Solar Energy 159 (2018) 984–991

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Brief Note

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

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ARTICLE INFO

Keywords:
Solar box cookers
Concentration ratio
Thermal performance parameters for solar cookers
Solar energy

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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https://doi.org/10.1016/j.solener.2017.11.021
Received 25 June 2017; Received in revised form 18 September 2017; Accepted 9 November 2017

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