots\ldots (4)$$

➢ *Cooking Power*

The cooking power is related with mass of water, specific heat capacity of water, difference between ambient temperature and water temperature at boiling point and change in time with the equation [5]:

$$P = \frac{M_w \times C_w \times dT_w}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

➢ *Standard Cooking Power*

The standard cooking power as given by [6] is:

$$P_{S=} \frac{700 \times M_w \times C_{pw} \times \Delta T}{t \times I_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Time (mins)	P(W)	Ps(W)	η_0	$I_b\ W/m^2$
$10{:}00 - 10{:}10$	72.45	95.87	65.94	529
$10{:}10 - 10{:}20$	89.25	110.38	67.02	566
$10{:}20 - 10{:}30$	66.15	78.62	67.81	589
$10{:}30 - 10{:}40$	154.35	173.99	68.62	621

Table 1:- Performance of the parabolic dish solar cooker.

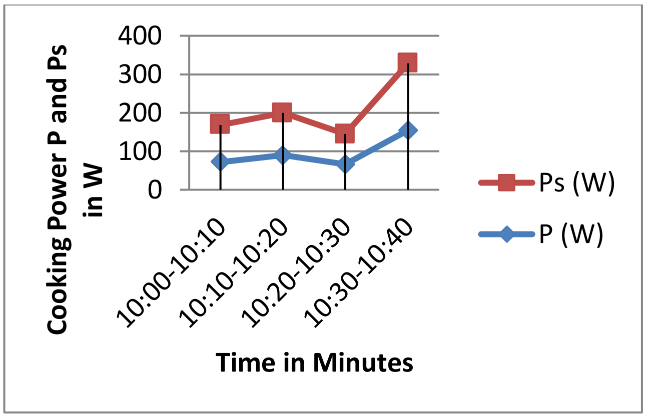

Fig 6:- The change in cooking power over time

IV. CONCLUSION

This shows that with the depletion of fossil fuel in Nigeria, solar energy will serve as an alternative means of cooking for domestic needs. The fact that solar energy is free, the low optical efficiency of the collector is immaterial as long as clean cooking is done and the good health of the users are preserved. The energy efficiency can be increased only marginally by increasing the reflectivity of the reflector, proper designing of the cooking point. The parabolic cooker tested, presents results encouraging as compared with other types of solar cooker.

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