Assessment of Thermal Performance of Box Type Solar Cookers under Gujarat Climate Condition in Mid Summer

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ABSTRACT :- ***A small review on the box type solar cooker applications and its designs given here. Two designs of cookers were tested. The first type has a painted black base and second type has a pained black with coal. These designs were examined under two modes of operations: at fixed position and on tracking system. The cooker at a fixed position had recorded thermal efficiencies ranging from 25.2 % to a sharp peak of 53.8% at the maximum solar intensity of the day around 12-13 pm with an average overall efficiency around 32.3%. Whereas, cooker with black coal pained installed on a sun tracking system gave higher water and pot temperatures, and thermal efficiency ranged from 28% to 62.1% with an average overall efficiency around 43.8 %. Cookers installed on sun tracking system had the advantage of maintaining a higher as well as closer range of thermal efficiencies through the daylight than the ones at fixed positions.***

Keywords: ***Box type solar cooker, tracking system, efficiency, Gujarat.***

NOMENCLATURE

T' : The temperature after a certain time (one hour in the conducted experiments)

Tw : Water temperature

$Twall$: Water temperature

Tg : Glass temperature

mc : Water heat capacity (kJ K-1)

$\tau\alpha$:The transmittance – absorptance product

Ag : The glass area (m2)

Ut : The top loss coefficient (w m-2 K-1)

Ta : The ambient temperature (K)

Ub : The bottom and lateral loss coefficient (w m-2 K-1)

Aw : The insulated wall area (m2)

Is : Values were

1. INTRODUCTION

Now a day's fuel price hicks vary rapidly so need to search for alternative cheaper source of energy is necessity. Therefore, solar energy is becoming a feasible option for us. Solar cookers are rather important applications in thermal solar energy conversion. The use of solar cooker for cooking purposes is spreading widely in most developing countries and in particular in villages and remote areas. Current designs of solar cookers normally used are box cookers, concentrators, and flat plate collector cookers. The solar cooker must be high quality, light weight, affordable, user friendly, stackable and a family size. The basic purpose of a solar box cooker is to heat things up - cook food, purify water, and sterilize instruments. A solar box cooks because the interior of the box is heated by the energy of the sun. Sunlight enters the solar box through the glass. It turns to heat energy when absorbed by the dark absorber plate and cooking pots. This heat input causes the temperature inside of the solar box cooker to rise until the heat loss of the cooker is equal to the solar heat gain. Sufficient temperature for cooking and pasteurizing water is achieved. Capacity of heat increases with the properties of material (density and weight) is increased. Because of this additional heat storage capacity rocks, bricks, heavy pans, water, or heavy foods will take longer to heat up so interior of a box including heavy materials. In the box, incoming energy is gathered as heat in these materials.

The important parts of a hot box solar cooker include a) outer box: made of galvanized iron or aluminum sheet, b) inner cooking box: made from aluminum sheet and coated with black paint so as to easily absorb solar radiation and transfer the heat to the cooking pots, c) thermal insulator: The space between the outer and inner box is packed with insulating material such as glass wool pads to reduce heat losses from the cooker, d) mirror: used in a solar cooker to increase the radiation input on the absorbing space and fixed on the inner side of the main cover of the box. This radiation is in addition to the radiation entering the box directly and helps to quicken the cooking process by raising the inside temperature of the cooker, e) cooking containers: generally made of aluminum or stainless steel. These pots are also painted black on the outer surface so that they also absorb solar radiation directly. The main objective of this present work is to investigate two designs of solar coolers. Figure 1 presents two designs of solar cookers under investigation. Also, evaluate the various parameters affecting cookers performance under different modes of operation such as at fixed position and moving on a tracking system. Experimental work and validation of mathematical modeling are carried out and compared. An overview and up to date literature will be presented. Figure 1 Tested solar cookers: i) Black painted box type cooker, and ii) Black coal painted box type cooker

1.1 OBJECTIVE OF THE STUDY:

The objective of the study is to analyze the performance of Box Type Solar Cookers under Gujarat Climate Condition in Mid Summer to improve the workability of cooker.

1.2 SCOPE OF THE STUDY:

To evaluate the performance of Box Type Solar Cookers under Gujarat Climate Condition in Mid Summer. The readings obtained from the conducted tests have been evaluated and the results and graphs are compared. Location of **Mehsana**, Gujarat, India (**Latitude**: 23° 40' 0 N, **Longitude**: 72° 30' 0 E)

2. A REVIEW ON SOLAR COOKERS:

Solar cookers are simple, cheap, and trouble-free with good efficiency. Solar cookers were used as early as 1776 by DeSaussure, who used a hot box-type oven. Telkes [1] and Burkhardt [2] presented one of the earliest reviews on solar cookers. From early design considerations on the development of an urban solar cooker goes back for more than 30 years [3]. There are several different designs for the hot box-type ovens which can be summarized as follows: Simple plane hot box ovens where the food pot is enclosed inside the oven box. The oven is heated by direct solar radiation transmitted through its glass cover [4]. Mannan et al. [5] described a solar oven with compound conical reflectors. Indirect hot box ovens in which the cooker is heated indirectly by means of steam flowing through heat pipes which are enclosed in a plate collector, Whillier [6]. The Telkes oven is one of the most familiar configurations of hot box oven types [7]. Several research works were conducted on the thermal testing and performance evaluation for concentrating solar cooker and combined concentrating/oven type solar cooker, and parameters that characterize the performance of the solar cooker [8].Evaluation of solar cooker thermal performance using different insulating material [9]. The hot box solar cooker was tested in an indoor solar simulator with covers consisting of 40 and 100 mm thick Transparent Insulation Material (TIM) [10]. The addition of a plane reflector to a box-type solar cooker increases the obtained cooker temperature and thermal performances [11].

3. EXPERIMENTAL SYSTEM SET-UP

The experimental tests on the solar cookers were carried out during the successive days from the 07/05/2011 to 09/05/2011. Each experiment starts from 8:00 am in the morning to 17:00 pm in the evening. The electrical and electronic parts were tested and calibrated before being used on the various designs on both solar cookers. The experimental work was fully carried out in the Alternate Energy laboratory at the Mechanical Engineering Department, L. C. Institute of Technology, Bhandu, Gujarat, India. The first part of this research work concentrated on testing of two box type cookers: traditional black painted cooker and black pained with coal cooker as shown in Figure 1. Both cookers are fixed at a position towards the south. The second part is testing the coal black painted cooker with a tracking system to the sun movement. Figure 2 shows schematic diagram of three dimension of the solar cooker installed on a horizontal sun tracking system. It shows the base, motor and bearing and sun cooker.

Figure 1 presents two designs of solar cookers under investigation

Figure 2 Three dimensional views of the designed solar cooker. Thermocouple connections in the cooker three thermocouples at different locations a) Outer glass temperature, b) Metallic pot side temperature, and c) water temperature inside the pot are installed. Solar intensity radiation was measured by Kipp and Zonen Pyranometer type (CM5) and fixed at a horizontal position. A Digital multi-meter was used to record the output voltage in mV. The device records the data on an accumulative basis and shows the radiation on an instantaneous basis. The temperature measurements were carried out using *K* type thermocouple coupled to digital thermometer with range from -50 to150 oC. The accuracy of this thermometer is in the range of 0.3 oC.

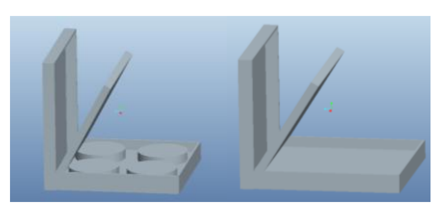

Figure 2 Three dimensional views of the designed solar cooker,

4. RESULTS AND DISCUSSION

The total input solar energy $Q_{total} = (\tau\alpha)I_s A_g$ which is equal to the summation of the stored internal energy inside the cooker Q_i and the energy loss from the top side Q_{top}, and the energy loss from both bottom and lateral Q_{bottom}. Well established model which neglects the heat capacity of the pot is presented by Jansen 1985 and Kreith and Kreider 1978. It applies the following expression:

$$Q_{water} = Q_{total} - Q_{losses} = Q_{total} - (Q_{total} + Q_{bottom})$$

$$mc(T - T_w) / \Delta_t = [(\tau\alpha)I_s A_g - U_t A_g (T_g - T_a) - U_b A_{wall} - (T_{wall} - T_a)]$$

In the case of fixed cooker, the $\tau\alpha$ (transmittance – absorptance product) changes at different altitude angle as the sun changes its position hourly. Whereas, in the case of tracking system $\tau\alpha$ is at maximum of 0.9.

The thermal performance of both proposed cookers with internally black coated surface and black coal painted is investigated in this section. The results obtained are plotted as recorded water and metal temperatures against the operating time for fixed position and on tracking system.

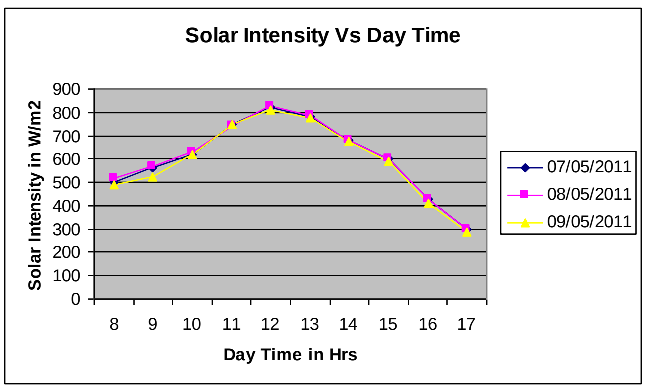

Figure 3 Solar intensities for the three working days

Figure 3 shows the change in the hourly solar intensity for the three working days. It is clear the maximum solar intensity was around mid noon (12:00 – 13:00 pm).

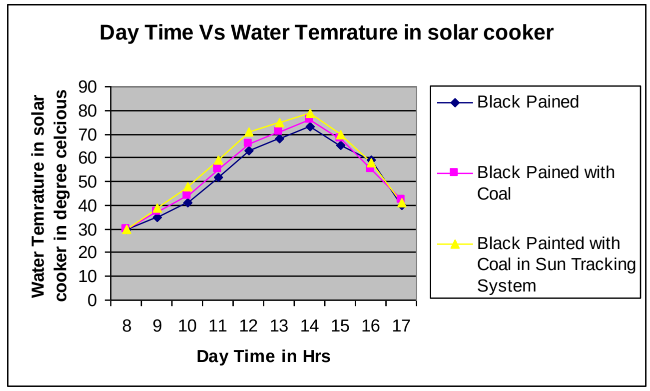

Figure 4 Average water temperatures for the three proposed systems at the three working days.

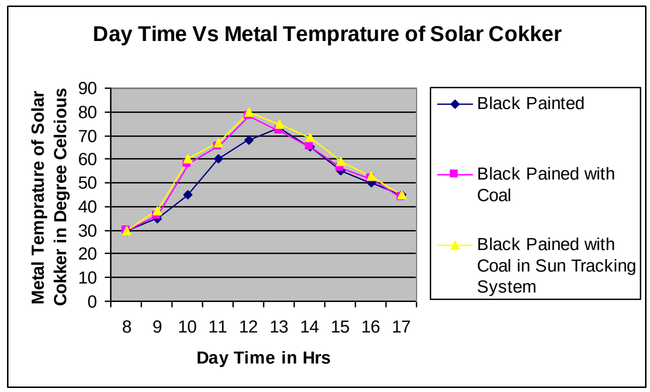

Figure 5 Average metal temperatures for the three proposed systems at the three working days.

Figures 4 and 5 show the recorded water and metal temperatures through typical summer days (07/05/2011 to 09/05/2011) from 8:00 am to 17:00 pm. Experiments were carried out for three working days to validate the results obtained. The Figures show an increase in water and metal temperature during early hours of the day until it reaches the maximum temperature around mid noon corresponding to the highest solar radiation then decreases as the sunsets. It is clear that cookers at fixed position with either black coated surface or black painted with coal gave close water and metal temperature readings. Whereas, cookers installed on a tracking system gave higher temperature readings and this is expected due to maintaining maximum solar energy entering the cooker system. It was noticed that the maximum water temperatures were recorded around 13:00 – 14:00 pm. whereas, the maximum metal temperature were recorded around 12:00 – 13:00 pm. This is logic where the metal of pot will heat up first then the inside water.

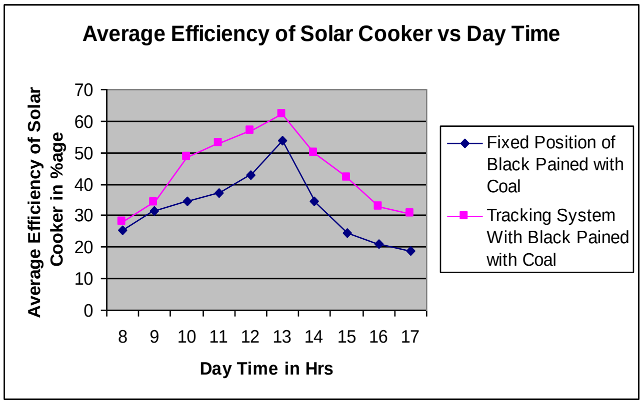

Figure 6 Average efficiency for cookers at fixed and on tracking systems for the three working days.

Figure 6 illustrates that cookers at a fixed position had recorded thermal efficiencies ranging from 25.2 % to a sharp peak of 53.8% at the maximum solar intensity of the day around 12-13 pm with an average overall efficiency around 32.3%. Whereas, cooker with black coal painted installed on a sun tracking system gave higher water and pot temperatures, and thermal efficiency ranged from 28% to 62.1% with an average overall efficiency around 43.8 %. Cookers installed on sun tracking system had the advantage of maintaining a higher and closer range of thermal efficiencies through the daylight than the ones at fixed positions.

5 CONCLUSION

After conducting arithmetical analysis on the data obtained from the cookers, It is clear that both types of cookers (black coated and black coated with coal) at fixed position gave similar thermal performance where the averaged water and pot temperatures were close within ±3% margin of error. The cookers thermal efficiencies at a fixed position ranges from 25.2 % to an increasing sharp peak of 53.8% at the maximum solar intensity of the day around 12-13 pm with an average overall efficiency around 32.3%. Whereas, cooker with black painted with coal installed on a sun tracking system gave higher water and pot temperatures, and thermal efficiency ranged from 28% to 62.1% with an average overall efficiency around 43.8 %. Cookers installed on sun tracking system had the advantage of maintaining a higher and closer range of thermal efficiencies through the daylight than the ones at fixed positions.

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