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Brief Note

Experimental determination of effective concentration ratio for solar box cookers using thermal tests

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ABSTRACT

Solar box cookers (SBCs) are generally equipped with a booster reflector to increase the radiation flux; consequently, the heating of the absorber plate and for fast cooking. Hence, it is crucial to assess the impact of booster reflector and quantify the Opto-Thermal performance of the SBCs considering the enhanced radiation flux. In the present work, Effective Concentration Ratio (ECR) is defined to assess the effectiveness of booster reflector. ECR is determined experimentally using two thermal tests; with and without booster reflector employing the Cooker Opto-Thermal Ratio (COR) as a thermal performance parameter (TPP). It is shown that, ECR enables the assessment of the effect of the booster reflector in the estimation of Opto-Thermal performance of the SBCs. The value of ECR for specified SBC is determined to be 1.33.

1. Introduction

Solar box cookers (hereafter denoted as SBCs) have been investigated all over the world with different intentions. A large number of them aim to study the design improvements in terms of optical performance including booster reflector performance, heat loss, cooking power, cooking load, energy storage and many more. Therefore, solar cooking is one of the well documented research field.

The concentration ratio (C) is the one of the established optical properties that characterize the optical performance of solar collectors. The flux concentration ratio (FCR) basically depends on the optical properties of reflecting surfaces. On the other hand geometric concentration ratio (here after referred as GCR) depends on the different dimensional parameters of solar collector and absorber. All the designs of SBCs essentially have an additional reflecting area in the form of booster reflector/s. It is evident that, the booster reflector/s reflects additional solar radiation flux through the aperture area to the absorber plate and the cooking pot. It ensures better thermal performance of the SBC. In the case of SBCs, GCR depends on the aperture area, the geometry of booster reflector/s and the absorber area. For a given design of SBC, area of the absorber plate (including the cooking pots) and the booster reflector/s can be kept constant. But, the use of booster reflector/s alters the effective aperture area of SBC seasonally. The performance of booster reflector depends on angle of incidence of solar beam radiation. As the angle of incidence decreases, booster reflector and SBC perform better and vice versa (El-Sabaii, 1997). Therefore, it is important to assess the effectiveness of booster reflector/s and increased radiation intensity on the Opto-Thermal performance of SBCs.

A number of studies, available in the literature, highlight the results to conclude on the effectiveness of booster reflector/s of the SBCs in the solar cooking process. Tabor (1966), Nahar (1983,1988), Dang (1986), Tiwari and Yadav (1986), Garg and Hrishikesan (1988), Narasimha Rao et al. (1988, 1989, 1991), Jubran and alsaad (1991), Grupp et al. (1991), Nandwani and Gomez (1993), Thulasi Das et al. (1994), El-Sebaii et al. (1994), Habeebullah et al. (1995), El-Sebaii (1997), Nandwani (1988), Algifri and Al-Towaie (2001), Negi and Purohit (2005), Jaramillo et al. (2007) Mirdha and Dhariwal (2008), Kurt et al. (2008), Saxena et al. (2010), Harmim et al. (2012a,b), Farooqui (2013, 2015) and Sethi et al. (2014) conducted investigations to assess the impact and role of booster reflectors in terms of the Opto-Thermal performance of SBCs. Also good reviews on solar cookers were done by Lahkar and Samdarshi (2010), Muthusivagami et al. (2010), Saxena et al. (2011) and Cuce and Cuce (2013). Table 1 enlists some of the parameters which identify the specific role of the booster reflector and quantify them to conclude on the performance of SBCs.

Different parameters, reported in the literature hitherto, to assess the performance of booster reflector/s in SBCs, are mainly the functions of the angle incident of the beam radiation, solar radiation flux, aperture dimensions and geometry, reflectivity of the booster reflector, cooker orientation (azimuth angle) and the reflector tilt. Hence, it is difficult to quantify the enhanced radiation on aperture, absorber plate and the cooking pot precisely owing to design, operation, and material

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Nomenclature

M_w (kg)	mass of water in a cooking pot
M_{pot} (kg)	mass of cooking pot
C	concentration ratio
$(C_p)_{pot}$ (J/(kg k))	specific heat of cooking pot
$(C_p)_w$ (J/(kg k))	specific heat of water
A_{Glz} (m^2)	heat absorption/aperture area and glazed heat loss area of box type solar cooker for No Booster Reflector Test
$A_{Eff.}$ (m^2)	effective inclined aperture area of box type solar cooker for Booster Reflector Test
$A_{ref.}$ (m^2)	area of booster reflector
A_{pot} (m^2)	area of cooking pot
(T_p) (°C)	absorber Plate Temperature
T_a (°C)	ambient air temperature
(T_{fmax}) (°C)	theoretical maximum achievable fluid temperature with booster reflector test
$(T_{fmax})_{NBR}$ (°C)	theoretical maximum achievable fluid temperature with no booster reflector test
$(F'\eta_o)$	optical efficiency factor
$(F'U_l)$ W/(m^2 K)	heat loss factor
α	elevation angle of the sun
α_1	angle of first mirror with concentrator base
α_2	angle of second mirror with horizontal
W_1	width of first mirror
W_2	width of second mirror
D	width of absorber plate
D′	length of aperture
Φ	latitude
F_D	collection coefficient for the cooker for direct incident radiation
F_{Rh}	collection coefficient for the reflections from the vertical south facing fixed reflector
F_{Rs}	lower value of the collection coefficient for the reflection from the south facing lid reflector (either F_{Rs1} or F_{Rs2})
F_{RN}	lower value of the collection coefficient for the reflection from the vertical north facing fixed reflector (either F_{RN1} or F_{RN2})
θ_U	solar altitude angle for upper parabola
W	absorber plate width
l	constant (function of focal distance)
h	constant (function of θ_U and W)

Abbreviations

NBR	No Booster Reflector

Table 1
Various parameters used to evaluate concentration ratio and performance of booster reflector/s.

Author	Parameter	Equation of parameter
Narasimha Rao et al. (1989)	Concentration factor (*CF*)	$CF = \frac{\text{Total energy incident on the aperture } (E_T)}{\text{Direct energy flux incident on the aperture } (E_I)}$
Algifri and Al-Towaie (2001)	Orientation factor of the reflector (F_o), Reflector performance factor (F_p)	$F_O = \frac{\text{Energy intercepted by the reflector and falling on the cover } (q_{ref.th})}{\text{Maximum theoretical Energy intercepted by the reflector } (q_{ref.(th.max)})}$ $F_p = \frac{\text{Reflectivity of the reflector } (\rho) \times F_O}{\sin(\propto)}$
Negi and Purohit (2005)	Concentration factor (*C*)	$C = \frac{D' + W_1 Cos(\propto_1 + \varnothing) + W_2 Cos(\propto_2 - \varnothing)}{D}$
Jaramillo et al. (2007)	Performance factor (*C*)	$C = \frac{\text{Total incident radiation on the solar oven}(Q_O)}{\text{Incident radiation on the solar oven}(Q_h)}$
Mirdha and Dhariwal (2008)	Net collection coefficient (F_T)	$F_T = F_D + F_{Rh} + F_{RS} + F_{RN}$
Harmim et al. (2012b)	Effective geometric concentration ratio (*C*)	$C = \frac{l - h\sin(90 - \theta_U)}{W}$

related issues. Therefore, in spite of substantial influence on the TPPs, the effectiveness of booster reflector is not unerringly computed in the study of its impact on the performance of solar cookers.

Therefore, in the present work, a parameter, Effective Concentration Ratio (hereafter denoted as ECR) is defined to assess the impact and usefulness of the booster reflector/s in the Opto-Thermal performance of the SBCs. In the above mentioned literature references, the authors have not found any evidence of experimental determination of ECR/identical parameter for SBCs. Hence, for the first time, the Effective Concentration Ratio (ECR) for SBCs is being proposed to determine using two thermal tests (with and without booster reflector) and water as standard test load. For this purpose, Cooker Opto-Thermal Ratio (COR) is used as a TPP. Also, the applicability of ECR in the grading of SBCs on the basis of opto-thermal performance is discussed.

2. Effective Concentration Ratio (ECR)

Effective Concentration Ratio (ECR) of the solar box cooker (SBC) is the ratio of Cooker Opto-Thermal ratios determined with and without booster reflector. ECR can be calculated using Eq. (1).

$$ECR = \frac{COR}{(COR)_{NBR}} = = \frac{\left(\frac{\eta_0 C}{u_l}\right)}{\left(\frac{\eta_0}{u_l}\right)} \quad (1)$$

Alternatively,

$$ECR = \frac{\left(\frac{\eta_0 C}{u_l}\right)}{\left(\frac{\eta_0}{u_l}\right)} = \left(\frac{T_{fmax} - \overline{T}_a}{(T_{fmax})_{NBR} - \overline{T}_a}\right)\left(\frac{\overline{G}_{Th}}{\overline{G}_{TE}}\right) \quad (2)$$

where COR and COR_{NBR} are the Cooker Opto-Thermal Ratios with and without booster reflector respectively; η_o is the optical efficiency; C is the concentration ratio; $\overline{G}_{Th}$ and $\overline{G}_{TE}$ are the average values of solar radiations on the glazed heat loss area (A_{Glz}) and effective inclined aperture area, ($A_{Eff.}$), respectively; $\overline{T}_a$ is average ambient air temperature for the interval of experiment on the given day; (T_{fmax}) and $(T_{fmax})_{NBR}$ are the theoretical maximum achievable fluid temperatures that can be reached with a specified SBC with and without booster reflector respectively at a location under given meteorological conditions. Details regarding *COR*, COR_{NBR}, (T_{fmax}) and $(T_{fmax})_{NBR}$ are given in the Appendix A.

It is to be noted that COR (Lahkar et al., 2012) is derived from the Hottel-Whiller-Bliss (HWB) equation. Fig. 1 shows the inclined aperture area, A_{Eff} and the glazed heat loss area, A_{Glz} for a specified SBC. The HWB equation considers the effect of GCR on the thermal performance of solar collectors. Alternatively, if one uses experimental values of the other parameters in the HWB equation to calculate the concentration ratio, the resulting value gives flux concentration ratio. Notably, the

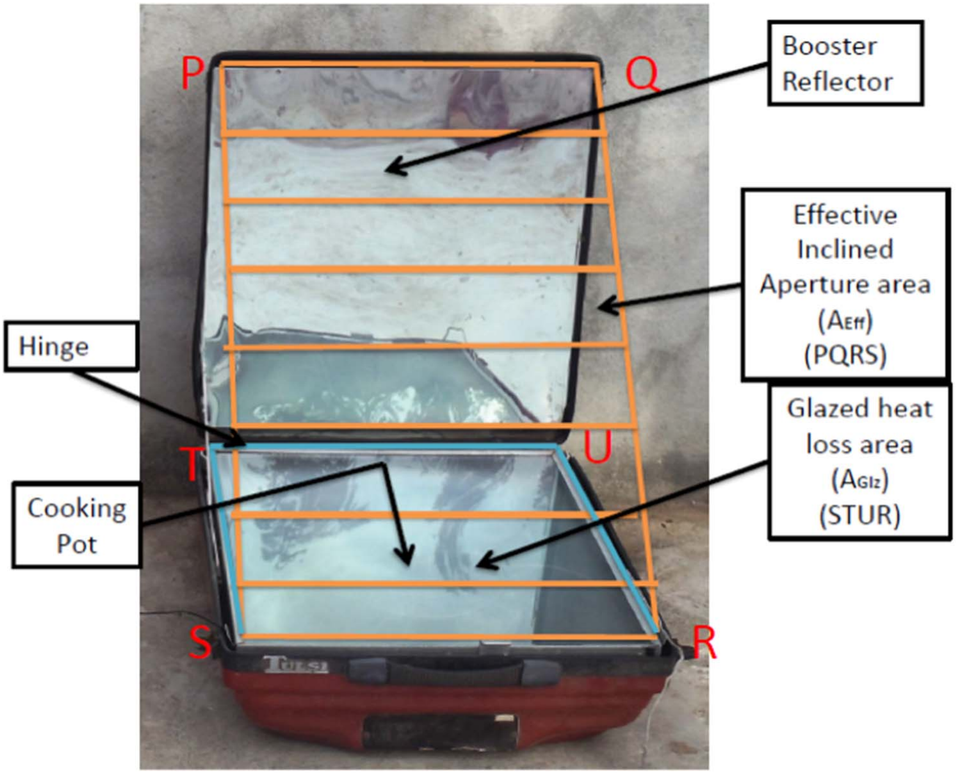

Fig. 1. Inclined aperture area (A_{Eff}) and the glazed heat loss area (A_{Glz}) for a specified SBC.

GCR changes with the inclination of booster reflector according to variations in season and/or location/latitude (see Results and Discussion section). The tilt angle of the booster reflector can be found for all months at a specified location using Eq. (A.3) (Sethi et al., 2014), given in the Appendix A. From the experimentally determined values of (COR) and $(COR)_{NBR}$ using the Eqs. (A.1) and (A.2), given in the Appendix A, the ECR can be estimated using Eq. (1) which facilitates to predict the actual effective contribution of the booster reflector in determination of thermal performance of the specified SBC under specified test conditions.

Also, it is assumed that, the errors in the measurement of different parameters (G_{Th}; G_{TE}; T_a; T_w) will be reflected in the accuracy of determination of the TPP using thermal tests. But its impact on the value of ratio of two measurements will be minimal. Therefore, for a given design of SBC, the influence of measurement errors on ECR is expected to be low. However, inaccurate tracking and inappropriate orientation/inclination of the SBC and/or booster reflector will lead to an inaccurate estimation of the ECR value for a specified SBC under specified test conditions. It needs to be considered separately keeping the results of experimental data being presented here.

3. Experimental procedure to determine ECR

Two thermal tests were conducted to determine ECR for a specified SBC and the COR was used as a TPP. In the first thermal test, named as no booster reflector test, the booster reflector was covered with black cloth. The second thermal test, named as booster reflector test. In this test, the booster reflector was used to reflect the solar radiation onto the glazed area of the SBC. For both the thermal tests, normal water was used as a standard test load and loaded at 2.5 kg/m^2 of aperture area of the SBC. An SBC, equipped with a single booster reflector [Area (A_{ref}) = 0.23 m^2)] made up of anodized aluminum (reflectivity, ρ = 0.83), was used for the experiments. The standard test load was kept in one pot only. For both the thermal tests, the temperature of the standard test load was recorded via a calibrated J-type thermocouple sensor. The sensor was placed at the center of water away from the bottom of the pot through a hole available at the center of the cooking pot lid. The hole was properly sealed to eliminate any vapor loss through it. In both the thermal tests, the standard test load was allowed to be heated under solar radiation from ambient temperature up to 95 °C. Fig. 2a shows the experimental set-up for no booster reflector test. In the no booster reflector test, the total solar insolation (G_{Th}) was measured on the plane of the glazed heat loss area A_{Glz}. Here the radiation reflected from the wall is included and that from the ground is not, obviously because the contribution from ground reflected radiation is zero.

In a subsequent step, the second thermal test was conducted using the same SBC and the previously described test procedure (Lahkar et al., 2012) to estimate the value of COR. Fig. 2b shows the test setup for booster reflector test. The effective inclined aperture area (A_{Eff}) in case of specified SBC may be securely taken as the area of the opening (with the reflector) (Refer Fig. 1; area PQRS), which catches solar flux on the experimental days at the location. In the present case, the value of A_{Eff} varies (winter to summer) between 0.33 m^2 to 0.40 m^2 with mean value of ~0.37 m^2. For the booster reflector test, the total solar radiation (G_{TE}) was measured on the inclined aperture plane (PQRS, see Fig. 1) using a research pyranometer (Dynalab, India) facing the sun as shown in Fig. 2b.

For both the thermal tests, temperature of the standard test load (T_w), ambient air temperature (T_a) and total solar radiations, G_{Th} and G_{TE} were recorded at a regular interval of 90 s using a data logger (Dynalab, India). Wind speed was measured with a wind sensor (Dynalab, India) and recorded using the data logger.

The average absolute instrumental error of 0.5 °C in temperature, 1% in solar radiation and 0.5 m/s in the wind speed measurement were possible. A proper windshield was used to minimize the wind disturbances at the experimental setup. The thermal tests were conducted at ± 90 min. of local solar noon at the location 17.66°N; 75.32°E. Each test was repeated for three times, under the environmental conditions: G_{Th} and $G_{TE} \geq 700$ W/m^2; 20 °C ≤ T_a ≤ 40 °C; wind speed ≤1.5 m/s. Out of three tests, only one test data is presented here. SBC and inclined pyranometer were appropriately oriented in the direction facing the sun

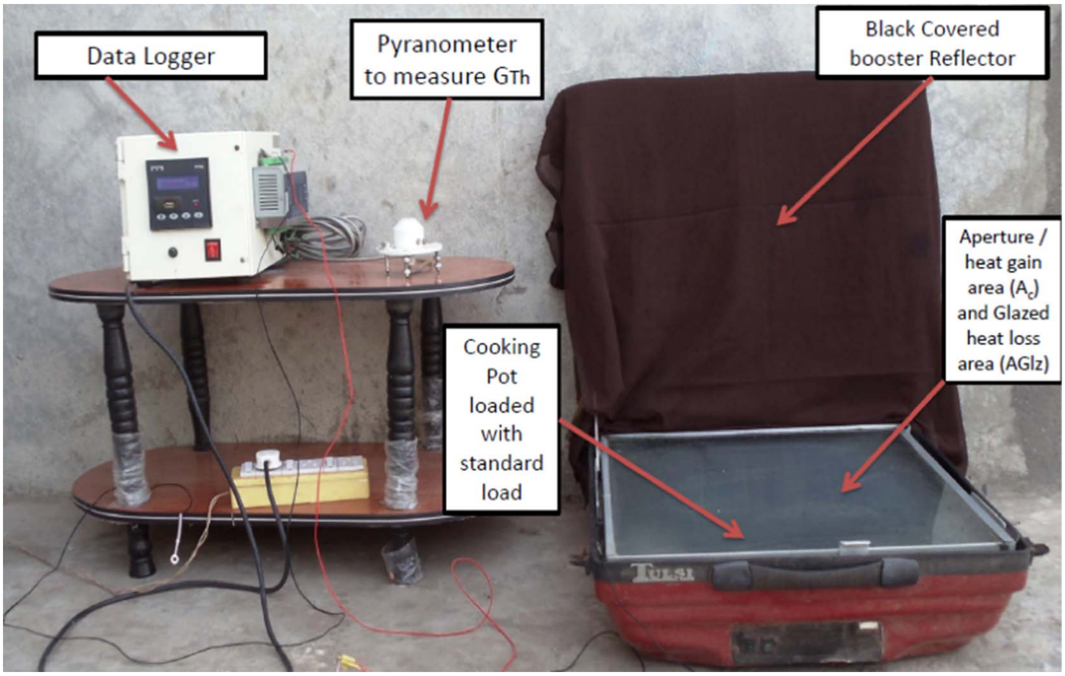

Fig. 2a. Test set up for No Booster Reflector Test.

and manual tracking was done, as per necessity, for both.

The experimental data of no booster reflector and booster reflector tests was used to plot $\frac{\dot{Q}''}{\bar{G}_{Th}}$ *vs.* $\frac{(T_{wm}-\bar{T}_a)}{\bar{G}_{Th}}$ and $\frac{\dot{Q}''}{\bar{G}_{TE}}$ *vs.* $\frac{(T_{wm}-\bar{T}_a)}{\bar{G}_{TE}}$ respectively from which the value of $\dot{Q}''$ can be calculated using Eq. (3) (Lahkar et al., 2012) and Eq. (4).

$$\dot{Q}'' = \frac{(M_w C_w) w (T_{w2} - T_{w1})}{A_{Eff}\,\Delta t} \tag{3}$$

where $\dot{Q}''$ is the rate of useful heat gain by water per unit area, M_w is mass of water; C_w is specific heat capacity of water, and $(M_w C_w)_w$ is sum of heat capacity of water and the cooking pot (M_{pot} = 0.54 kg is the mass of cooking pot and $(C_p)_{pot}$ = 510 J/kg K is the specific heat capacity of cooking pot); T_{w1} and T_{w2} are the initial and final temperature of the standard test load (water), respectively; T_{wm} is mean of T_{w1} and T_{w2}, and Δt is the time interval in seconds.

Finally, the slope and intercept of a linear plot fitted through the point give the parameter set $F'\eta_o$ and $F'U_l/C$ was used to determine the values of *COR* and COR_{NBR}.

It is to be noted that, for the no booster reflector test, Eq. (3) can be rewritten as Eq. (4) by replacing the A_{Eff} with A_{Glz}.

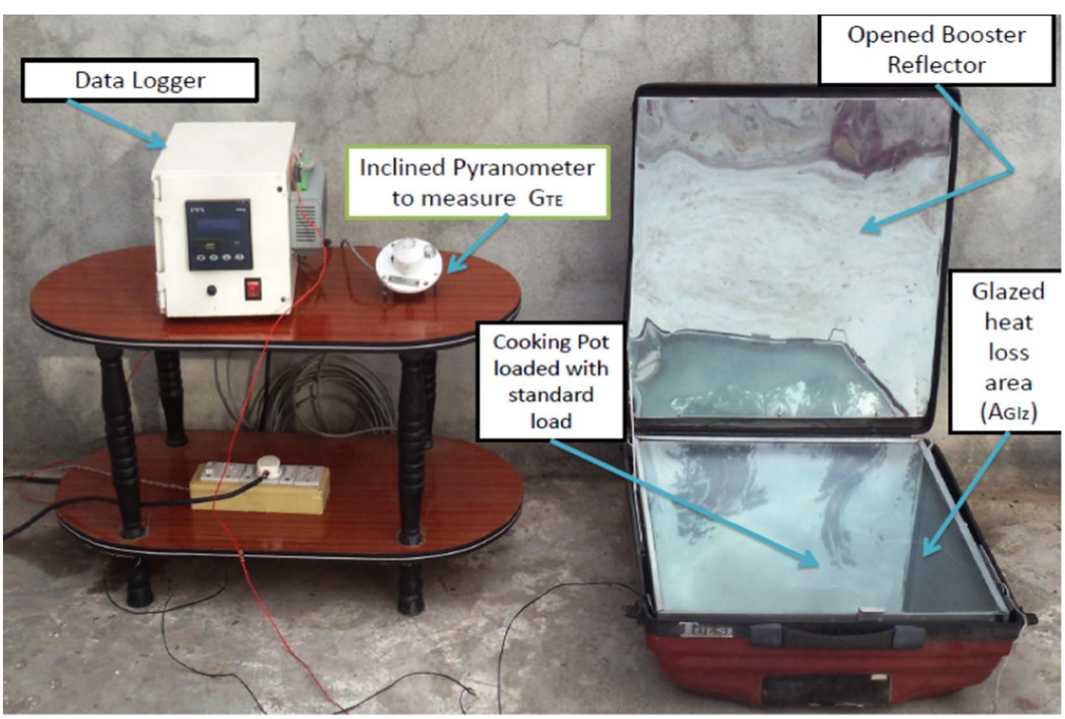

Fig. 2b. Test set up for a Booster Reflector Test.

$$\dot{Q}'' = \frac{(M_w C_w) w (T_{w2} - T_{w1})}{A_{Glz} \Delta t} \tag{4}$$

Also, the slope of the linear plot fitted through the points gives the parameter $F'U_l/C$ ($C = 1$ for no booster reflector test); as the radiation is measured on the plane of the glazed heat loss area (A_{Glz}) only which happens to be aperture area in this case.

4. Results and discussions

Figs. 3a, 3b, 4a and 4b depict plots of exponential fit of variation of temperature of standard test load (water) with time of day, $\frac{\dot{Q}''}{\bar{G}_{Th}}$ vs. $\frac{(T_{wm} - \bar{T}_a)}{\bar{G}_{Th}}$ and $\frac{\dot{Q}''}{\bar{G}_{TE}}$ vs. $\frac{(T_{wm} - \bar{T}_a)}{\bar{G}_{TE}}$ for no booster reflector and booster reflector tests, respectively. The values of COR_{NBR} (the values are 0.102, 0.108, 0.101) and the COR (the values are 0.136, 0.139, 0.137) computed over the complete timeline of sensible heating on the three different experimental days. Therefore, the mean values of COR_{NBR} and the COR are 0.103 and 0.137 respectively. However, the values of COR_{NBR} and the COR can diverge to some extent because of different factors (Lahkar et al., 2012). It is seen that, the boiling time for standard test load on a typical day is decreased from 117 min for no booster reflector test to 82 min for the booster reflector test (Refer Figs. 3a and 4a). Also, the typical value of absorber plate temperature increase from 131.2 °C to 149.8 °C for no booster reflector and booster reflector test, respectively. The mean values of $(T_{fmax})_{NBR}$ and (T_{fmax}) for no booster and booster reflector tests are estimated to be 137.4 °C and 177.7 °C, respectively. Higher value of the temperature (T_{fmax}) is expected due to the use of the booster reflector in the specified SBC. From Figs. 3b and 4b, it is clear that, the value of $F'\eta_o$ and $F'U_l/C$ decreases for booster reflector test. It is to be noted that a part of the total incident radiation on the aperture, which falls on the booster reflector, is reflected to the absorber plate and cooking pot through glazing. As the reflectance of the reflector is less than one, a decrease is expected in the effective $F'\eta_o$ value. Further, during winter the booster reflector not only appears to help in reducing the convective heat loss by weakening the impact of wind on the glazed heat loss area; but also, in the reducing the radiative heat loss by reducing view factor. These are expected to reduce the $F'U_l/C$ for a specified SBC. A decrease of 27% and 46.4% is seen in the values of $F'\eta_o$ and $F'U_l/C$, respectively, with booster reflector test as compared to no booster reflector test and shown in Table 2.

It is obvious that, the total solar radiation on the booster reflector is a sum of beam, diffuse, and the ground reflected solar radiation. But the

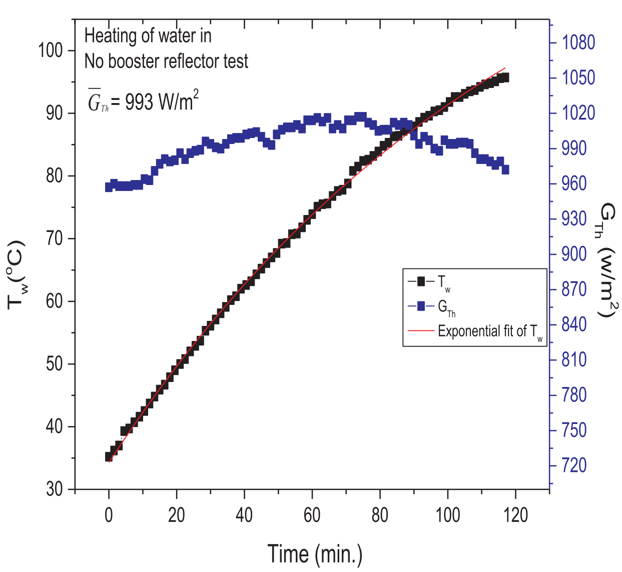

Fig. 3a. Variation of water temperature with time for no booster reflector test.

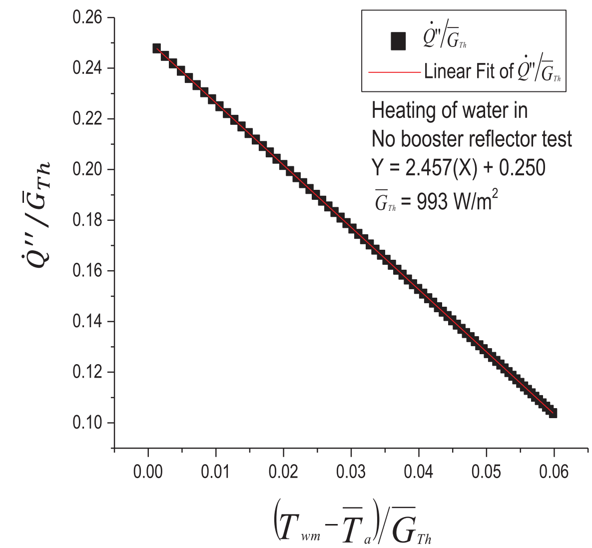

Fig. 3b. Plot of $\frac{\dot{Q}''}{\bar{G}_{Th}}$ with $\frac{(T_{wm} - \bar{T}_a)}{\bar{G}_{Th}}$.

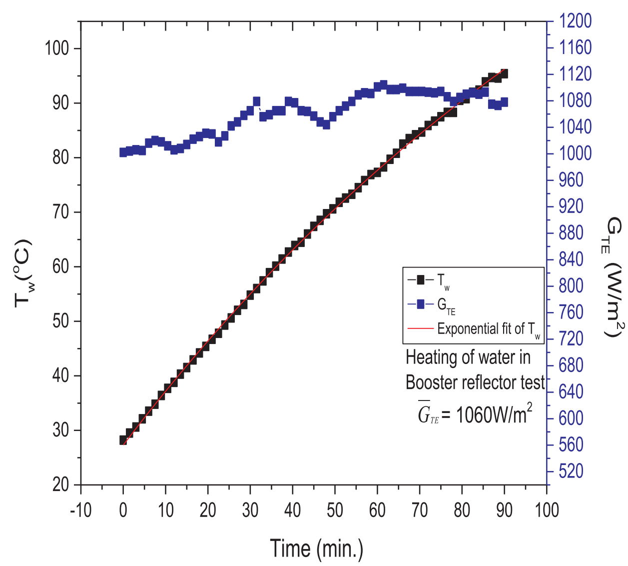

Fig. 4a. Variation of the water temperature with time for booster reflector test.

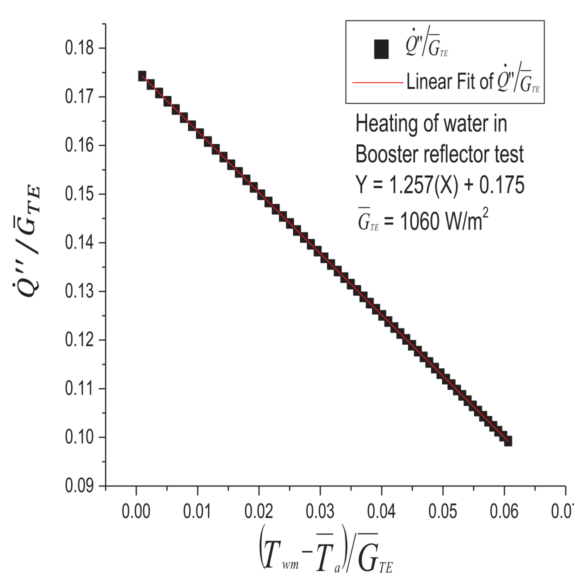

Fig. 4b. Plot of $\frac{\dot{Q}''}{\bar{G}_{TE}}$ with $\frac{(T_{wm} - \bar{T}_a)}{\bar{G}_{TE}}$.

Table 2
Percentage (%) decrease in the $F'\eta_o$ and $F'U_l/C$ values for booster reflector test as compared to no booster reflector test.

Type of test	No Booster Reflector Test		Booster Reflector Test		% Decrease	
Parameter	$F'\eta_o$	$F'U_l/C$	$F'\eta_o$	$F'U_l/C$	$F'\eta_o$	$F'U_l/C$
Value of the parameter	0.264 ± 0.0150	2.544 ± 0.0812	0.177 ± 0.006	1.29 ± 0.056	27%	46.4%

Table 3
Mean values of parameters obtained experimentally for no booster reflector and booster reflector tests.

S.N	Parameter	Mean value of parameter for No booster reflector test	Std. deviation	Mean value of parameter for booster reflector test	Std. deviation
1.	Cooker Opto-Thermal Ratio	0.103	± 0.0038	0.137	± 0.0015
2.	Theoretical Maximum Achievable Fluid Temperature	141.9 °C	± 5.32	177.7 °C	± 3.51
3.	Effective Concentration Ratio (ECR) for specified SBC	1.33 ± 0.0152			

diffuse and ground-reflected radiation on the booster reflector may be neglected (Jubran and Alsaad, 1991; Thulasi Das et al., 1994; El-Sebaii, 1997) as it has a minimal contribution to total incident radiation on the glazed absorber. In fact, the angle of incidence of diffuse radiation (coming from the sides in the booster reflector test) will be high in most of the cases. The difference in the value of G_{Th} or G_{TE} is taken care of by rationalizing it during the estimation of relevant TPP (either COR or COR_{NBR}) which is the slope of linear fit of plot 3b or 4b.

Although solar radiation drops slowly after solar noon, it allows slow heating of absorber plate and standard test load. Also, high time constant of SBC nullifies the impact of decreased solar radiation flux on temperature (Refer Figs. 3a and 4a).

It is evident that, the value of GCR varies seasonally in the case of the SBC. It increases after winter solstice, till the summer solstice with an increase in the incidence angle and vice versa. At the solar noon of the location (17.66°N; 75.32°E), from the minimum and maximum values of solar incident angle with respect to horizontal are seen to be of 48.9° and 89.9° respectively in winter to summer. Therefore, for the SBC used in the present case, the variation in the tilt of booster reflector is seen to be positive (90° + λ) at solar noon of the location for all months as detailed in Appendix-A. Taking these values the GCR is estimated to vary from a minimum value of 1.44 to maximum value of 1.75.

The plots of *COR* and COR_{NBR}, as shown in the Figs. 3a and 4a obtained on different experimental days, respectively, yield identical results. From the experimental results, it is observed that the typical value of either COR or COR_{NBR} for specified box cooker remains approximately unaltered with small deviations. Therefore, only the mean values of COR_{NBR} and the *COR* are used to obtain the value of ECR for a specified SBC and it is determined to be 1.33 ± 0.0152 using the Eq. (1). A clear and significant distinction is seen in the values of GCR and ECR for a specified SBC with single booster reflector. As stated earlier, the value of GCR varies in between 1.44 and 1.75 in a year and logically, the ECR is expected to show the similar variation as GCR. But the average value of ECR is 1.33 i.e. between ~80 and 90% of GCR in this case. As the variation in the values of either COR or COR_{NBR} is small, minimal variation is seen in the value of ECR obtained for different seasons at the specified location. Thus ECR clearly provides a tool for assessing absolute real impact of booster reflector and in the rating of SBCs. Table 3 indicates the mean values of the parameters obtained experimentally for no booster reflector and booster reflector tests.

Therefore, the determination of ECR facilitates the characterization of radiation augmentation device based design variation and provides actual/effective value of the flux concentration ratio for the SBC. Consequently, the higher values of ECR predict superior optical performance of SBC. ECR is a design dependent parameter and therefore, it is not expected to change with environmental, meteorological and operational parameters (tracking/ sun angles). Hence, ECR characterizes the effectiveness of booster reflector which plays a vital role in (i) enhancing the radiation flux to cooker interior and also (ii) reducing the impact of radiative and convective component of the heat loss in the case of the SBC. It is to be noted that, ECR value reflects the specific design of the entire SBC including the reflector. However, to accommodate the impact of change in latitude (if any), it is suggested to derive the effective to geometric concentration ratio (EGR) as explained in the Appendix B.

5. Conclusions

ECR is determined experimentally using thermal tests described in earlier sections and obtained from the respective equations analytically. ECR can be employed to assess conventional SBC and similar flat plate horizontal cookers. The ECR can be used as a tool for grading of solar box cookers. The SBC with a high value of ECR may be graded higher than the one having a lower value of ECR. Grading of SBC's based on ECR, assist the users to select the best alternative amongst the available one. Also, ECR is not applicable to the SBCs or panel cookers which do not use any booster reflector/s. Furthermore, it is recommended to study the Opto-Thermal performance of the SBCs, with more than one booster reflectors.

Acknowledgements

Authors want to thank Prof. Dr. T.C. Kandpal for fruitful discussions.

Appendix A

Appendix-A provides information about the Cooker Opto-Thermal Ratio (COR), a TPP used in the present work. Also, T_{fmax}, the Theoretical Maximum Achievable Fluid Temperature is defined and explained in detail. These two parameters were used in the thermal analysis of specified SBC and ECR is determined from the COR values of with and without booster reflector tests using Eq. (1). The tilt of booster reflector is computed from the equation specified by Sethi et al., 2014.

A.1. Definition of Cooker Opto-Thermal Ratio (COR)

COR is defined as a ratio of product of optical efficiency and concentration ratio of the given design of solar cooker to the heat loss factor (Lahkar et al., 2012) and given by Eq. (A.1) as

$$COR = \frac{\eta_0 C}{U_l} = \frac{T_{fmax} - \overline{T}_a}{\overline{G}_T} \tag{A.1}$$

where η_0 is the optical efficiency, C is the geometric concentration ratio (GCR) for the specified SBC, u_l is the heat loss factor.

A.2. Definition of theoretical maximum achievable fluid temperature (T_{fmax}):

Theoretical maximum achievable fluid temperature is the temperature of the standard test load that can be reached with a specified design of solar cooker (in the present case, SBC) at a location under given meteorological conditions. It is one of the objective parameter (Lahkar et al., 2012). The value of T_{fmax} for a specified SBC on a given experimental day under meteorological conditions of a location can be calculated with an Eq. (A.2) (Lahkar et al., 2012),

$$T_{fmax} = \overline{T}_a + COR(\overline{G}_{TE}) \tag{A.2}$$

It is specifically to be noted that, for no booster reflector test, the value of GCR (ratio of heat absorption area (aperture area), A_c to the glazed heat loss area, A_{Glz}) will be unity as the areas of heat absorption and heat loss are the same. Therefore, Eqs. (A.1) and (A.2) can be rewritten as

$$COR_{NBR} = \frac{\eta_0}{U_l} = \frac{(T_{fmax})_{NBR} - \overline{T}_a}{\overline{G}_{Th}} \tag{A.3}$$

$$(T_{fmax})_{NBR} = \overline{T}_a + COR(\overline{G}_{Th}) \tag{A.4}$$

A.3. Inclination of the booster reflector

In order to enhance the reflected radiation onto the absorber plate of the SBC; the booster reflector must be tilted at an appropriate angle for all months at a specified location. The value of an inclination angle of the booster reflector for horizontally placed SBC at a specified location can be found from Eq. (A.5) (Sethi et al., 2014)

$$\lambda = \frac{90° - 2\theta_z}{3} \tag{A.5}$$

where (λ) is the optimum inclination angle of the booster reflector, θz is the zenith angle. In the present case, the tilt angle (λ) of the booster mirror for specified design of SBC has been computed for all months at the location (17.66°N; 75.32°E) at solar noon. It is seen that, (λ) is remains in positive value (90° + λ) for all months of a year at the location. The change in the value of θz at a given location is seen to be 41.1°. The minimum and maximum values of (λ) at a location are estimated to be 2.6° and 29.9° respectively. Therefore, the values of GCR are estimated to be 1.44 and 1.75 respectively. The positive values of (λ) can be ascribed to the smaller value of ($\theta z \le 45°$). It is obvious that at $\theta z \le 45$, the reflector should be perpendicular to the absorber plate which makes (λ) = 0. However, it may be possible to have negative values of (λ) at higher latitudes (at 30°, 40° and 50°N).

Appendix B

B.1. Proposal for Effective-to-Geometric Concentration ratio (EGR)

From the experimental results, it is seen that, the ECR is almost constant for a specified design of SBC at a specified location. However, to annul the impact of location/latitude (if any) and to have the booster reflector characterization parameter, i.e. Effective Concentration Ratio (ECR) independent of the inclination of booster reflector, it is proposed to use the Effective-to-Geometric Concentration ratio (EGR). EGR is the ratio of Effective Concentration Ratio (ECR) to the Geometric Concentration Ratio (GCR) of the given design of SBC for the day/location and is given by the Eq. (B.1)

$$EGR = \frac{ECR}{GCR} \tag{B.1}$$

For the SBC used in the present case, the value of EGR is estimated to be 0.827 ± 0.0120. However, further detailed investigation is recommended to assess the impact of change in location/latitude as it is not the part of present work.

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