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Performance Evaluation of Parabolic Solar Disc for Indoor Cooking

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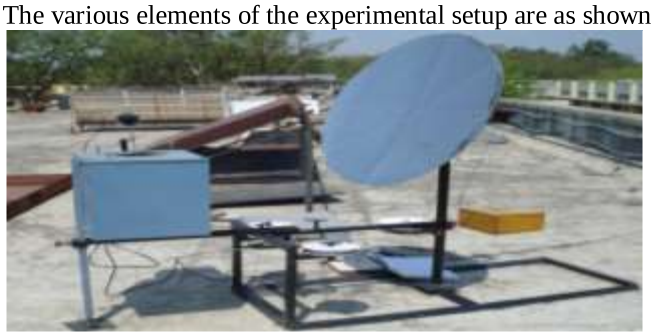
Abstract: *In present energy crisis scenario, it has become necessary to exploit new energy sources. Among these sources solar energy has an infinite potential and available at free of cost. For efficient utilization of solar energy, focusing type paraboloidal solar collector was designed and fabricated having aperture area 0.628 m^2, focal length 0.8 m, receiver area 0.015m^2 and optical concentration ratio 40.Bi-axial manual tracking mechanism is developed which can be operated from the kitchen. It was tested for its thermal performance and cooking abilities. Also comparative analysis with box type solar cooker was done. The system was found useful in cooking a variety of food materials.*
Keywords: *In-house cooking, manual bi-axial tracking, parabolic disc, solar energy.*

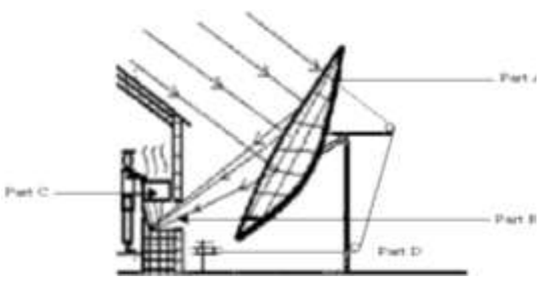
I. Introduction

In this paper attempt is being made to trace the path of how solar concentrators evolved and to present the vision as to be the use of these Solar Concentrators could lead. With the depletion of the fossil fuels resources there is growing need for non-conventional sources of energy like solar energy, wind energy etc, out of these solar energy forms the promising future energy source. Solar energy has the greatest potential of all available energy sources. Solar energy will be one of the important alternate energy sources if a portion of it is effectively harnessed, especially for the day to day life. This energy can be harnessed by using different type of collectors such as flat plate collector, solar collector, photo voltaic cell and solar ponds. In this paper we tried to utilize solar energy for the cooking purpose. Aim is to make the solar cooking as comfortable as possible and also it should be similar to conventional cooking system. In box type solar cooker with flat collectors only boiling and steaming is possible. However, use of concentrating type collector permits all operations like boiling, stewing, steaming, roasting and frying with relatively high capacity. Therefore keeping in view the food habits of rural people and for efficient utilization of solar energy, paraboloidal type concentrating collector was fabricated.

II. Experimental Set-up (Parabolic Concentrating Solar Cooker)

The various elements of the experimental setup are as shown in figure.





The system of parabolic cooker comprises a primary reflector (part A), a secondary reflector (part B), and tracking mechanism(partD). The primary reflector produces a converging beam of sunlight aligned with an axis of rotation which is parallel to the axis of the earth, and which passes through the centers of both reflectors. The tracking unit rotates the primary reflector around its axis of rotation, keeping the reflected beam aligned with the axis of rotation as the sun moves. The fixed secondary reflector reflects the beam from the primary reflector onto a cooking pot or frying surface (part C). As the cooking system is concentrating type, therefore it is necessary to keep the primary reflector always in a normal position to the sun rays. The sun is continuously moving therefore to keep the orientation of primary reflector normal to the sun rays the sun tracking mechanism is required. For this type of cooking system two axes tracking is necessary (i.e. solar altitude angle and solar azimuth angle).
This work is mainly focus on the development of solar cooking system basically for the rural areas where the peoples technically are not that much skilled. Therefore it is necessary to make the system simpler. Hence

manual tracking arrangement is adopted. The unique feature of the tracking arrangement is that the operator doesn't have to go outside the kitchen for setting the primary reflector normal to sun rays time to time as the tracking arrangement will be provided inside the kitchen. Manual sun tracking arrangement is designed to track both the axis by using the wire ropes and pulleys. Two rotating drivers are provided to which the wire ropes are attached. Out of two one rotating driver is for adjusting or setting primary reflector as per the solar altitude angle and another one is to adjust azimuth angle. The operator has to rotate these two rotating drivers to set the orientation of primary reflector normal to the sun once in 10 to 15 minutes.

III. Testing Methodology

Performance of paraboloid concentrating solar cookers is quite sensitive to design parameters and operational conditions, and therefore, the task of evolving and implementing a test procedure for the purpose of standardization and certification is quite involved and challenging. Presently, no specific test standard is available for performance evaluation of paraboloid concentrator solar cookers. Some work was done at IIT Delhi to develop a thermal test procedure for these solar cookers. The cooker was tested for its thermal performance and cooking abilities by conducting following tests:

i. **No Load Test:** In the no load test, temperature was determined by monitoring the top and bottom temperature of an empty pot kept at the cooking place of the solar cooker. Thermocouples are placed at bottom centre and 20 mm from the top of the cooking vessel respectively. By using the pyranometer direct solar radiations are measured in 15 minutes of interval. The test was carried out until there was not much variation in the temperatures at bottom and top of the cooking vessel. Also the ambient temperature was recorded in 15 minutes of interval.

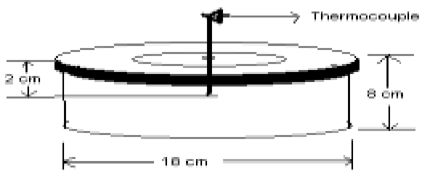
ii. **Water Heating and Cooling Tests:** The water heating test was conducted by placing a vessel with half liter and one liter of water at room temperature on the cooker. The temperature at the middle of the water mass was monitored. The water temperature, ambient temperature and direct solar radiation were measured in15 minutes of interval. The pot with a full load of water is heated by exposing the concentrator to solar radiation until boiling occurs and then cooled by shading the concentrator. Set readings of heating and cooling test are recorded. The overall heat loss factor ($F'U_L$) was obtained from the cooling curve and the optical efficiency factor ($F'\eta o$) was determined from the heating curve--both under full load conditions.

iii.Cooking test: This was done to evaluate the time taken to cook a certain quantity of food items like rice, green gram, red gram, bean nut and khichadi. An equal quantity of these items was cooked individually on solar cooker.

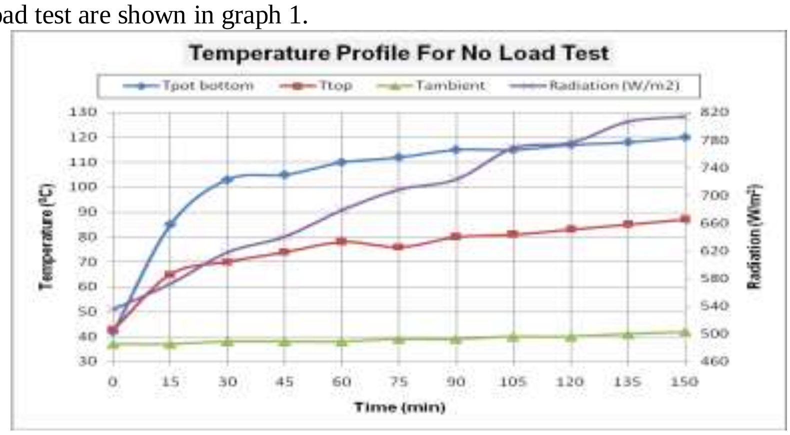
An equal quantity of water was added with each item. During the test the ambient temperature, direct solar radiation and time taken to cook the food were recorded. Also the cooker was tested for tea and coffee.

IV. Results and Discussion:

4.1 No Load Test: In the no load test an empty pot was kept at the cooking place of the solar cooker as shown in figure. The pot was made up of aluminum which is coated with black paint.



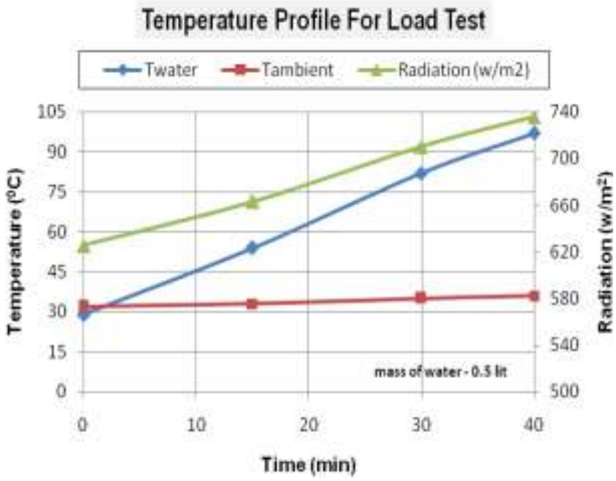
The results of no load test are shown in graph 1.



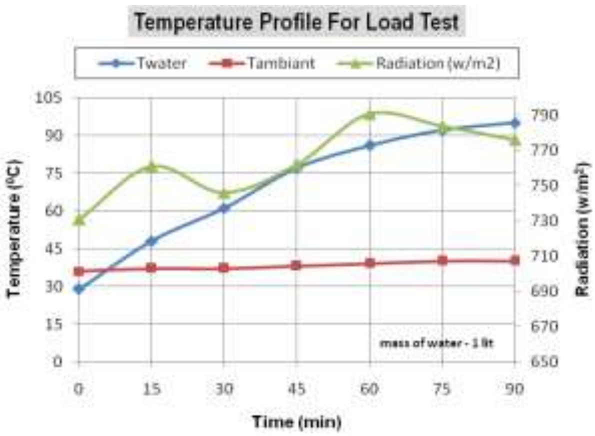
Graph No - 1

The maximum temperature recorded at the top was 87^0C and at the bottom it was 120^0C.The test was conducted in morning time. The average ambient temperature and average solar radiation were 39^0C and 694.27 W/m^2 respectively.

4.2 Heating Test: The water heating test was conducted by placing a vessel with half litre and one litre of water at room temperature on the cooker. The temperature at the middle of the water mass was monitored. Graph.2 and.3 shows the variation in water temperature, ambient temperature and solar radiation for the water having different masses.



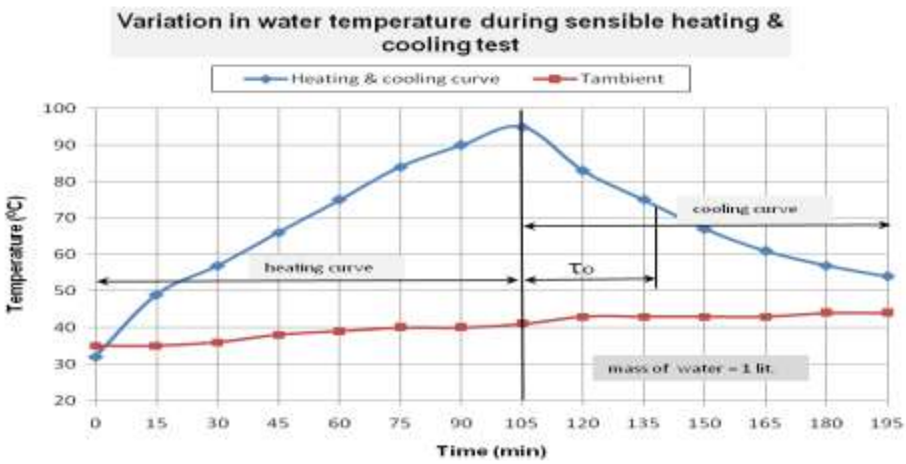
Graph. No - 2



Graph. No -.3

For one litre water test, maximum water temperature achieved was 95^0C and time taken for this was 90 minutes. The average ambient temperature and direct solar radiation recorded were 40.42^0C and 764 W/m^2 respectively.

4.3 Heating and Cooling Test: The pot with one litre of water was heated by exposing the concentrator to solar radiation until the temperature reached to 95^0C and then cooled by shading the concentrator and the complete setup. A set reading of heating and cooling test was recorded. Results of heating and cooling tests are shown in graph 4. The total duration for both heating and cooling test was 2 hr 15 minutes. Water temperature, ambient temperature and direct solar radiation are recorded in time interval of 15 minutes.



Graph. No - 4

4.3.1 Analysis from cooling curve

Analyzing over an infinitesimal time interval during the sensible cooling of water, the time taken, dr for a fall of dT,. (negative) in water temperature is

$$dr = -\frac{(MCp)wdTw}{QL}$$

$$dr = -\frac{(MCp)'wdTw}{AtF'UL(Tw-Ta)} \quad \text{------ [1]}$$

Assuming that the heat loss factor U_L and ambient temperature T_a are constant during the cooling test. Eqn (1) can be integrated over the time interval r, during which the water temperature falls from Two to Twi:

$$\tau = -\frac{(MCp)'w}{AtF'UL}\ln\left[\frac{(Tw - Ta)}{(Two - Ta)}\right]$$

$$(Tw - Ta) = (Two - Ta)e^{-\tau/\tau o}$$

$$\text{where} \qquad \tau o = (MCp)'w/AtF'UL$$

The temperature difference (Tw - Ta) falls to (1 /e) of the initial value after a time $\tau = \tau o$. For the analysis, time interval τ = 15 min. When $\tau = \tau_o$, e = 2.718, 1/e = 0.3679.

From above equation

$$F'UL = \left(\frac{(MCp)'w}{At \times \tau o}\right)$$

$$F'UL = \left(\frac{1 \times 4187}{0.0254 \times 35 \times 60}\right)$$

F'UL = 30.90 W/m^2

4.3.2 Analysis from heating curve

During the sensible heating of water, the time taken, dr, for a water temperature rise dTw is

$$dr = \frac{(MCp)'wdTw}{Qu}$$

$$dr = \frac{((MCp)'wdTw)}{F'[Ap\eta oIb - AtUL(Tw - Ta)]}$$

If the insolation and ambient temperature are constant over a certain interval of time, τ, then above eqn can be integrated over this time interval. If the water temperature rises from Tw_1 to Tw_2:

$$\tau = -\tau o \ln\left[\frac{F'\eta o - \frac{F'UL}{C}\left(\frac{Tw2 - Ta}{Ib}\right)}{F'\eta o - \frac{F'UL}{C}\left(\frac{Tw1 - Ta}{Ib}\right)}\right]$$

where τo is the time constant obtained from the cooling curve and C is the ratio (Ap/A,). Above equation shows the dependence of time τ on solar radiation and ambient temperature.

$$15 = -35\ln\left[\frac{F'\eta o - \frac{30.9}{40}\left(\frac{95-38}{746.12}\right)}{F'\eta o - \frac{30.9}{40}\left(\frac{32-38}{746.12}\right)}\right]$$

$$15 = -35\ln\left[\frac{F'\eta o - 0.059}{F'\eta o + 6.21 \times 10^{-3}}\right]$$

By simplifying we get,

The cooker performance, F'ηo = 0.18.

4.4 Cooking Test: Many different food items were cooked using the cooker at the Institute. Quantity of each item cooked and the time taken are shown in Table1. The cooker was found capable of cooking all the food items such as rice, various types of dal's, khichadi and tea, coffee needed for a family quite comfortably. The tracking arrangement, operation, loading and unloading were found to be convenient to use. The exposed vessel sustained considerable heat loss in the windy season resulting in longer cooking hours.

Table No – 1

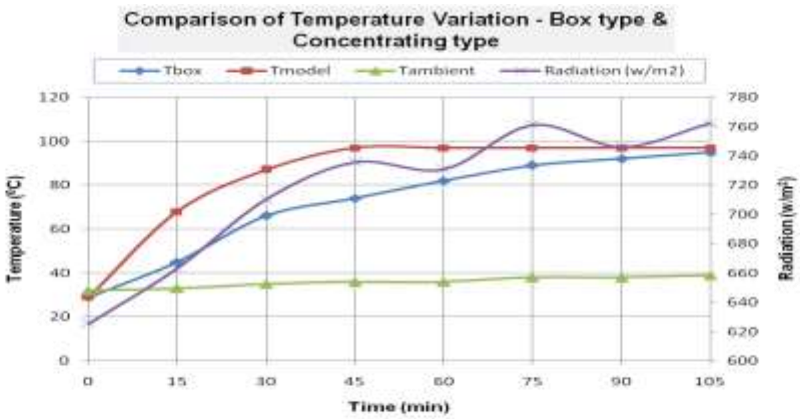
Food cooked	**Quantity**	**cooking Time (min)**	**Ambient temp. ^{0} C**	**Average direct solar radiation (w/m^2)**
Rice	Rice 100 gms Water 200 ml	15	36	696.82
Khichadi	Rice 100 gms Red gram 20 gms Water 300 ml	35	37	673.65
Green gram	Green gram 100 gms Water 200 ml	25	33	704.25

Bean nut	Bean nut 100 gms Water 200 ml	30	36	675.41
Red gram	Red gram 100 gms Water 200 ml	35	38	711.50
Tea	3 cup (450 ml water, 150 ml milk)	20	39	720.14
Coffee	1 cup (200 ml)	10	37	712.45

V. Comparison with box type solar cooker

The performance of parabolic solar cooker is compare with the box type solar cooker by conducting water heating and cooking tests.

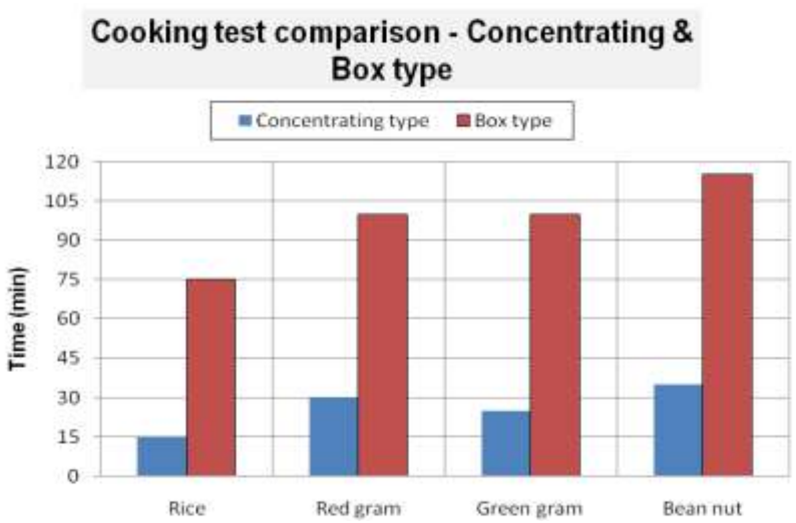
5.1 Heating Test: The water heating test was carried out in the parabolic solar cooker and box type solar cooker at the same time. Half litre of water was loaded in the cooking vessels. The vessels used were of the same size, which made up of aluminum and coated with black paint. The comparative variation in the temperatures of both cookers is shown in graph.



Graph. No - 5

Test result shows that water heating process in parabolic solar cooker is very fast compared to box type solar cooker. Time taken was only 38% of the time taken in box solar cooker.

5.2 Cooking Test: The various food items were cooked in both the types of solar cookers. Comparison of the time taken for cooking various food items by parabolic solar cooker and box solar cooker is shown in bar chart which indicates that cooking process in parabolic solar cooker is faster than box solar cooker.



Graph. No – 6

VI. Instruments used for testing

6.1Thermocouples and Temperature Indicator: Thermocouples are used for temperature measurement. In this project it is used to measure water temperature, ambient temperature, and temperature at the focus point and at the bottom of the cooking pot. Temperature indicator used to display the temperature which is sense by the thermocouple. The electric supply is needed to this temperature indicator.

6.2 Pyranometer: Solar radiation flux is usually measured with the help of a pyranometer. A pyranometer is an instrument which measures either global or diffused radiation over a hemispherical field of view. The pyranometer is generally used in India. An accuracy of about +_ 2 % can be obtained with the instrument.

6.3 Digital Multimeter: It is used to display the voltage sensed by the pyranometer which is in the range of mill-volts. By setting the rotary switch to volt-mode and connecting the probe tips parallel with the voltage source (i.e. pyranometer) it measures the voltage. Conversion formula is:

$$s = \left(\frac{mV \times 1000}{13.27}\right)$$

Where, S = Solar Flux in W/m^2 and

mV = mV reading shown by the pyranometer.

VII. Conclusion

The concentrating cooker was found to provide adequate temperatures needed for cooking. Most of the recipes could be cooked within one to two hours in bright sunshine days. The ambient temperature affects the performance of concentric solar cooker on a minor scale in the morning hours. The ambient temperature is less hence the rate heat transfer from the vessel and its contents to the ambient is more hence there is a slight decrease in the efficiency in the morning hours. In the afternoon due the higher ambient temperature there is a less rate o heat transfer correspondingly higher efficiency. Unique feature of cooker is the sun tracking arrangement. Though it is manually operated but fully controlled within the kitchen only. That means the operator doesn't need to go in sunny place to set primary reflector normal to sun rays every time. It was found that wind velocity if more affects the performance of solar cooker. For efficient performance of cooker, it is desired to have wind velocity less than 1m/s.

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