Experimental Analysis of Plane Reflector Augmented Box-Type Solar Energy Cooker

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Abstract— In this paper present a box type solar cooker design philosophy, construction, measured performance, and experimental analysis of plane reflector augmented box type solar energy cooker. The experimental solar cooker consisting of two plane reflector suitable positioned in a north-south configuration on an inclined framework, is mounted of box type solar cooker to reflected solar radiation on the base absorber of the cooker. The top cover (Glazing) is tilted at 23.16° corresponding to the latitude of Jabalpur (the location of the test site). The performance testing and comparison were done experimentally during summer season in the month of May at Jabalpur. Provision is made for four cooking vessels (two different size), each capable of holding 1 kg of water. The experimental result obtained show stagnation absorber plate temperatures of 144°C and 124°C for the with and without plane reflector in place respectively. It show that stagnation temperature 20-30 °C higher than that of the without reflector. Boiling time of water 48 minute and 52 minute for 1 kg of water equally distributed of each vessels, 76 minute and 95minute for 1 kg load with one pot loaded, for the cooker with and without the plane reflector place, respectively were recorded. The solar cooker performance has been rated using the first figure of merit (F1) is 0.1126 & 0.09 with and without plane reflector respectively on the no load test and the second figure of merit (F2) is 0.2380& 0.2764 on sensible heat test with and without plane reflector place respectively. Also calculating the optical efficiency of glass is 59.58%. The boiling time of water and second figure of merit compared to using different quantity of water with and without plane reflector. Thus box type solar cooker with plane reflector place to increased heat collection and faster cooking compared to the without reflector.

Key words: Box Type Solar Cooker, Optical Design, Inclination Angle of Glazing, Measured Performance Rating, First and Second Figure of Merit, Boiling Time of Water

I. Introduction

Solar energy is considered a suitable alternative for variety of application. It is a largest renewable resources, freely available everywhere in adequate amount, making in one of the most promising, clean, non- pollution sources. It is a simplest, safest, most convenient way to cook food without consuming fuel or helping of the kitchen. Most of the cooking energy requirement is met by non-commercial fuels such as fire wood, agricultural waste, cow dung cake, kerosene in rural areas [1].

Nomenclature

F_1	First figure of merit	$m^2\ kw^{-1}$
F_2	Second figure of merit	Unit less
U_L	Overall heat lose coefficient	$WK^{-1}m^{-2}$
η_0	Optical efficiency	Unit less
η	Cooker overall efficiency	Unit less
T_{ps}	Absorber plate stagnation temperature	K
T_{as}	Ambient temperature at time of stagnation	K
I_s	Insolation on a cooker surface at stagnation	Wm^{-2}
$(MC)_w$	Product of mass and heat capacity of water in	$KJ/\ {}^0C$
C_R	Heat capacity ratio	Unit less
T_{w1}	Initial temperature of water	K
T_{w2}	final temperature of water	K
T_a	Ambient temperature	K
T_{av}	Average ambient temperature	K
T_P	Absorber plate temperature	K
Tf	Final water temperature	K
Ti	Initial water temperature	K
Tw	Water temperature	K
X	Insulation thickness	m
τ	Measured time for sensible heating of water	Second
A	Aperture area of box type solar cooker	m^2
F’	Heat exchange efficiency factor	Unit less
A_s	Cooker surface area	m^2
A_L	Heat loss area	m^2
C_p	Specific heat capacity of water at consent pressure	$J\ kg^{-1}\ K^{-1}$
C_r	Heat capacity ratio	Unit less
F'	Heat exchange factor	Unit less

I	Insolation	Wm^{-2}
I_{av}	Average total Insolation incident on cooker surface	Wm^{-2}
K	Thermal conductivity of the fiber glass wood insulation	$Wm^{-1}k^{-1}$
M	Mass of water	Kg
q	Rate of energy absorbed by the cooker	W
q_L	Desired maximum rate of heat loss from cooker wall	W
q_u	Rate of useful heat gain by water	W
t	time	S
t_{boil}	time required to boil water	S

In the history of solar cookers, in 1764, Horace de Saussure (French inventor) produce temperature of 225° F in glass-covered boxed inclined with black cork. Another Frenchman, Augustin Muchot, design a solar oven in the 1870s that was used for many years by the French Foreign Legion, and Ducurla improved on the hotbox design by adding mirrors to reflect more sunlight and insulating the box. The Stove was made out of mahogany, painted black, buried into sand for better insulation and covered by a double glazing to reduce the loses [2]. Solar cookers of various types were the subject of several theoretical and experimental studies all over the world. Negi and Purohit [3] conducted an experimental study of a box-type solar cooker with two non-tracking planar reflectors to enhance solar radiation in the box of the cooker. Amer [4] developed a double exposure box-type solar cooker; in such design the absorber is exposed to solar radiation from the top and the bottom side. Nahar [5] investigated experimentally the thermal analysis of a double reflector box-type solar cooker with transparent insulation materiel. A.V.Narasimha Rao et al [6] have investigated the effect of keeping the cooking vessel on lugs and also a cylindrical cooking vessel with central annular cavity; they showed by experiments that the cooking vessel with central cavity improves effective heat transfer surface. Avala -raji reddy et al [7] The mathematical model considers a double glazed hot box type solar cooker loaded with two different types of vessels, kept either on the floor of the cooker or on lugs.. E. Cuce et al [8] is performed in a thematic way in order to allow an easier comparison, discussion and evaluation of the findings obtained by researchers, especially on parameters affecting the performance of solar cookers. A review of solar cookers was made by Muthusivagami et al. [9]. Subodh Kumar [10] the paper presents a simple test procedure for determination of design parameters to predict the thermal performance of a box-type solar cooker. Suhail Zaki Farooqui [11] presented a novel mechanism for one-dimensional tracking of box type solar cookers along the azimuth has been reported in this paper. H.P. Garg [12] Enhancement in solar energy on flat plate collector by plane booster mirrors a comprehensive analysis of a system consisting of a flat plate collector augmented with two reflectors is presented. O.V. Okechuku & N.T. Ugwuoke [13] presented design philosophy, construction and measured performances of a plane-reflector augmented box-type solar-energy cooker are presented. S. C. Mullick et al. [14] [15] checking the Performance of Solar Cooker with Various Load and Number of Pots and thermal testing procedure of box type solar cookers.

The present work aims at developing a solar cooker design that can enhance the heat capacity of a box type solar cooker by augmentation of the solar energy in the box for efficient cooking by using the two reflector and tracking the optics. A laboratory model of a box type solar cooker employing two reflector with double glazing has been designed and fabricated, and its thermal performance has been evaluated experimentally. The solar cooker design employs two mirrors in an north - south configuration, suitably fixed on a framework tilted at a certain angle with respect to the upper surface of the cooker such that all incident solar rays impinging on the mirrors within a certain specified range hm (acceptance half angle) with respect to the normal to the concentrator aperture plane are reflected onto the base absorber of the box of the cooker. The cooker is designed with the framework of the concentrator tilted at an angle equal to the latitude of the site with a provision for seasonal tilt adjustment to keep the concentrator aligned with the direction of the sun. The absorber, i.e. the box of the cooker is kept stationary in a horizontal position. Performance testing of the laboratory model of the solar cooker was conducted with and without reflector. A number of tests were conducted under varying operating conditions to determine the stagnation temperature and to study the heat capacity of the cooker. Further, in order to quantify the increase in the temperature achieved with the laboratory model of the solar cooker, a comparison of the performances of the two cookers indicates that with reflector cooker provides higher stagnation temperature and faster boiling of water than without reflector box type solar cooker. The experimental results have been analysed and discussed in detail. Accordingly, the design of the traditional box-type solar cooker is being improved with respect to shortened cooking time, reduced cost and local availability of construction materials, efficient utilization of energy (i.e. improved energy input and reduced heat loses), tidy cooking chamber and improving solar radiation transmission.

II. Description of the Solar Cookers

Important general considerations in the selection of materials for construction of the cooker included, local availability, low cost, easy handling during fabrication, lightness of weight for easy handling during use, weather ability and long service life (i.e. ability to withstand environmental and operating conditions) and non-toxic effects. Box type solar cookers has been constructed using locally available materials as well as local technical assistance. This simple box type solar cooker consists mainly of an outer box, with and without reflector and glass cover (glazing) fitted at particular latitude angle 23.14 corresponding to the latitude of Jabalpur (the location of the test site). The important parts of a hot box solar cooker include; a) outer box: the outer box of a solar heater is generally made of galvanized iron. The inner box is slightly smaller than the outer box. It is coated with black paint so as to easily absorb solar radiation and transfer the heat to the heating (cooking) pots. The insulating material should be free from volatile materials. Reflectors used in the solar cooker to increase the radiation input on the absorbing space and attach on the inner side of the main cover of the box. Commercially available 0.001 m (1 mm) thick aluminium plate was used as the absorber plate. This was painted matt black to improve its absorptivity. Aluminium satisfies the absorber plate desirable characteristics of good thermal conductivity and high resistance to corrosion [16] and an aluminium plate thickness of between 0.0005 m (0.5 mm) and 0.001 m (1 mm) has been determined previously to give optimum results [17]. Copper, which is a better material, is expensive and not readily available. The glazing material was commercially available 0.004 m (4 mm) thick and spacing between them 15 mm tempered glass. Glass satisfies the cover desirable properties of high optical transmittance, low reflectivity, low transmittance to heat and low absorptance of solar radiation. Double glazing was adopted as it is most appropriate for the desired temperature elevation. Glasswool was used for insulation. It has low thermal conductivity, it is stable at the operating temperature regimes and is cheap and readily available. The gap between the box and the absorber plate is filled with glass wool insulation. In this setup we used two reflectors; both are having 3 mm thickness. The three internal lateral sides are covered by aluminum foil and on the opposed side to the aperture area a mirror of 0.62×0.62 m is fixed by screws. For box-type solar cooker, the absorber tray consists of an aluminum sheet painted black of a surface of 0.30 m by 0.30 m and 0.8 mm thickness. We have performed a comparatively experiment without reflector solar cooker and second time use with two reflector mirror solar cooker. The reflector consists of a galvanized iron-framed commercially available plane mirror, which is sized to form a cover for the box when not in use. Provision is made for four cooking vessels each capable of holding up to 1 kg of water. The temperature of the absorber plate, temperature of the internal hot air measured at the centre of the internal cooker volume. They reflect the radiation entering the box directly to the container and helps to quicken the cooking process by raising the inside temperature of the cooker. A glass lid covers the inner box or tray. It is slightly larger than the inner box and used flat absorber plate inside bottom surface of solar cooker and a rubber strip is affixed on the edges of the frame to prevent any heat leakage. The heating container is made of aluminum. These pots are also painted black on the outer surface so that they also absorb solar radiation directly. Six thermocouples at different locations were installed on the solar cooker. Photograph of this absorber plate is shown in Fig. 1. We used two different type of pot, two pot is big and two is small. Size of two big pot of 19 cm diameter and height 60 mm and two small pot of 17 cm diameter and height 58cm.

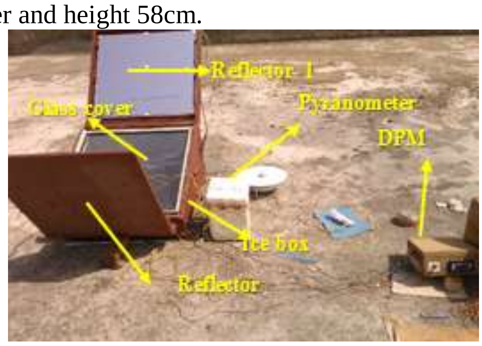

Fig. 2: Experimental setup of solar cooker with reflector

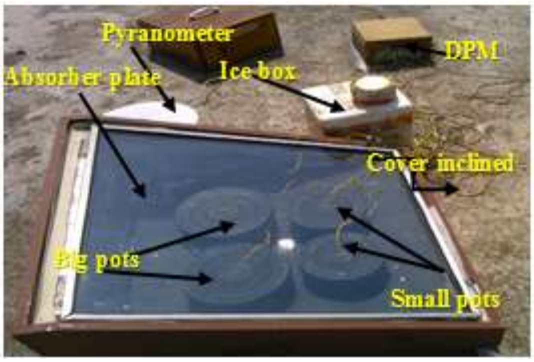

Fig. 2: Experimental setup of solar cooker without reflector

A. *Instrumentation:*

For each cooker, the temperature of the absorber plate, the temperature of water in each cooking vessel is also measured by the same type of thermocouple introduced through a small hole at the lid centre. Ambient temperature and wind speed measurements were taken by euro lab mini anemometer (accuracy ±3%, range 0.1-25.00 m/s and resolution 0.01 m/s) with thermometer (range 0-100° C). Solar intensity radiation was measured by precision Pyranometer. A Digital processing meter was used to show the output voltage in mV. mV convert to degree centigrade, calibrated with the help of hypsometer and also convert to w/m2 . The temperature measurements were carried out using K type thermocouple range from 0-1100 °C.

III. DESIGN PARAMETERS

The design parameters are as follows: mass of water to be boiled, (m) 1.5 kg; initial water temperature, (T_i) 28°C; desired final temperature of water, (T_f) 100°C; specific heat capacity of water at constant pressure (C_p), 4200 J kg^{-1} K^{-1}; time desired for boiling of water, (t) 1 h (3600 s); anticipated average total insolation (during the time t), (I_{av}) 800 Wm^{-2}; assumed overall solar cooker efficiency, (η) 0.35; ambient air temperature, (T_a) 30°C (303 K); anticipated absorber plate maximum temperature, (T_p) 140°C (413 K); desired maximum heat loss rate through the cooker walls, (q_L) 7% (of I_{av}); solar cooker surface area dimensions (calculated), (A_s) 0.62 × 0.62m (0.384 m^2); thickness of wall insulation (calculated), (x) 0.057 m. Insolation values, I >850 Wm^{-2} are prevalent in the location during the dry season [18]. Taking into consideration fluctuations in insolation which are usually minor during the season [18], an average insolation value of 800 Wm^{-2}during the desired cooking time is used in the design.

If $MC_p \Delta T$ is the energy required to raise the temperature of the water from T_i to T_f (where ΔT = T_f–T_i) and $I_{av\eta}A_s$ is the amount of solar energy available to boil the water, then the solar radiation collection area (i.e. cooker surface area) is obtained as,

$$A_s = \frac{MCp\Delta T}{I_{av}t\eta} \quad (1)$$

This gives a cooker surface area of 0.45 m^2. For ease of construction cooker surface dimensions of 0.62 × 0.62 m are chosen. The cooker wall insulation thickness, x = 0.0571 m is estimated from Fourier’s law of conduction as,

$$X = \frac{KA_LT_p}{q_L} \quad (2)$$

Where K is thermal conductivity of the fibre glass wool insulation (K=0.04 $Wm^{-1}K^{-1}$) , A_L is the heat loss area (bottom + side walls, $A_L \approx$ 0.7m^2), ΔT is the temperature difference between the absorber plate and ambient, (T_p - T_a) = 110°C, q_L is the desired maximum rate of heat loss through the cooker walls (q_L = 7% of incident insolation = 49 W).

IV. THEORY

Standard rating procedures for the performance of solar cookers have until recently been non-existent. Solar cookers have generally been rated previously by test procedures that are dependent not on unique solar cooker properties but on climatic parameters, namely insolation, ambient temperature and local wind speeds and thus do not lend themselves easily to standardisation. These procedures included no-load stagnation tests, sensible heat (water boiling) tests (i.e. evaluating the time required to boil given amounts of water and the thermal efficiencies of the cookers). The performance of the experimental solar cooker in this study is also being assessed by the performance rating procedure of the first and second figures of merit suggested as being cooker unique parameters [14, 15]. The theory of these rating procedures is shown below for completeness. A simple energy balance on a horizontal solar cooker under no-load condition at some quasi steady state, namely at stagnation, can be given by,

$$\eta_o I_s = U_L(T_{ps} - T_{as}) \quad (3)$$

Where η_o and U_L are the optical efficiency and heat loss factor of the cooker respectively, Is,

T_{ps} And T_{as} are the insolation on a horizontal surface, absorber plate temperature and ambient temperature respectively at stagnation. High optical efficiency and low heat loss are desirable for efficient cooker performance. Thus the ratio η_o/U_L which is a unique cooker parameter can serve as a performance criterion referred to as the first figure of merit, F_1 and defined as,

$$F_1 = \frac{\eta_o}{U_L} = \frac{(T_{ps} - T_{as})}{H_s} \quad (4)$$

In simple terms, higher values of F_1 would indicate better cooker performance. Accordingly, a minimum value of F_1 can be specified for different climatic conditions (i.e. insolation and ambient temperature [14]). For our local typical average insolation value of 800 Wm^{-2} (on a good day) and ambient temperature of 30°C, a desired minimum plate temperature of say 100°C (for boiling to be achieved), a minimum value of F_1 = 0.1 Km^2W^{-1} is specified for a cooker. A lower F_1 value may be specified for periods of lower insolation values. F_1 is thus a unique cooker design number for any given climatic condition? The second figure of merit, F_2, is derived from the sensible heating of water. The time interval dt, required to raise the temperature of a known mass M of water of specific heat capacity, C_p by dT_w is given as,

$$dt = \frac{(MCp)'_w dTw}{q_u} \quad (5)$$

Where q_u is the rate of useful heat gain by the water, $(MCp)_w$ heat capacity of water and the cooking utensils. If we define the useful heat gain,

$$q_u = A_s F'[\eta_o I - U_L(T_w - Ta)] \quad (6)$$

Where A_s and Fare the cooker surface area and heat exchange factor respectively, then,

$$dt = \frac{(MCp)'w\ dTw}{A\ F'[I\eta_o - U_L(Tw - Ta)]} \quad (7)$$

And substituting F_1 for $\frac{\eta_o}{U_L}$ in Eq. (4) gives,

$$dt = \frac{(MCp)'w\ dTw}{A\ F'\eta_o\ [I - \frac{1}{F_1}(Tw - Ta)]} \quad (8)$$

Assuming constant insolation and ambient temperature, and integrating Eq. (8) over the time, t required to raise the water temperature from a certain temperature T_{w1} to T_{w2} ,

$$\Rightarrow\ t = \frac{-F_1(MCp)'_w}{AF'\eta_o} \ln\left[\frac{I - \frac{1}{F_1}(T_{w2} - T_a)}{I - \frac{1}{F_1}(T_{w1} - T_a)}\right] \quad (9)$$

The time, t in Eq. (8) is not a unique property of the cooker (depending on climatic conditions, I and T_a). Eq. (8) can be re-written to obtain an expression for a cooker parameter, $F'\eta_o$ as follows,

$$F'\eta_o = \frac{F_1(MC)'_w}{At} \ln\left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{I}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{I}\right)}\right] \quad (10)$$

Computing $F'\eta_o$ would require the value of $(MCp)'_W$, which is not easily determinable. However, $(MCp)_W \approx (MCp)'_W$. Introducing a heat capacity ratio (which is an additional cooker parameter), Cr = $(MCp)_W/(MCp)'_W \approx 1$, Eq. (10) can be re-written as,

$$F_2 = F'\eta_o C_R = \frac{F_1(MC)_w}{A\tau} \ln\left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_a}{I}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_a}{I}\right)}\right] \quad (11)$$

$F'\eta_o C_R$, which is a cooker parameter, can easily be evaluated and thus serves as the second figure of merit F_2, I and T_a have been assumed constant for the integration of Eq. (7). In reality, there are slight variations only, in I and T_a if tests are taken ±2 h of solar noon, thus the mean values $I_{av}$and T_{av} during the test period can be used in Eq. (11) above. The time for sensible heating from ambient temperature Ta to 100°C can be evaluated [14, 15] from,

$$t_{boil} = \frac{F_1(MCp)_w}{F_2} \ln\left[1 - \frac{1}{F_1}\left(\frac{100 - T_{av}}{I_{av}}\right)\right] \quad (12)$$

This is a simplification of Eq. (9) assuming T_{w1} =T_a and T_{w2} = 100°C.

V. EXPERIMENTATION

The principal objective of this work is a preliminary testing of a two reflector box type solar cooker with and without reflector. The outdoor thermal performance tests were undertaken under no-load conditions to determine the stagnation absorber plate and resident air temperatures and the diurnal thermal response of the cooker to variation in insolation under no-load conditions. Sensible heat tests were also carried out to determine the time required to boil given quantities of water and first and second figure of merit (F_1 & F_2). The experiments were performed during the month of April-May at the geographical location of Jabalpur Engineering college at Jabalpur (latitude L= 23.16° North and longitude Φ = 79.95° East). Measurements were taken at intervals of 10 min for the no-load and sensible heat tests respectively and during the effective sunshine period of 9 h to 15 h local time. Temperature was measured by the calibrated K type thermocouple with sensitivity (0.5°C) connected to the digital panel meter (DPM) which gives us output by digital display in mV. During the experiment solar radiation intensity on a horizontal surface was measured by Eppley precision pyranometer connected to DPM which display the reading in mV at the same time of stagnation and these values are used to calculate value of F_1 and values of T_{ps}, T_{as} and H_s are recorded and use these values for calculation of F_1. The water is allowed to increase temperature up to the boiling point of water and T_{w1} =65°C and T_{w2} =95° C were taken under the temperature range mentioned by Mullick et al. for the calculation of F_2. The plane mirror reflectors was oriented normally North-Southwards and the reflector tilt angle and cooker off-south orientation adjusted at regular intervals of 30 min to ensure that the reflected rays covered the entire glazing surface (i.e. exchange factor = 1). Sometime was allowed for the absorber plate temperature to rise to 90°C or above before loading. The same procedure was followed for the without reflector box type solar cooker and finally F_2 and boiling time of water will be calculated. Also determine the optical efficiency of new and conventional box type solar cooker. We used six thermocouple for better understanding of during calibration process. In calibration process for finding calibration factor, we take hypsometer and plate heater for heating of hypsometer and also used DPM. Solar radiation also measured by DPM so there calibration factor 1mV = 122.7 W/m^2. By the calibration we found that Calibration factors these are show temperature reading equal to 1 mV in table 3.1:

S.N.	Name of thermocouple	Used place	Value in Temperature in °C
1.	(H) Type 1	Absorber plate, pot A	23.69
2.	(E) Type 2	Lower glazing	23.80
3.	(F) Type 3	Upper glazing	23.63
4.	(D)Type 4	Cooker air tem., Pot D	24.15
5.	(C) Type 5	Pot C	23.80
6.	(B) Type 6	Pot B	23.80

Table 5.1: Calibration factor of thermocouple

VI. Results and Discussion

A. *No - Load Test*

Typical diurnal variations in the applied weather conditions, namely insolation and ambient temperature and the transient response of the solar cooker under no-load condition are presented in Figs. 6.1 and 6.2, for the conditions when both the plane reflector is in place and without the reflector in place respectively. These results are only representative of a series of tests undertaken. It can be seen from both Figs. 6.1 and 6.2 that the transient responses of the cooker follow closely the insolation patterns. This is true of all the other tests performed under no load conditions. Maximum absorber plate and chamber air temperatures of 144°C and 127°C respectively were recorded with the reflector in place at 12.50 h local time and at an insolation value of 924 Wm^{-2} immediately following an insolation peak of 963 Wm^{-2}. For most of the time between 10 h and 14 h local time when insolation was appreciable, the absorber plate temperature was above 100°C. Inclement conditions (i.e. cloud overcast) resulted in drops in the temperatures after 15 h. The absorber plate temperature measured was expectedly consistently higher than other temperatures in the cooker. This is desirable as the anticipated major mode of heat transfer to the cooking vessels is by conduction from the absorber plate. Cooking chamber air temperatures were also expectedly high, between 80°C and 127°C for most of the test period. These results indicate a possible use of the design with minor modifications as inclined cover plate and small air gap between absorber plate and insulation. The pattern of the test results for the cooker without the reflector in place (Fig. 6.2.)

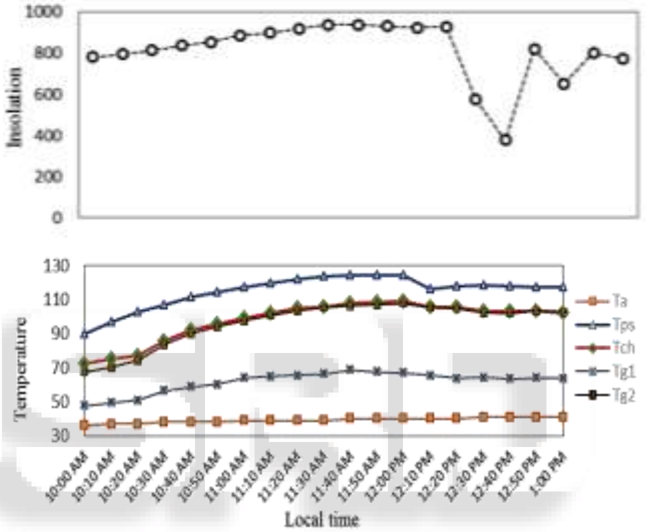

Fig. 6.1: Transient diurnal performance of solar cooker (with both reflector in place) under no load. (Ta= ambient temperature; T_{ps}= absorber plate temperature; T_{ch}= cooking chamber air temperature; T_{g1}= outer glazing temperature; T_{g2}= inner glazing temperature).

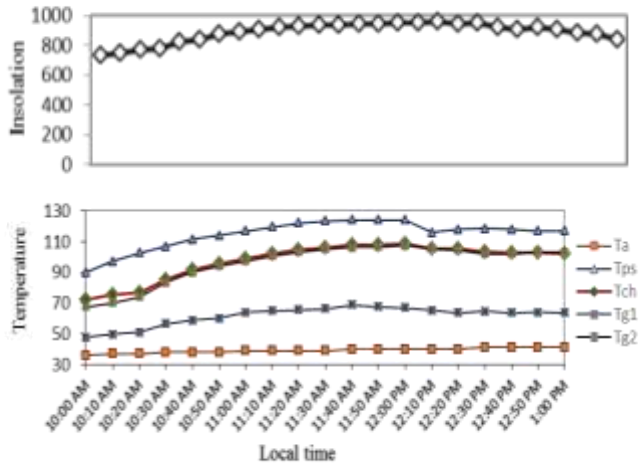

Fig. 6.2: Transient diurnal performance of solar cooker (without reflector in place) under no load on cloud day. (Ta= ambient temperature; T_{ps}= absorber plate temperature; T_{ch}= cooking chamber air temperature; T_{g1}= outer glazing temperature; T_{g2}= inner glazing temperature).

Was similar to the case with the reflector in place. However, for the same range of insolation and ambient temperatures encountered for both tests, the cooker without reflector recorded expectedly lower temperatures. For peak insolation values of between 930 Wm^{-2} and 960 Wm^{-2} (for both tests), the peak plate temperature without the reflector was about 124°C compared to 144°C when the reflector is in place. Peak chamber air temperature was 109°C (without reflector) compared to 127°C (with reflector). This pattern is the same for all the other temperatures within the cooker and for all the other test results. These results clearly illustrate a superior performance of the cooker with the plane reflector in place.

B. Sensible Heat Tests

Typical variations in the applied weather conditions, namely insolation and ambient temperatures and the transient cooker performance during the sensible heat tests for both the cooker with and without the reflector in place are illustrated in Fig.6.3. The two test results are only representative of a series of sensible heat tests undertaken. Due to the absence of cloud

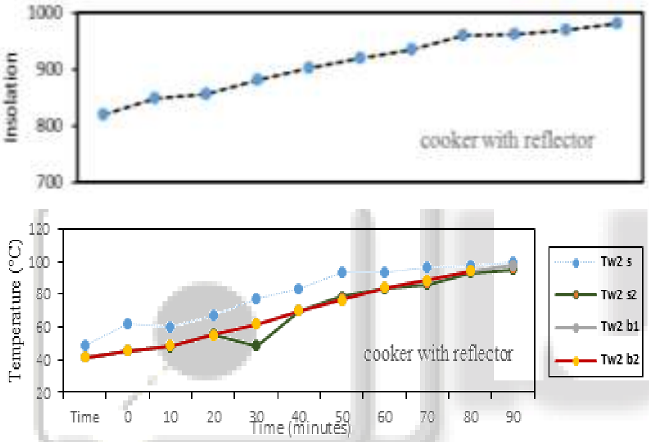

Fig. 6.3: Transient performance of solar cooker during sensible heat (water boiling) test with all four pots loaded. (T_{w2s}= water temperature of small pot A; T_{w2s2}= water temperature of small pot B; T_{w2b1}= water temperature of big pot C; T_{w2b2}= water temperature of big pot D).

Overcast, insolation levels were fairly high and with little variability. Under comparable insolation values encountered, it took about 91 min (5460 s) to boil 1 litre (1 kg) of water (distributed over the four cooking vessels) for the cooker with reflector while the cooker without the reflector boiled the same quantity of water in the four vessels in 97 min (5820 s). In some of the tests conducted, the water failed to boil and in one case could only attain a maximum water temperature of 90°C due to inclement weather characterised by cloud overcast and poor insolation. Results for the test with the same quantity of water (1 litre) placed in only one of the cooking vessels and with the reflector in place are shown in Fig.6.5. At comparable levels of insolation encountered, it took a much longer time (more than 70 min) to boil 1 litre of water in one pot, compared to placing the water in the four pots (Fig. 6.3). This is anticipated as boiling in just one pot reduces the heat transfer surface area.

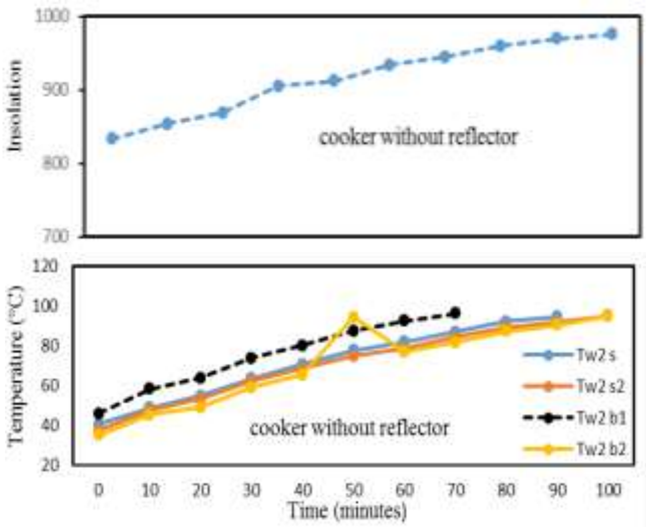

Fig. 6.4: Transient performance of solar cooker during sensible heat (water boiling) test with all four pots loaded. (T_{w2s}= water temperature of small pot A; T_{w2s2}= water temperature of small pot B; T_{w2b1}= water temperature of big pot C; T_{w2b2}= water temperature of big pot D).

C. Performance rating of Solar Cookers

For the experimental solar cooker with the reflector in place, we have calculated a first figure of merit, F_1 = 0.1126 m^2w^{-1}at stagnation, with values of T_{ps} = 144°C, T_{as}= 38°C and I_S = 941 Wm^{-2} from Eq. (4). For the cooker without the reflector in place, F1 was obtained as 0.09064 m^2w^{-1} at T_{ps}= 124°C, T_{as}= 39.75°C and *Is* = *929.5* Wm^{-2}. As anticipated, the cooker with reflector has a higher F1 value (at comparable levels of insolation encountered) and consequently a better performance than cooker without reflector. F_2 is computed from the sensible heating (i.e. water heating) curves in Fig. 6.5 using Eq. (11). T_{w1} And T_{w2} and the corresponding time interval t, are read off from the curves as appropriate. Some flexibility is allowed in the choice of T_{w1} and the time interval t, of the sensible heating process in Eq. (11). Values of $T_{w1} > T_a$are recommended [14, 15]. Values of T_{w2} lower than the boiling point are recommended [15]since the water heating curve flattens towards the boiling point and considerable error can be introduced in reading t from the curve if T_{w2} is taken as the boiling point. Extensive validation of Eq. (12) with experimental data has been carried out previously [15]. Using Fig. 6.5 and Eq. (11), the second figure of merit F_2 was obtained as 0.2380 for the cooker with reflector, using F_1 = 0.1126 m^2 kw^{-1}, M = 1 kg, C_p = 4200 J kg^{-1} K^{-1}, A_s = 0.384 m^2, t = 48 min (2880 s), T_{w1} = 65°C, T_{w2} = 95°C, T_{av} = 32.98°C and I_{av} = 908.33 Wm^{-2}. The corresponding F_2 value for the cooker without the reflector was calculated as 0.2764, using F_1 = 0.0906 m^2 kw^{-1}, M = 1 kg, C_p = 4200 m^2 kw^{-1}, A_s = 0.384 m^2, t = 52 min (3120 s), T_{w1}= 65°C, T_{w2}= 95°C, T_{av} = 33.10°C and I_{av} = 921.60 Wm2. Using Eq. (19), we estimated the time, t_{boil} required to boil 1 kg of water from ambient temperature, as 91.805 min and 96.467 min, respectively, for the cooker with and without the reflector. These calculated values compare favourably with the experimentally obtained values of 120 min and 150 min for both case,

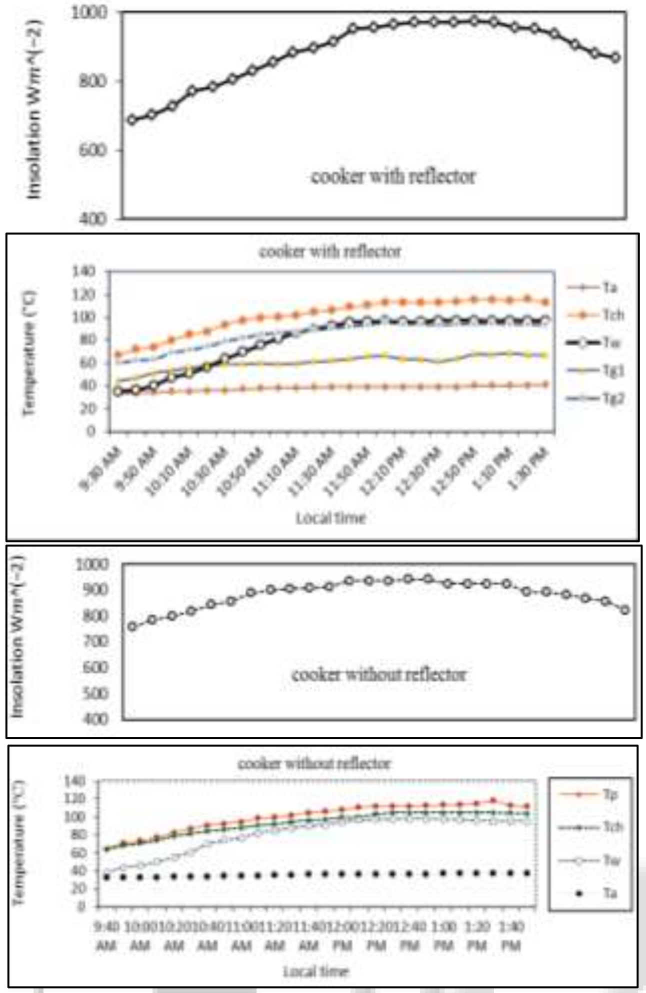

Fig. 6.5: Transient performance of solar cooker during sensible heat (water boiling) test with one loaded. (Ta= ambient temperature; Tp= absorber plate temperature; Tch= cooking chamber air temperature; Tw= water).

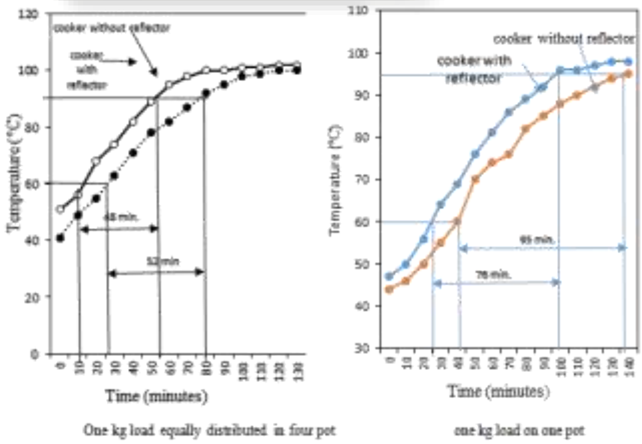

Fig. 6.6: Variation of water temperature with time (for F2 analysis).

Respectively. The effects of load (i.e. mass of water) and insolation on the boiling time for both cases of cooker with and without reflector are illustrated in Fig. 7. It can be seen clearly, as anticipated, that the boiling time increased markedly with increasing load and decreasing insolation

VII. CONCLUSION

The results from this study show successful performance of the experimental plane reflector augmented box-type solar-energy cooker. The results justify the modifications made to the

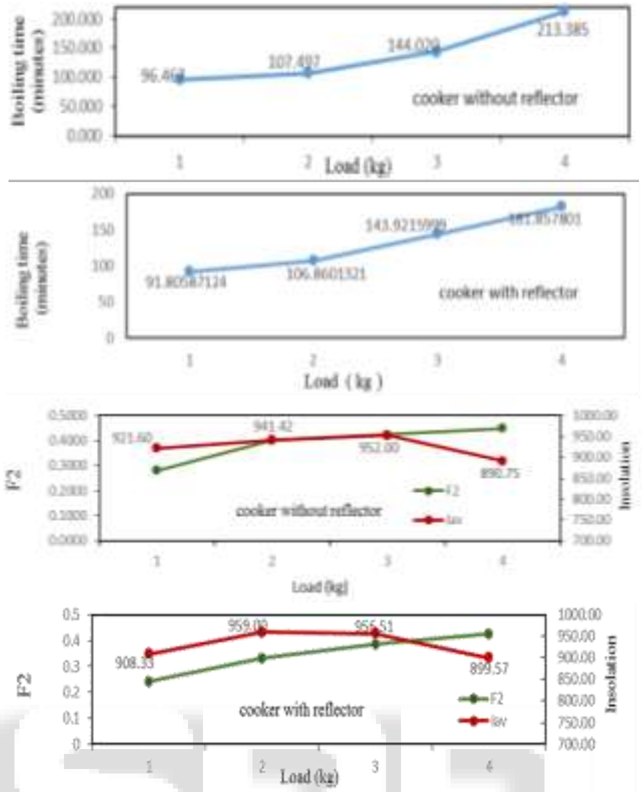

Fig. 7: Variation of boiling time with load and insolation

Design of traditional solar box cookers. The solar cooker performance was improved greatly with the plane reflector in place. Results also indicate that the cooker can be employed with minor modifications as a dehydrator. The analysis confirms the first and second figures of merit as reliable design and performance rating criteria for solar cookers. The results obtained in this study, of which only a small part is presented here, form a useful database for the validation of theoretical models in addition to their intrinsic value of characterising the cooker.

REFERENCES

[1] Lahkar Pranab J. and Samdarshi S.K., A review of the thermal performance parameters of box type solar cookers and identification of their correlations, 2010.
[2] GTZ and DME, Scarcity of Household Energy and the rationale of solar cooking. GTZ, Pretoria, 2002b. Solar cooker compendium volume 1.
[3] B.S.Negi, Purohit I. Experimental investigation of a box type solar cooker employing a Non-tracking concentrator. Energy Conversion and Management 2005; 46:575-60
[4] E.H. Amer. Theoretical and experimental assessment of a double exposure solar cooker Energy Conversion and Management 2003; 44:2651-63
[5] N.M. Nahar. Design, development and testing of a double reflector hot box solar Cooker With a transparent insulation material. Renewable Energy 2001; 23:167-79

[6] A.V. Narasimha Rao, Subramanyam S. Solar cookers part I: cooking vessel on lugs. Solar Energy 2003; 75:181-5
[7] Avala raji reddy, A.V.Narasimha rao. Predication and experimental verification of Performance of box type solar cooker –part. Cooking vessel with central cylindrical Cavity Energy Conversion and Management 2007; 48:2034-43
[8] Erdem Cuce, Pinar Mert Cuce, A comprehensive review on solar cookers. Applied Energy102 (2013) 1399–1421
[9] R.M. Muthusivagami, R. Velraj, R. Sethumadhavan, Solar cookers with and without Thermal storage—A review. Renewable and Sustainable Energy Reviews14 (2010) 691- 701
[10] Subodh Kumar, Estimation of design parameters for thermal performance evaluation of Box-type solar cooker. Renewable Energy 30 (2005) 1117–1126
[11] Suhail Zaki Farooqui. Gravity based tracking system for box type solar cookers. Solar Energy2013; 92: 62–68
[12] H.P. Garg enhancement of solar energy on flat plate collector by plane booster mirrors. Renewable Energy 1986.
[13] O.V. Ekechukwu, N.T. Ugwuoke, Design and measured performance of a plane reflector augmented box-type solar-energy cooker, Renewable Energy 2002.
[14] Mullick SC, Kandpal TC, Saxena AK. Thermal test procedure for box-type solar cooker. Solar Energy 1997; 39(4):353–60.
[15] Mullick SC, Kandpal TC, Subodh K. Testing of box-type solar cooker: second figure of merit F2 and its variation with load and number of pots. Solar Energy 1996; 57(5):409–13.
[16] Eggers-Lsura A. Solar energy in developing countries. In: The Pergamon European Heliostudies. New York, USA: Pergamon Press; 1979.
[17] Thulasi-Das TC, Karmakar S, Rao DP. Solar box-cooker: part II—analysis and simulation. Solar Energy 1994; 52(3):273–82.
[18] Ekechukwu OV, Norton B. Effects of seasonal weather variations on the measured performance of a natural circulation solar-energy tropical crop dryer. Energy Conversion and Management 1998; 39(12):1265–76.

