Solar Energy 171 (2018) 354–365

Contents lists available at ScienceDirect

Solar Energy

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

Enabling rating of intermediate temperature solar cookers using different working fluids as test loads and its validation through a design change

Atul A. Sagade[a], S.K. Samdarshi[a,b,*], Partha S. Panja[a]

[a] Center for Energy Engineering, Central University of Jharkhand, Ranchi, Jharkhand 835205, India

[b] Centre of Excellence in Green and Efficient Energy Technology, Central University of Jharkhand, Ranchi, Jharkhand 835205, India

ARTICLE INFO

Keywords:
Solar cooker
Thermal performance of solar cookers
Cooker Opto-Thermal Ratio
Test fluid/load

ABSTRACT

Solar cookers working at intermediate temperature (120–240 °C) promise faster propagation of solar cooking technology as they offer a range of cooking options with reduced cooking time. As the thermal losses in such cases would be relatively high, it is pertinent to develop an appropriate rating technique. This paper attempts to identify and investigate the suitable test loads that enable the selection/rating of different designs of solar cookers at intermediate temperatures. Thus, two different working fluids have been used as the tests loads. Two different designs of solar cookers have been tested to serve the purpose using Cooker Opto-Thermal Ratio (COR) as a thermal performance parameter (TPP). The experimental results show that the use of proposed test loads yields approximately identical value of TPP for a specified design of solar cooker at intermediate temperature and enables its rating/grading at such temperatures.

The impact of design change at an intermediate temperature on the TPP has been assessed by changing the radiative characteristics of the cooking pot surface to validate the proposal. It is observed that in the case of concentrating solar cooker the design change has a large impact on the TPP value and accordingly the maximum achievable cooking temperature and reference time show substantial improvement. However, in a box type cooker, the impact of design change is seen to be insignificant.

1. Introduction

Solar cookers of diverse designs have been developed to cook various types of food as per the preference and cooking methodology prevalent for the purpose. The operating principle of different designs of solar cooker is approximately identical. But, their thermal response to collected solar radiation may be different. Any design of solar cooker must be capable enough to provide adequate heat energy at a desired rate and at the required temperature to the quantity of food being cooked (Lof, 1963). Many intermediate temperature (120–240 °C) cooking processes such as frying, baking, and roasting are being used extensively to prepare different types of food items. The thermal performances at these temperatures are expected to be influenced adversely due to relatively high thermal losses. Although solar cookers have been studied worldwide, they are still under investigation because of different issues. One of the most important and neglected issues is the rating of different designs of solar cookers for above mentioned intermediate temperature cooking processes. This may be because of limitations of the use of water as a standard test load (http://www1.lsbu.ac.uk/water/water_unexpected.html); problems in the availability of suitable high boiling temperature test loads/fluids as test loads and applicability of existing TPPs to assess and grade the intermediate temperature solar cookers. This appears to be one of the factors, hindering the propagation of solar cooking technology. Therefore, to test different designs of solar cookers at elevated temperature, a sensible selection of appropriate test loads/fluids using suitable TPP are the essential prerequisites. Hitherto, it is evident that, water is the most suitable and preferred standard test load/fluid to test the solar cookers because of its availability in pure form and stable thermal/thermodynamic properties at low temperatures (~ 100 °C). Also, lower boiling temperature and instability in the thermodynamic properties of water at elevated temperatures (http://www1.lsbu.ac.uk/water/water_unexpected.html) limits the testing of intermediate temperature solar cookers. Further, the thermal performance rating of intermediate temperature solar cookers done at a lower temperature (≤ 100 °C) may not grade them appropriately. The first step to address this issue is to find suitable materials/fluids with reasonably stable thermodynamic properties at an intermediate temperature as a standard/test load. Recently, a number of researchers carried out studies using different materials/fluids on improved designs of solar cookers which work at

* Corresponding author at: Center for Energy Engineering, Central University of Jharkhand, Ranchi, Jharkhand 835205, India.
E-mail address: drsksamdarshi@rediffmail.com (S.K. Samdarshi).

https://doi.org/10.1016/j.solener.2018.06.088
Received 5 March 2018; Received in revised form 19 June 2018; Accepted 22 June 2018

Nomenclature and abbreviations

$\bar{G}_T$	average total solar irradiance (W/m^2)
$\dot{Q}''$	rate of useful heat gain per unit aperture area (W/m^2)
$\bar{T}_a$	average ambient air temperature (°C)
Δt	time interval (seconds) (unless otherwise specified)
$T_{m(DEG)}$	mean temperature of DEG (°C)
$T_{m(GLY)}$	mean temperature of Glycerin (°C)
T_{wm}	mean temperature of water (°C)
T_{fmax}	highest achievable load temperature (°C)
τ_R	reference time (min)

intermediate temperature (Aman, 1985). Sharma et al. (2009) reviewed the materials/fluids for solar cookers. Some of these materials/fluids are magnesium nitrate hexahydrate (Domanski et al., 1995); stearic acid (Buddhi and Sahoo, 1997); acetamide (Sharma et al. 2000); acetanilide (Buddhi et al., 2003); engine oil (Nahar, 2003); paraffin wax (Sharma and Buddhi (1999), Lecuona et al. (2013) and Geddam et al. (2015)); erythritol (Sharma et al., 2005; Lecuona et al.,2013) and peanut oil (Coccia et al., 2017). Most of these materials have been used either as heat transfer fluid or phase change material (PCM) for heat storage related studies and not as standard test fluids/loads. Above works of literature help only to identify different materials used in the study of solar cookers as the present work does not intend to investigate the storage aspect of solar cookers.

Beaumont et al. (1997) categorized the solar cooker designs as solar box cookers (SBCs) and solar concentrating type cookers (SCCs). Kundapur (1998), and Cuce and Cuce (2013) reported reviews on various technical designs and thermal performance aspects of different types of solar cookers. Some researchers, Nahar et al. (1994), El-Sabaii et al. (1994), Suharta et al. (1998), Ekechukwa and Ugwuoke (2003), Mirdha and Dhariwal (2008), Harmim et al. (2012) and Coccia (2017) suggested the additional collection area in the form of reflecting surface/s in SBCs for improved thermal performance and fast cooking. Several design options to improve thermal performance and alternative cooking requirements such as improved designs of cooking utensils, finned vessels and hybrid cooking have been proposed by Tiwari and Yadav (1986), Buddhi and Sharma (2003), Ozturk (2007), Harmim et al. (2008), Mahawar et al. (2012), Suhail (2013), and Joshi and Jani (2015). Recently, Mahavar et al. (2015) reported the optimized load range for SBCs.

Different designs of solar box type cookers (SBC) are being investigated using number of thermal performance parameter/s (hereafter denoted as TPP/s) such as F_1 and F_2 (Mullick et al., 1987); standard cooking power (SCP) (Funk, 1998); thermal efficiency (Kurt et al., 2008; Kumar et al., 2010) and Cooker Opto-Thermal Ratio (COR) (Lahkar et al., 2012). The figures of merit were studied for their response to the change in the design parameters of a box cooker separately; therefore, their evaluation is still in the progress (Kumar, 2004; BIS, 2000). SCP is a temperature dependent parameter and the resolution of its curve to a design change may be low (Funk, 1998). Out of different designs of solar cookers, concentrating cookers (SCC) are preferred for fast and intermediate to high-temperature cooking. SCCs can be assessed using two parameters; heat loss factor ($F'U_l$) and optical efficiency factor ($F'\eta_o$) proposed earlier (Mullick et al., 1991) and analyzed in detail (Kumar S. et al., 1993, 1994, 1996). Sardeshpande et al. (2011) proposed latent heat based test protocol for SCCs working at intermediate temperatures. Also, SCCs have been analyzed for heat transfer enhancement (Sonune and Philip, 2003; Chandak, 2010; Lokeswaran and Eswarmoorthy, 2012; Zamani et al., 2015); and exergy calculations (Ozturk, 2004; Kaushik and Gupta, 2008). Different studies have been conducted to assess the ability of solar cookers (hybrid in nature) to reach intermediate/high temperatures with the help of design change induced relative change in the achievable maximum temperature under given meteorological condition at a location. Some of them are Haraksingh and Doom (1996); Balzar et al. (1996); Stumpf et al. (2001); Kumar et al. (2001); Mehmet Esen (2004); Esen et al. (2005); Hussein et al. (2008); Farooqui (2013); Kim et al. (2013); Singh et al. (2015) and Craig and Dobson (2016, 2017).

From the literature, it is evident that hitherto, most of SBCs and SCCs have been tested at a relatively low temperature (~100 °C) using water as a standard test load. As stated earlier, due to the limitations of the use of water at intermediate temperatures and atmospheric pressure for prediction of consistent TPP value, it is difficult to conclude on the expected rating/grading of solar cookers designed to work at intermediate temperatures. From the literature discussed above, authors have not found evidence of rating/grading of intermediate temperature solar cookers using appropriate test load/s and corresponding TPP/s for their thermal performance analysis above 100 °C. In fact, neither the TPPs (determined at a lower temperature) nor the corresponding test procedure may be employed for the rating/grading of the intermediate temperature solar cookers, because of change in the phase and heat transfer characteristics of water. Thus, it is essential (i) to identify different test fluids as test loads for intermediate temperature solar cookers; (ii) to investigate the thermal performance of various designs of solar cookers working at intermediate temperature/s using appropriate TPP and corresponding test procedure and (iii) to study the impact of design change on solar cookers performance to be able to intra-cooker design comparison.

Another apprehension related to existing TPPs is their resolution and stability at intermediate temperatures. A test load with the specific heat lower than that of water will offer a higher resolution in design induced change in TPP/s and the rise in temperature per unit heat gain will be clearly visible and vice versa. In the current work, the heat capacities of the selected test loads are proposed to be kept identical and equivalent to that of water in order to facilitate the study of the resolution and stability of the TPP used.

Different test loads with heat capacities equivalent to that of water may enable (i) the testing and comparison of impact of their use on TPP vis-a-vis water as the test load; (ii) to assist in testing of different designs of solar cookers with any test load/fluid (with reasonably stable thermal/fluid dynamic properties) and (iii) the accurate prediction of TPP for a specified design of solar cooker at low as well as intermediate temperatures.

Thus, in the present work, two different test fluids-di-ethylene glycol (DEG) and glycerin are identified as test loads. Two dissimilar designs of solar cookers (Solar box cooker and parabolic concentrating cooker) have been tested to serve the purpose using Opto-Thermal ratio (COR) as a TPP. The impact of design change at intermediate temperature has been assessed by changing the radiative characteristics of the cooking pot surface. The resolution and stability of relevant TPP is also verified. However, the highest achievable load temperature and the reference time (derived from the TPP) and their role in the selection and rating of specified designs of intermediate temperature solar cookers are required to be introduced and discussed here.

1.1. Highest achievable load temperature

Highest achievable load temperature, T_{fmax} is the highest temperature attained by the test load for a specific design of solar cooker under a given meteorological condition of a location (Lahkar et al., 2012). In the present work, effectiveness and ability of the TPP are tested for accuracy of prediction of T_{fmax} values for different test loads.

1.2. Reference time

The *reference time* (τ_R) is the time required by the standard test load of a given solar cooker to reach a reference cooking temperature of 95°C (Lahkar et al., 2010). Thus, the upper limit of reference cooking temperature is fixed (95 °C). The reference time characterizes the rate of heat supply to the food being cooked. The higher the rate of heat supply, lower will be the reference time and vice versa. To carefully define reference time in terms of TPP, it is necessary to fix its lower limit as well. The highest possible ambient temperature is taken as the lower limit in the present study. Because the lower limit, i.e. the ambient temperature may differ at various meteorological locations, it is suggested to fix it at 50 °C, which is the highest ambient temperature expected for a solar cooker in any part of the world. The present work proposes to estimate the value of reference time from a COR and confirm it experimentally for different test loads/fluids for two designs of solar cookers. Thus, *reference time,* τ_R may be redefined as the time required by the standard test load of a given solar cooker to attain a reference cooking temperature of 95 °C from a lower limit of temperature (50 °C). τ_R can be determined using an analytical expression (1) which gives the theoretical time taken by the fluid to heat up from lower to the upper limit of temperature under given meteorological conditions of a specified location.

$$\tau_R = \frac{M_f C_{pf}}{A_p F' \eta_o} \times COR \times ln\left[\frac{\bar{G}_T - \frac{T_{f1} - \bar{T}_a}{COR}}{\bar{G}_T - \frac{T_{f2} - \bar{T}_a}{COR}}\right] \quad (1)$$

where τ_R is the *reference time*, M_f is mass of test load; C_{pf} is the specific heat of test load; A_p is the aperture area of solar cooker; η_o is the optical efficiency; F' is heat exchange factor; C is the concentration ratio of given design of solar cooker; $\bar{G}_T$ and $\bar{T}_a$ are the average total solar radiation on the aperture area of solar cooker and average ambient air temperature, respectively, recorded for the entire period of experimentation on the given day at the location; COR is the Cooker Opto-Thermal Ratio; T_{f1} = 50 °C and T_{f2} = 95 °C are the lower and upper limit of temperature of the test load, respectively, for the purpose of estimation of reference time.

2. Experimental details

In the present experimental work, two different laboratory grade fluids, diethylene glycol (M/S Molychem, India) (hereafter referred to as DEG) and glycerin (M/S Thomas Baker (Chemicals) Pvt. Ltd. India) were used as test loads. The properties of the DEG and glycerin are enlisted in Table 1 and some of these properties were verified by detailed DSC-TGA analyses which are given in Appendix C. As the COR is applicable to any design of solar cooker (Lahkar et al., 2012), two solar cookers – Solar Box Cooker (SBC) equipped with single booster mirror (Area of booster mirror = 0.23 m^2; reflectivity = 0.83) and Square Parabolic Dish Solar Concentrating Cooker (SPD-SCC) made up of anodized aluminum reflecting mirrors (ALANOD ® GmbH and Co. KG, Germany; Grade 320G; reflectivity = 0.86) (Chandak A., 2010) were used for testing purpose. The specifications of both solar cookers are enlisted in Table 2. It is assumed that (i) the test load with density value near to that of water will have no effect on test load/fluid volume; (ii) the volume of test load/fluid is expected to have negligible impact on the overall heat transfer in the SBC and SCC; (iii) although the cooking pots are different, their heat capacity is relatively low to have any impact on the measured data; and iv) the measurement errors of different parameters (G_T, T_a, *and* T_f) will be reflected in the estimation of the TPP; but their impact on the value of TPP is expected to be minimum. It is to be noted that, the inaccurate tracking of solar cookers and inappropriate orientation of booster reflector in case of SBC will lead to an incorrect estimation of the TPP. Hence, during experimentation care should be taken to complete the experiment with minimum tracking.

Table 2
Values of parameters used in the determination of TPP (COR).

Parameter	Value for SBC	Value for SPD-SCC
Aperture area of Solar Cooker (A_p) (m^2)	0.37	1.52
Area of Cooking Pot (A_{pot}) (m^2)	0.06	0.12
Glazed Area of Solar Cooker (A_{glz}) (m^2)	0.23	Not Applicable (hereafter denoted as NA)
Geometric Concentration Ratio (C)	1.44–1.75	12.34
Effective Concentration Ratio (ECR) Sagade et al. (2017)	1.33	NA
Material for Cooking Pot	Stainless Steel	Aluminum
Specific heat of Cooking pot (J/(kg K))	510	910
Mass of Water in Cooking pot (kg)	0.94	3.8
Mass of DEG in Cooking pot (kg)	1.5	6.08
Mass of Glycerin in Cooking pot (kg)	1.3	5.28
Mass of Cooking Pot (M_{pot}) (kg)	0.54	1.63
Specific heat of DEG (C_{pDEG}) (J/(kg K))	2617	
Specific heat of Glycerin (C_{pGly}) (J/(kg K))	3014	
Specific heat of Water (C_{pw}) (J/(kg K))	4186	

In the present experiments, non-coated cooking pots with a standard load of 2.5 kg of water per m^2 aperture area were used in the experiments for each design of solar cooker. It is proposed to keep the heat capacity ($M_f C_{pf}$) of each test load to be identical and equal to the heat capacity of standard test load of water (i.e. 2.5 kg/m^2). Therefore, the equivalent values for DEG and glycerin were estimated at 4 kg and 3.47 kg, respectively, per m^2 aperture area of solar cooker.

Initially, both the solar cookers with cooking pots filled with test loads were kept in open so as to be in thermal equilibrium with the ambient. Thereafter, the SPD-SCC was oriented such that the bright spot of the concentrated radiation fall at the bottom of the cooking pot. In case of SBC, the load was kept in one pot only. The absorber plate was allowed to heat up adequately above ambient temperature (near to 55°C) before it was loaded with the test load in the cooking pot. It avoids the initial cold start in the heating of test load. In case of the SBC, the aperture area is taken as the area of the opening (with the booster mirror), which receives the solar flux (Lahkar et al. 2012, Sagade et al., 2018).

The temperature of test load was recorded using a calibrated J-type (Copper-Constantan) temperature sensor for the complete timeline of sensible heating. The temperature sensor was placed at the center of test load and away from the bottom of the cooking pot through a hole available at the center of the cooking pot lid. The hole was sealed

Table 1
Properties of DEG and glycerin.

S.N.	Parameter	DEG	Glycerin
1.	Density (kg/m^3)	1113	1200
2.	Specific Heat (J/(kg/K))	2617[± 2.25% from 50 °C to ~150 °C]	3014[± 4.40% from 50 °C to ~220 °C]
3.	Boiling point (°C)	244	290
4.	Flash point (°C)	138	160

properly to avoid any heat escape through it. Total solar radiation (G_T) and wind speed were measured using a pyranometer and wind sensor (Dynalab, India), respectively. G_T was measured on the inclined plane, normal to the beam radiation and corresponds to the maximum value of solar radiation recorded in that direction. Both the solar cookers and pyranometer were tracked manually as per necessity. All the measuring instruments and sensors were connected to a data logger (UniLog, India) and temperature of the test loads (T_f), ambient air temperature (T_a) and total solar radiation (G_T) were recorded at a regular interval of 90 s. The average of ($\bar{G_T}$) and ($\bar{T_a}$) was made for the entire timeline of sensible heating (i.e. for the whole period of the experiment) of around ± 90 min of the solar noon and their mean value was used in the calculations.

The experiments on both SBC and SPD-SCC were conducted at a location (17.66°N, 75.32°E) around ± 90 min. of solar noon; under ambient conditions as ($\bar{G_T}$) ≥ 700 W/m^2; 20 °C ≤ ($\bar{T_a}$) ≤ 40 °C and wind speed ≤ 1.5 m/s. Fig. 1 shows the experimental test setup. The average absolute instrumental error of 0.5 °C in temperature and 1% in solar radiation measurements were possible. The windshield was used to reduce the wind disturbances during the experimentation. Proper safety precautions were taken to avoid the toxicity (if any) and handling of hot test loads/fluids (DEG and glycerin) (Such as use of hand gloves and nose cover). The experimental data was used to find the value of $\dot{Q}''$using Eq. (2) (Lahkar et al., 2012) as

$$\dot{Q}'' = \frac{(M_f C_{pf})'_f (T_{f2} - T_{f1})}{A_p \Delta t} \tag{2}$$

where $\dot{Q}''$is the rate of useful heat gain by the test load/fluid per unit aperture area; $(M_f C_{pf})'_f$ is the sum of the heat capacity of test load and the pot; T_{f1} and T_{f2} are the initial and final temperatures of the test loads, respectively and Δt is the time interval in seconds.

The experimental data of both the solar cookers were used to plot Temperature of the test load (T_f) vs. Time plot and the linear plot of $\frac{\dot{Q}''}{\bar{G_T}}$ vs. $\frac{(T_{fm} - \bar{T_a})}{\bar{G_T}}$ for each solar cooker. From the linear plot of $\frac{\dot{Q}''}{\bar{G_T}}$ vs. $\frac{(T_{fm} - \bar{T_a})}{\bar{G_T}}$, set of two parameters, $F'\eta_o$ and $F'U_l/C$ were calculated. The ratio of $F'\eta_o$ to the $F'U_l/C$ gives a value of COR for specified design of solar cooker (Lahkar et al., 2012). The values of parameters depicted in Table 2 were used in the calculations of COR.

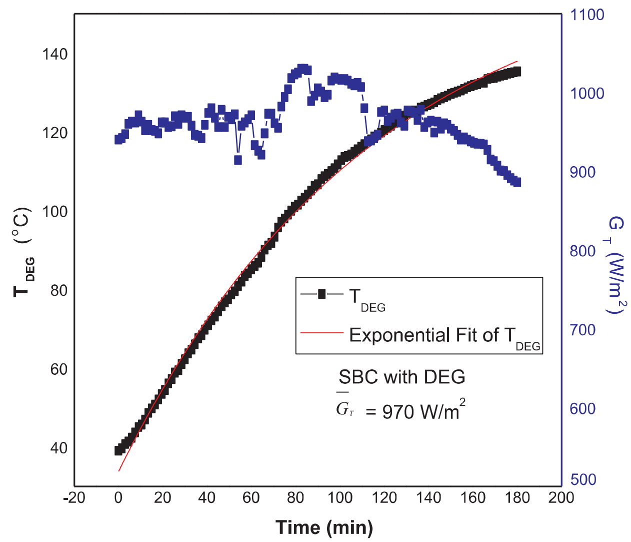

Fig. 2a. Time vs. (T_{DEG}) plot for SBC.

3. Results and discussions

3.1. Determination of TPP of solar cooker using different test loads

Figs. 2a and 4a depict the rise in the temperatures of test loads, DEG and glycerin in SBC and Figs. 3a and 5a depict the same in SPD-SCC, respectively. The respective linear plots of $\frac{\dot{Q}''}{\bar{G_T}}$ vs. $\frac{(T_{m(DEG/Gly)} - \bar{T_a})}{\bar{G_T}}$ are shown in Figs. 2b and 4b for SBC, and in Figs. 3b and 5b for SPD-SCC. As expected, the initial rate of rise in temperature of test load is high. After a certain time, it starts stagnating at a temperature depending upon the ambient conditions and the design of solar cooker. It is observed that, within a short window of solar noon, the attainment and hence determination of the actual stagnation temperature of the test loads is difficult for outdoor experiments. The experimental plots (Refer Figs. 2a, 3a, 4a and 5a) testify the same.

For the SBC, the typical values of apparent stagnation temperature (T_{st}) attained using glycerin and DEG as test loads are 120.8 °C and 133.9 °C, respectively, on the given experimental day. Similarly, for the

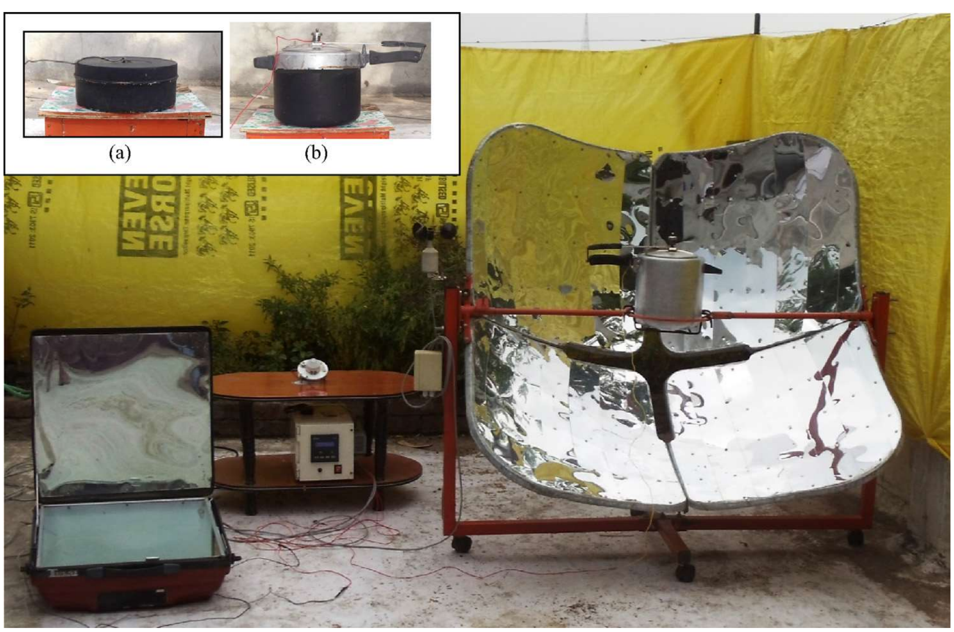

Fig. 1. Test setup: SBC and SPD-SCC with non-coated cooking pots and different test loads. (Insets: Matt Black coated cooking pots: (a) SBC and (b) SPD-SCC).

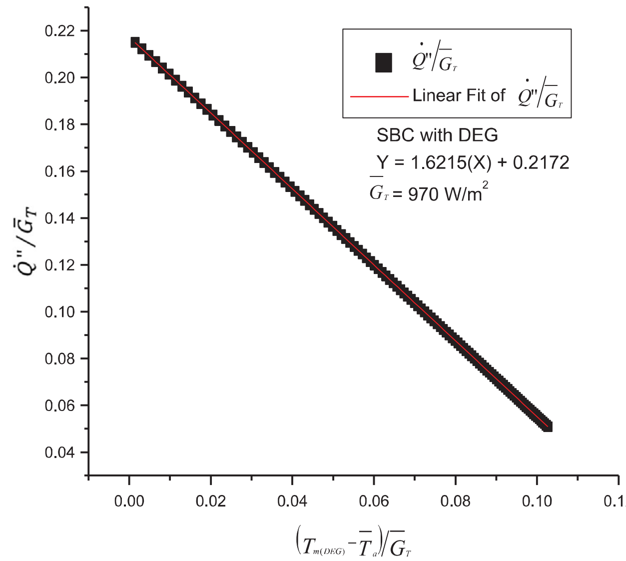

Fig. 2b. $\frac{\dot{Q}''}{\bar{G}_T}$ vs. $(T_{m(DEG)}-\bar{T}_a)/\bar{G}_T$ plot for SBC.

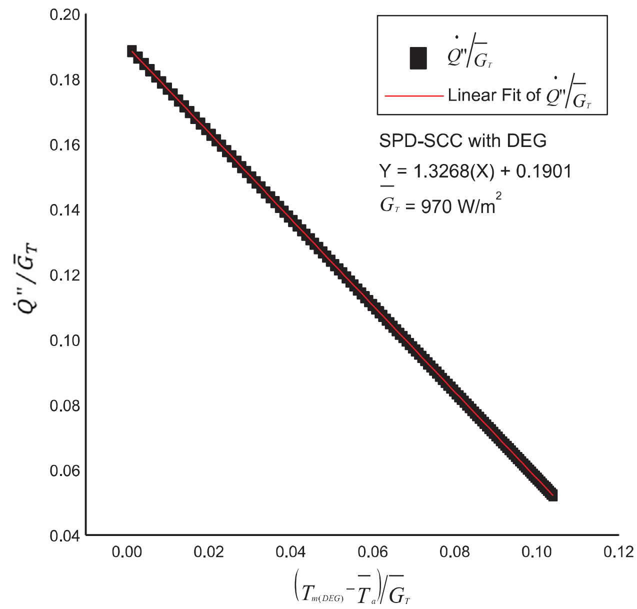

Fig. 3b. $\frac{\dot{Q}''}{\bar{G}_T}$ vs. $(T_{m(DEG)}-\bar{T}_a)/\bar{G}_T$ plot for SPD-SCC.

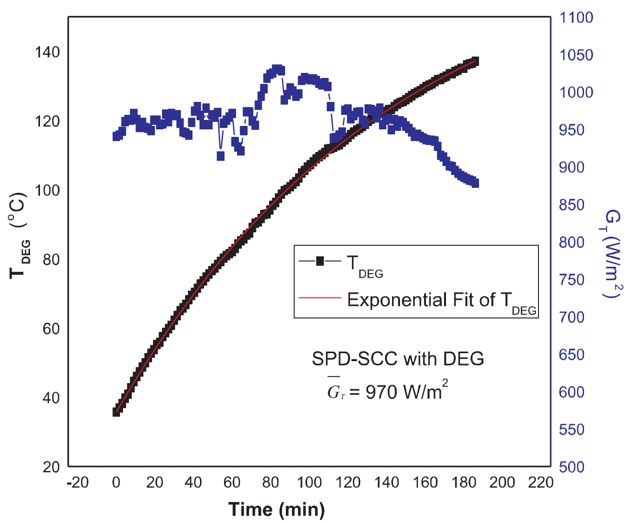

Fig. 3a. T_{DEG} vs. Time plot for SPD-SCC.

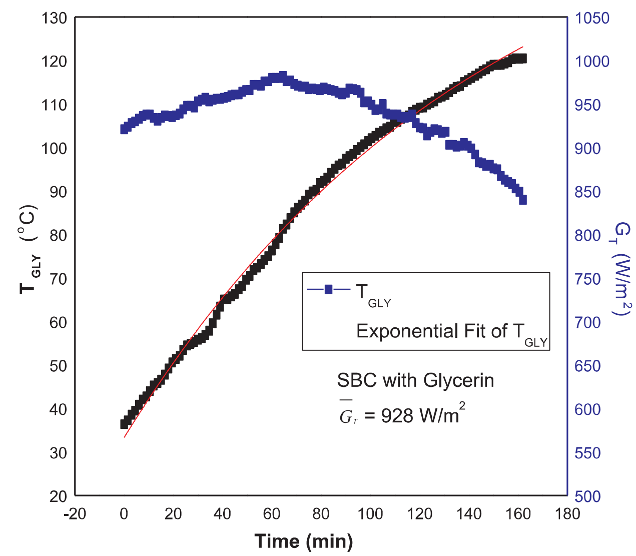

Fig. 4a. T_{GLY} vs. Time plot for SBC.

SPD-SCC, the typical values of T_{st} for the glycerin and DEG are 140.2 °C and 144.7 °C, respectively. As the name suggests, the apparent stagnation temperature (T_{st}) of solar cooker can be defined as the onset temperature at which rate of heat gain of the test load is approximately equal to heat loss. The typical value of T_{st} depends on fluid dynamic characteristics of the test load and meteorological conditions of the location on an experimental day. It is evident that, after solar noon, the intensity of solar radiation falls slowly and continuously. But, it is adequately high to maintain/raise the temperature of absorber plate/cooking pot in case of SBC and influences the possible attainment of actual stagnation temperature. Because the time constant of SBC is high, there is a delayed response to the decline in solar radiation flux on the temperature of the test load. In case of SPD-SCC, the load capacity/volume of cooking pot is sufficient enough to retain heat at lowered solar radiation. Thus, a very slow but steady rise in the temperature of the test load can be seen (Refer Figs. 2a, 3a, 4a and 5a). It is seen that, for a specified design of solar cooker, the value of T_{st} remains ± 2 °C of the temperature attained during the experimentation period around the solar noon on an experimental day at a location. Also, the value of T_{st} varies seasonally and lower values are anticipated in winter as compared to summer.

For the SBC used in the present case, the value of effective concentration ratio remains approximately equal to ∼1.33 (Sagade et al., 2017). The values of $F'\eta_o$ and $F'U_l/C$ are determined from the respective linear plots of $\frac{\dot{Q}''}{\bar{G}_T}$ vs. $\frac{(T_{m(DEG/Gly)}-\bar{T}_a)}{\bar{G}_T}$ for the SBC using each test load and their mean values are enlisted in Table 3 with a percentage standard deviation between ± ∼2% to ± ∼9% and ± ∼3% to ± ∼9%, respectively. Thus, the value of COR is expected to remains practically unaltered in case of SBC (Sagade et al., 2017).

In case of SPD-SCC, it is evident that the thermal performance is dependent more on optical efficiency than the thermal losses. The overall thermal losses from the SPD-SCC are small due to small heat loss area and mainly radiative. The mean values of $F'\eta_o$ and $F'U_l/C$ for SPD-SCC using both the test loads are enlisted in Table 3 with a percentage standard deviation between ± ∼5% to ± ∼9% in both the parameters, respectively. The variation in the $F'\eta_o$ values can be ascribed to material characteristics of reflecting and cooking pot surfaces, whereas, the small variation in the $F'U_l/C$ values can be ascribed to ambient conditions. Hence, the value of COR is expected to remain approximately unchanged with some deviation for SPD-SCC also.

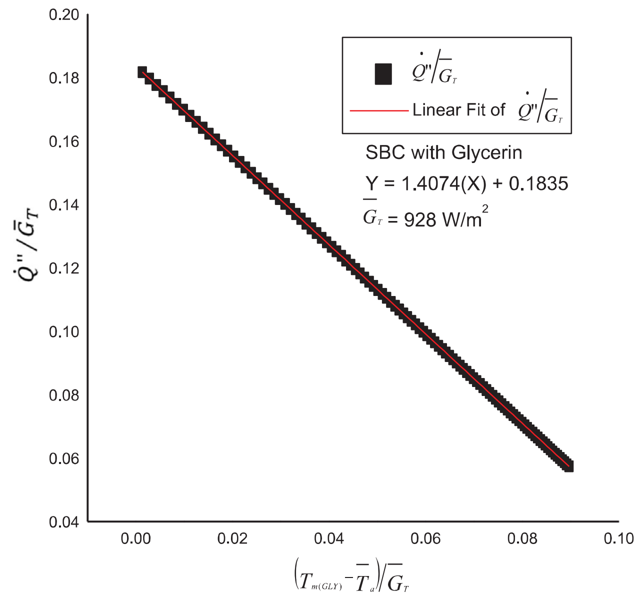

Fig. 4b. $\frac{\dot{Q}''}{\bar{G}_T}vs(T_{m(GLY)}-\bar{T}_a)/\bar{G}_T$. plot for SBC.

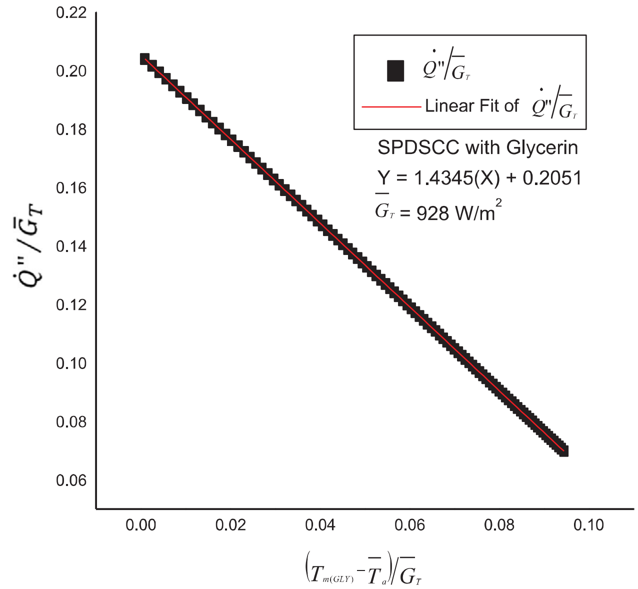

Fig. 5b. $\frac{\dot{Q}''}{\bar{G}_T}$vs. $(T_{m(GLY)}-\bar{T}_a)/\bar{G}_T$plot for SPD-SCC.

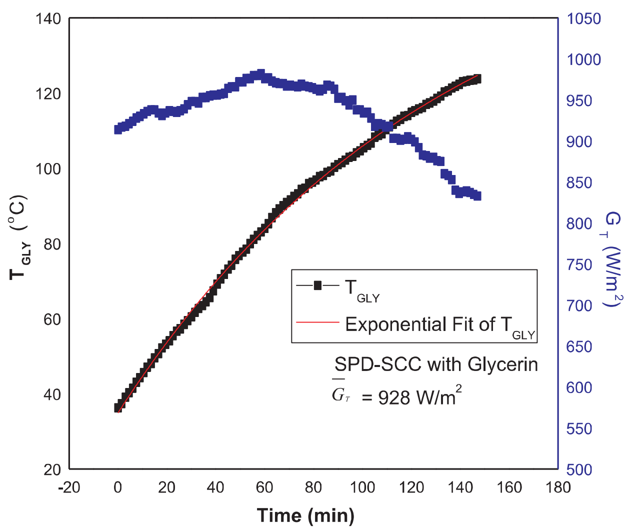

Fig. 5a. T_{GLY} vs. Time plot for SPD-SCC.

Table 3
Mean values of parameters for solar cookers with non-coated pot and different test loads.

	Mean values of parameters		
	$F^{'}\eta_o$	$F^{'}U_l/C$	COR
Results for SBC and test load with non-coated pot			
SBC with DEG	0.193 ± 0.0187	1.463 ± 0.132	0.133 ± 0.00292
SBC with glycerin	0.180 ± 0.0038	1.377 ± 0.0426	0.131 ± 0.00131
SBC with water	0.177 ± 0.0044	1.317 ± 0.0768	0.134 ± 0.00381
Results for SPD-SCC and Test load with non-coated pot			
SPD-SCC With DEG	0.184 ± 0.0099	1.295 ± 0.0795	0.143 ± 0.00174
SPD-SCC with glycerin	0.194 ± 0.0103	1.364 ± 0.0778	0.142 ± 0.00197
SPD-SCC with water	0.171 ± 0.0152	1.204 ± 0.107	0.143 ± 0.00108

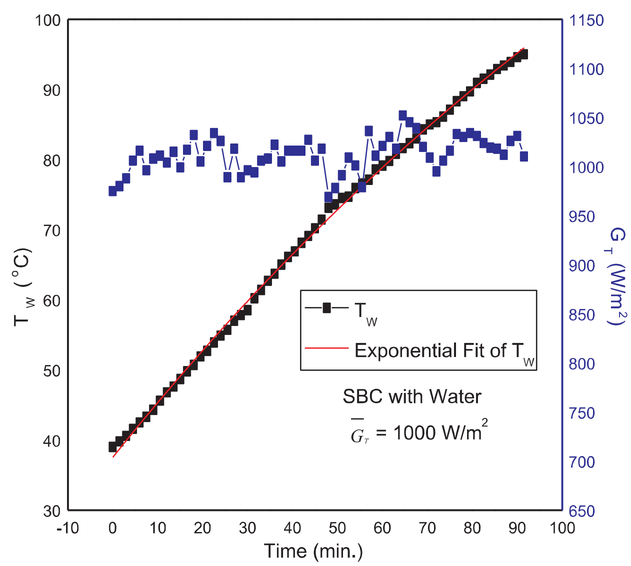

Fig. 6a. T_w vs. Time with time for SBC.

The mean value of the COR for SBC and SPD-SCC using the DEG as a test load are 0.133 ± 0.00292 and 0.143 ± 0.00174, respectively; and that using glycerin are 0.131 ± 0.00131 and 0.142 ± 0.00197, respectively. Hence, the mean value of COR for a specified design of solar cooker remains approximately unchanged with small deviations. The deviation in the COR values of SBC and SPD-SCC is estimated to be ± ~2% and ± ~1.4%, respectively, (Refer Table 3) as expected. Also, the literature results (Lahkar et al., 2012; Sagade et al., 2017) confirm the same. More importantly, present work confirms that COR is independent of the type of test load/fluid (Refer Table 3).

It is observed that, near actual stagnation, the non-linearity and incorrect identification of the temperature of the test loads tends to influence the value of COR to some extent (Refer Appendix B for the further details). As stated earlier, test load is unable to reach the actual stagnation temperature in a small window of solar noon. Hence, the apparent stagnation temperature should be identified correctly in the case of intermediate temperature cooking.

To cross check the applicability of different test loads, the same SBC and SPD-SCC described earlier were tested with water as a standard test load and non-coated cooking pots. The corresponding plots are shown in Figs. 6a and 6b, and Figs. 7a and 7b. Now, the experimentally determined values of COR for the respective design of solar cooker (using DEG and glycerin as test loads) are compared to reach the conclusion.

The experiments were conducted and the analysis was done in the

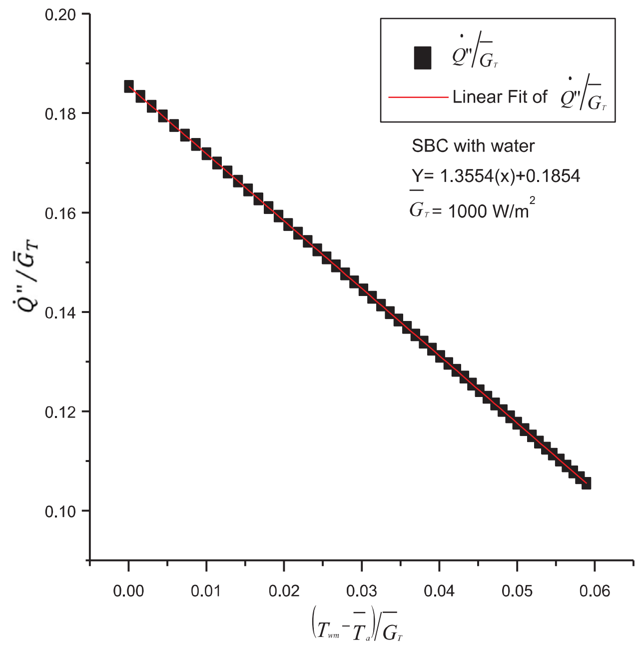

Fig. 6b. $\frac{\dot{Q}''}{\bar{G}_T}$ vs $(T_{wm}-\bar{T}_a)/\bar{G}_T$. plot for SBC.

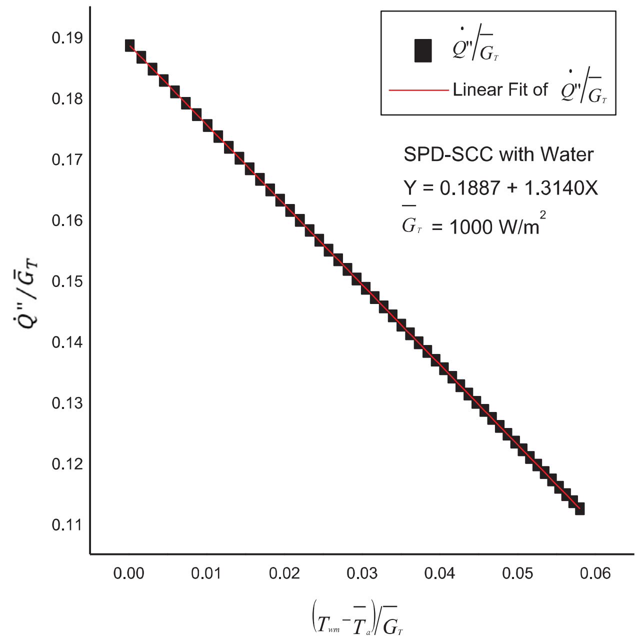

Fig. 7b. $\frac{\dot{Q}''}{\bar{G}_T}$ vs. $(T_{wm}-\bar{T}_a)/\bar{G}_T$ plot for SPD-SCC.

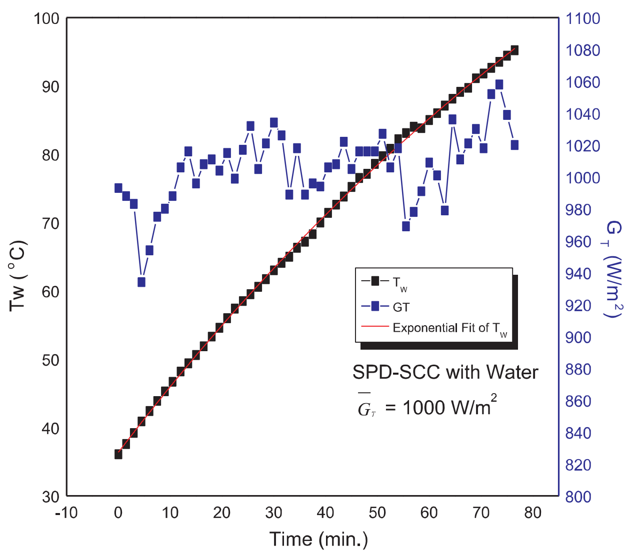

Fig. 7a. T_w vs. Time plot for SPD-SCC.

similar manner as described in Section 2 and 3, respectively. The mean values of $F'\eta_o$ and $F'U_l/C$ and COR for both SBC and SPD-SCC are enlisted in Table 3.

It can be seen that the values of COR for the respective design of solar cooker determined using water as a standard load are approximately identical to the one obtained using DEG and glycerin as test loads. It confirms that COR is independent of the type of test load/fluid. Thus, it can be concluded that any test load/fluid having stable thermal properties offers a good opportunity to test any design of solar cooker.

4. Assessment of the impact of change in radiative characteristics of the cooking pot on TPP

Although designs of solar cookers are different, the radiative characteristics of cooking pot affects the TPP value of the respective design. Also, as the SPD-SCC is an open system, the impact is much more significant. Thus, it is important to study the response of the TPP to this design change in the respective design of solar cooker. The design change may be introduced to improve the optical or heat loss characteristics of the solar cooker. The change in the surface property of the cooking pot offers an opportunity to alter both of these characteristics. It will be interesting here to assess the impact of this on the response of TPP used. Therefore, to serve the purpose, the surface of each cooking pot was coated with Matt Black paint. It promises to increase the intermediate temperature value of the test load, T_{fmax} and reduce the value of τ_R for the given design of solar cooker. This design change may allow (i) the verification of the suitability of proposed test loads/fluids to test the solar cookers for the applications such as frying (ii) to check the resolution and stability of TPP used at elevated temperatures. The spectral analysis of Matt Black coated cooking pot/s is revealed in Supplementary information. Thus, the experiments were performed in the similar manner as described in earlier Section 2 on the cookers with the Matt Black coated cooking pots and DEG and glycerin as test loads. As the upper limit of the temperature of DEG usage is 190 °C only (Refer Appendix C), therefore, the use of DEG is avoided in the case of SPD-SCC-Matt black coated cooking pot combination.

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.solener.2018.06.088.

The experimental setup as shown in Fig. 1 was used with the Matt Black coated cooking pots (Fig. 1a and b inset) in the respective design of solar cooker. Figs. 8a and 8b depict corresponding plots for SBC and Figs. 9a and 9b that of for SPD-SCC.

Table 4 enlists the mean values of $F'\eta_o$; $F'U_l/C$ and COR for SBC and SPD-SCC using Matt Black coated cooking pots and a test load combination.

It is seen that both solar cookers perform better with the use of Matt Black coated cooking pots. The effect of black paint on the surface of cooking pots can be clearly seen for both cookers. Significant change can be seen in the mean values of $F'\eta_o$ for Matt black coated cooking pot-SBC and SPD-SCC combinations as compared to that of with non-coated cooking pots. As expected, it is seen that, with the increase in temperature of the test load, the thermal losses from the cooking pot also increases. However, the impact of the increase in the value of $F'U_l/C$, is seen to have minimal impact on the value of COR and an increase in the mean values COR can be seen in respective design of solar cookers (Refer Table 4). From the experimental results, it is seen that the impact of design change on COR is seen to be infinitesimal in

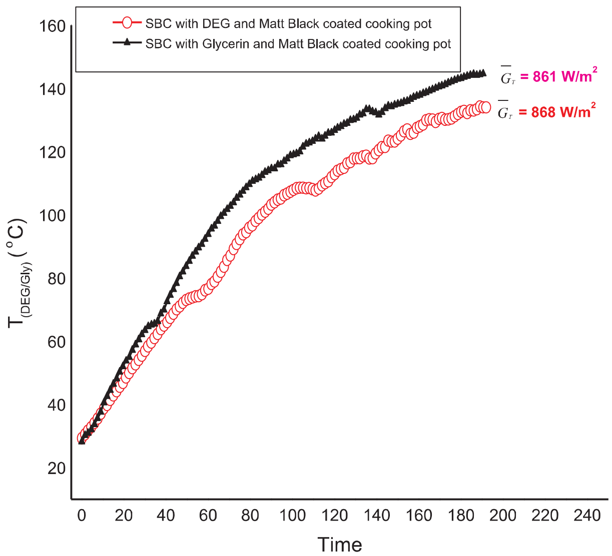

Fig. 8a. Time vs. Temperature ($T_{DEG/Gly}$) plot for SBC.

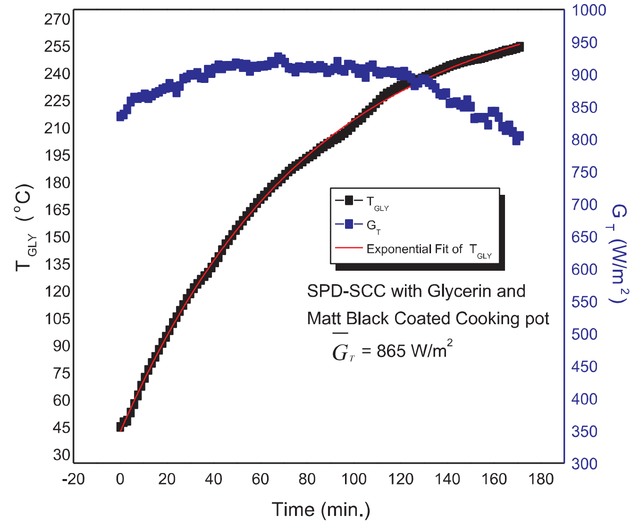

Fig. 9a. Time vs. T_{Gly} plot for SPD-SCC.

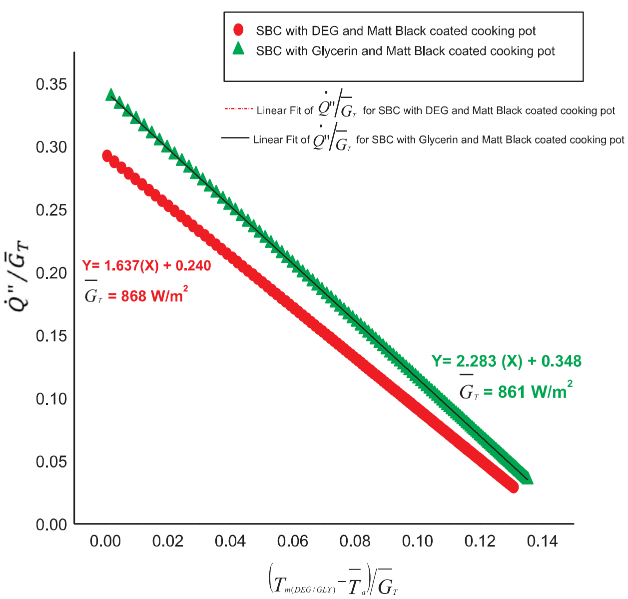

Fig. 8b. $\frac{\dot{Q}''}{\bar{G}_T}$ vs.$(T_{m(DEG/GLY)} - \bar{T}_a)/\bar{G}_T$ plot for SBC.

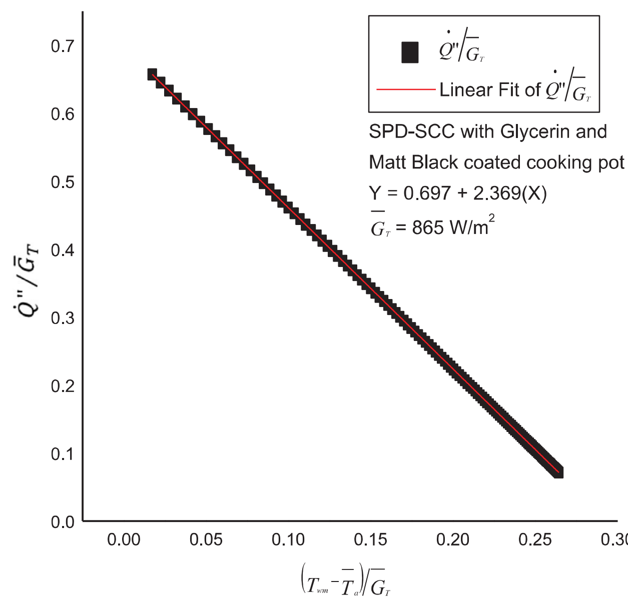

Fig. 9b. $\frac{\dot{Q}''}{\bar{G}_T}$vs.$(T_{m(Gly)} - \bar{T}_a)/\bar{G}_T$ plots for SPD-SCC.

the case of the SBC. However, significant improvement can be seen in the COR value of SPD-SCC.

4.1. Impact of change in radiative characteristics of cooking pots on highest achievable load temperature (T_{famx}) and the reference time (τ_R)

The highest achievable load temperature, T_{fmax} (Lahkar et al., 2010) assists in the selection of the appropriate design of solar cooker as per cooking methodology (boiling, frying, baking or roasting) and food preference of a user under given meteorological conditions of a location.

Table 5 indicates the typical values for T_{fmax} estimated for SBC and SPD-SCC using non-coated and Matt Black coated cooking pots and different test loads for a typical experimental day at a location. The T_{fmax} is an objective parameter (Lahkar et al., 2010) and is a function of COR, $\bar{T}_a$and $\bar{G}_T$ (Refer Appendix A). Therefore, T_{fmax} will have lower values in winter as compared to summer for the particular design of the solar cooker. Also, the relatively high value of T_{fmax} with DEG as compared to glycerin may be ascribed to the fluid dynamic characteristics of DEG. With Matt black coated cooking pot, a substantial improvement is seen in the values of T_{fmax} for SPD-SCC as compared to non-coated cooking pot. On the other hand, a small change in the value of T_{fmax} can be seen in case of SBC. It verifies the impact of the change in radiative characteristics of cooking pots on the TPP and thermal performance of respective design of solar cooker described in the present work.

It should be mentioned that if the heat capacity of any test load is the same; the T_{fmax} should be independent of load type. Therefore, the use of test load other than water enables the solar cooker to reach high temperatures. It helps to identify the cooking ability of a particular design of solar cooker at intermediate temperature and atmospheric pressure.

Table 4
Mean values of parameters for solar cookers obtained using Matt black coated cooking pots and different test loads

Results for SBC using test load with Matt Black coated cooking pot ↓	Mean Values of Parameters with Matt Black coated cooking pot			Mean Value of COR for SBC with non-coated pot (reported again for the ease of comparison)
	$F'\eta_o$	$F'U_l/C$	COR	
SBC with DEG	0.263 ± 0.029	1.820 ± 0.202	0.145 ± 0.00153	0.133 ± 0.00292
SBC with Glycerin	0.316 ± 0.030	2.112 ± 0.220	0.148 ± 0.00151	0.131 ± 0.00131
Results for SPD-SCC using test load with Matt Black coated cooking pot ↓	Mean Values of Parameters with Matt Black coated cooking pot			Mean Value of COR for SPD-SCC with non-coated pot (reported again for the ease of comparison)
	$F'\eta_o$	$F'U_l/C$	COR	
SPD-SCC with Glycerin	0.590 ± 0.0673	2.031 ± 0.233	0.301 ± 0.00497	0.142 ± 0.00197

Similarly, the values of COR (determined experimentally) for SBC and SPD-SCC have been used to predict theoretical values of the reference time (τ_R) of the respective design of solar cooker using Eq. (1). τ_R is also one of the objective parameters for any design of solar cooker (Lahkar et al., 2010) and dependent on meteorological conditions of a location. Table 6 enlists the typical theoretical and experimentally observed values of $\tau_R$for a typical experimental day at a location for SBC and SPD-SCC and its percentage deviation.

As expected, a slight deviation is seen in the experimental and theoretical values of $\tau_R$for both the solar cookers and can be ascribed to the limitation of the equation. Reference time, τ_R is one of the user-friendly parameter. It may assist the users in choosing a specific design of solar cooker on the basis of cooking time. In case of SPD-SCC, the value of τ_R is reduced significantly with Matt black coated cooking pot as compared to non-coated pot (Refer Table 6). But, in case of SBC, change in the value of τ_R is negligible. Thus, the impact of the change in radiative characteristics of cooking pots on the TPP of the respective design of solar cooker is clearly visible. Lower the reference time of particular design of solar cooker, lower will be the time required to attain the reference cooking temperature and higher will be the number of meals cooked per day and vice versa. Therefore, determination of τ_R for the different designs of the solar cooker at a location allows the intra and inter-cooker comparison based on the cooking time.

5. Conclusions

It is experimentally demonstrated that the use of proposed test loads enables the testing as well as rating/grading of two different designs of solar cookers (SBC and SPD-SCC in the present case) at intermediate temperatures with a reasonable degree of accuracy. The experimentally determined values of COR are seen to be approximately identical for a particular design of solar cooker-cooking pot combination using each of proposed test loads The mean values of COR for SBC using non-coated cooking pot and DEG, glycerin, and water as test loads are 0.133, 0.131, and 0.134, respectively, and that of for SPD-SCC are 0.142, 0.143 and 0.143, respectively. Similarly, the mean value of COR for SBC-Matt Black coated cooking pot and DEG and glycerin as test loads are estimated to be 0.145 and 0.148, respectively. In case of SPD-SCC-Matt Black coated cooking pot combination and glycerin as a test load, the mean value of COR is 0.301. Therefore, it can be concluded that the proposed test load/s-TPP combination facilitates the rating/grading of any design of solar cooker as well as inter and intra-cooker comparison at intermediate temperatures (120–240 °C). Thus, it enables the testing and rating/grading of different designs of solar cookers for applications such as frying, where oil reaches a temperature of around 230 °C. Reference time (τ_R) is determined using the value of COR for the respective design of solar cooker. The experimentally observed and theoretically predicted values of reference time correlate satisfactorily. The percentage deviation of 3.45%, 3.50% and 3.94% in the typical experimental and theoretical values of the reference time is observed in case of SBC-non-coated cooking pot combination and DEG, glycerin and water as test loads, respectively and that of for SPD-SCC is 4.11%, 3.25%, and 3.80%, respectively. For SBC-Matt Black coated cooking pot combination and DEG and glycerin as test loads, the percentage deviation of 4.47% and 5.46% respectively, is observed in the typical experimental and theoretical values of the reference time. Thus, τ_R assists in the rating/grading of different designs of solar cookers on the basis of cooking time. It is seen that the COR is able to characterize the design change precisely (in the present case, change in radiative characteristics of the cooking pot) at intermediate as well as low temperatures. The impact of design improvement is clearly reflected in the improved values of T_{fmax} and τ_R for SPD-SCC. The typical experimental value of τ_R is reduced to 27 min. and a typical value of T_{fmax} is increased up to 247.8 °C using glycerin as a test load. However, the impact of the change in radiative characteristics of cooking pot is seen to be negligible for the SBC. Therefore, it is recommended to incorporate some

Table 5
Typical values of T_{fmax} estimated for a typical day at a location.

Parameter ↓	Type of Solar Cooker and Typical value of T_{fmax} ↓							
	SBC				SPD-SCC			
Type of cooking pot →	Non coated pot		Matt Black Coated pot		Non coated pot		Matt Black Coated pot	
Type of test load →	DEG	Glycerin	DEG	Glycerin	DEG	Glycerin	DEG	Glycerin
Highest Achievable Load Temperature (T_{fmax}) (°C)	171.7	162.9	188.2	191.4	183.7	173.3	NA	247.8

Table 6
Typical values of the Reference time, τ_R and its percentage (%) deviation in the theoretical and experimental values for a typical day at a location.

Type of Solar cooker↓	Typical Value of Reference Time (in minutes)								
	DEG			Glycerin			Water		
	Theoretical	Experimental/ Observed	Percentage (%) Deviation	Theoretical	Experimental/ Observed	Percentage (%) Deviation	Theoretical	Experimental/ Observed	Percentage (%) Deviation
SBC with non-coated pot	61	63	± 3.45%	70	72	± 3.50%	66	68	± 3.94%
SBC with Matt Black coated pot	57	52	± 4.47%	51	49	± 5.46%	NA	NA	NA
SPD-SCC with non-coated pot	52	55	± 4.11%	53	54	± 3.25%	60	63	± 3.80%
SPD-SCC with Matt Black coated pot	NA	NA	NA	23	27	± 7.02%	NA	NA	NA

other design changes in SBCs. Hence, it is concluded that the use of proposed test loads allows the users to choose a particular design of solar cookers according to their food/cooking preference. Also, the experimental results verify that COR is independent of the type of test load/fluid and one of the useful, satisfactorily stable and effective TPP for rating/grading of solar cookers at low as well as intermediate temperatures. Finally, it is expected to ensure faster propagation of solar cooking technology.

Appendix A

A.1. Definition of Cooker Opto-Thermal Ratio

COR is defined as a ratio of the product of optical efficiency and concentration of given design of solar cooker to the heat loss factor and expressed by Eq. (A1) (Lahkar et al., 2012). COR is derived from the HWB equation at the apparent stagnation temperature of the fluid for a given ambient condition and irradiation level.

$$COR = \frac{\eta_0 C}{U_l} \tag{A1}$$

A.2. Highest achievable load temperature

Highest achievable load temperature, T_{fmax} is the highest temperature attained by the test load for a specific design of solar cooker under a given meteorological condition of a location (Lahkar et al., 2012). The theoretical value of T_{fmax} can be calculated for the solar cookers using the equation (A2) (Lahkar et al., 2012) on an experimental day at a location.

$$T_{fmax} = \bar{T}_a + COR(\bar{G}_T) \tag{A2}$$

Appendix B

B.1. Identification of apparent stagnation temperature of the test loads

It is evident that, after the solar noon at a location, the rate of heat addition to the test load slows down because of reduced solar radiation. Therefore, the rise in temperature of test load starts to retard. It may lead to incorrect identification of apparent stagnation temperature of test load. It is important to note that an error in the identification of apparent stagnation temperature below the actual stagnation temperature for both the solar cookers SBC and SPD-SCC may result in deviation of the COR values. From Figs. 2a, 3a, 4a and 5a, it can be seen that near the apparent stagnation temperature the slope of the heating curve starts decreasing. Table B.1 indicates the deviation in the value of COR for four different identification errors in actual stagnation temperature of test loads. It can be seen that the maximum deviation in COR is 16.26% for the case of SBC

Table B1
Estimated deviation of the value of COR for SBC and SPD-SCC using non-coated cooking pots with the error in the identification of apparent stagnation temperatures of test loads.

Type of Solar Cooker	SBC				SPD-SCC			
Error in the identification of apparent stagnation temperature below the actual stagnation temperature	3 °C	5 °C	7 °C	10 °C	3 °C	5 °C	7 °C	10 °C
COR value using DEG	0.1393	0.1438	0.1494	0.1577	0.1452	0.1467	0.1503	0.1548
Percentage (%) deviation in estimation of COR value using DEG	4.40	7.43	10.88	15.59	1.85	2.84	5.18	7.94
COR value using glycerin	0.1403	0.1485	0.1503	0.1566	0.1459	0.1496	0.1540	0.1585
Percentage (%) deviation in estimation of COR value using glycerin	6.53	11.69	12.75	16.26	3.10	5.48	8.22	10.82

using glycerin as a test load and for 10 °C deviation in an identification of apparent stagnation temperature. For SPD-SCC the errors are relatively less. Hence, it is recommended to allow the temperature to rise such that it is below, but close to the stagnation temperature of the test load.

Appendix C

A Differential Scanning Calorimetry and Thermogravimetric Analysis (DSC-TGA), and Differential Thermal Analysis (DTA) of test loads (DEG and Glycerin) were carried out for understanding their thermal behavior. A 34.455 mg sample of glycerin and 8.195 mg of DEG were analyzed using DSC-TGA (TA instruments, Model: SDT Q600 V20.9 Build 20). The samples were heated from 30 °C to 350 °C at a ramping rate of 10 °C/minute in the air atmosphere. The results are depicted in Figs. C1 and C2 for DEG and glycerin, respectively.

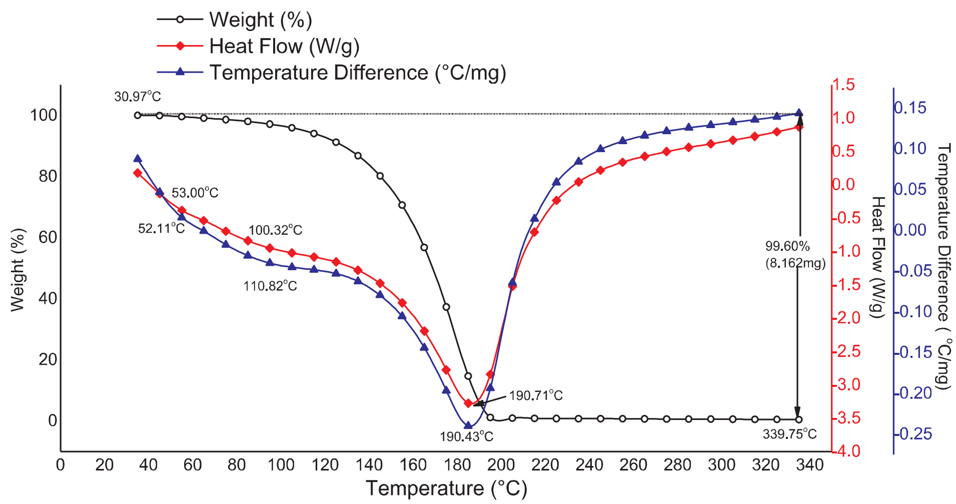

Fig. C1. DSC-TGA and DTA of DEG.

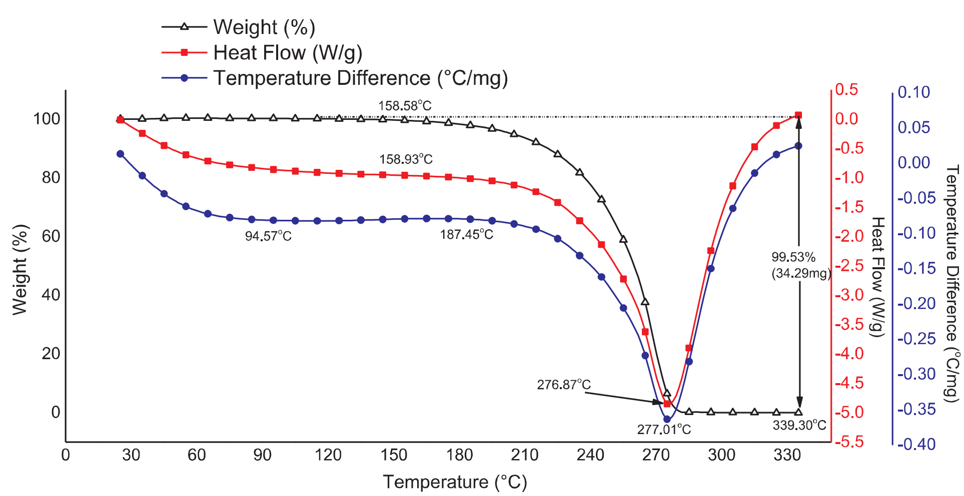

Fig. C2. DSC-TGA and DTA of Glycerin.

It can be seen from Fig. C1 that after an initial increase in the rate of heat flow in the sample to 53 °C, there is another sharper increase at about 190.43 °C. The later change corresponds to sharp weight loss indicating a change in phase at 190.43 °C. This temperature provides the upper limit of the use of the test load DEG. The corresponding DTA plot, shown in Fig. C1, also supports the conclusion. In the entire temperature range including the intermediate temperature, the calorific value of DEG remains approximately unchanged.

Fig. C2 illustrates the DSC-TGA and DTA curves of glycerin. It can be seen from the Fig. C2 that, the rate of heat flow is faster until around 53 °C and afterward, remains steady till the temperature reaches around 210 °C. A sharp increase can be seen in the heat flow at around 276.87 °C with rapid loss of weight indicating a change in phase. The DSC exothermic peak can be seen at 276.87 °C indicating the upper limit of glycerin usage. The corresponding DTA plot, shown in Fig. C2, supports the conclusion and indicates that the vapor phase has a lower heat capacity (C_p) than the liquid phase. Also, the calorific value of glycerin remains approximately identical for the entire range of temperature including the intermediate temperature.

Thus, in a thermal system, the impact of small variation in the heat capacity in the selected temperature range of the test loads is not expected to be high on the temperature of the test fluid/load. Also, in the calculations for a given temperature range, an average value of heat capacity has been taken which with a high mass of test load will have a low impact on the overall result.

References

Aman, D., 1985. An analytical study of a solar cooker augmented with a booster mirror using PCM as storage. Energy Convers. Manage. 25 (3), 255–261.

Balzar, A., Stumpf, P., Eckhoff, S., Ackermann, H., Grupp, M., 1996. A solar cooker using vacuum-tube collectors with integrated heat pipes. Sol. Energy 63–68. http://dx.doi.org/10.1016/0038-092X(96)00024-2.

Beaumont, G., Eiloart, T., Robinson, P., 1997. Ultra low cost solar cookers: design details and field trials in Tanzania. Renew. Energy 10, 635–640. http://dx.doi.org/10.1016/S0960-1481(96)00038-9.

BIS., 2000. Indian Standards for solar cookers: IS13429 (PART 1,2,3). Bureau of Indian Standards. Manak Bhavan, New Delhi-110002.

Buddhi, D., Sahoo, L.K., 1997. Solar cooker with latent heat storage: Design and experimental testing. Energy Convers. Manage. 38 (5), 493–498.

Buddhi, D., Sharma, S.D., Sharma, A., 2003. Thermal performance evaluation of a latent heat storage unit for late evening cooking in a solar cooker having three reflectors. Energy Convers. Manage. 44 (6), 809–817.

Chandak, A., 2010. Apparatus for Testing Solar Concentrators. Indian Patent.

Coccia, G., Di Nicola, G., Pierantozzi, M., Tomassetti, S., Aquilanti, A., 2017. Design, manufacturing, and test of a high concentration ratio solar box cooker with multiple reflectors. Sol. Energy 155, 781–792. http://dx.doi.org/10.1016/j.solener.2017.07.020.

Craig, O.O., Dobson, R.T., 2016. Parabolic solar cooker: Cooking with heat pipe vs direct spiral copper tubes. AIP Conf. Proc. 10 (1063/1), 4949245.

Craig, O.O., Dobson, R.T., 2017. A novel indirect parabolic solar cooker. J. Electr. Eng. 5, 137–142. http://dx.doi.org/10.17265/2328-2223/2017.03.003.

Cuce, E., Cuce, P.M., 2013. A comprehensive review on solar cookers. Appl. Energy 102, 1399–1421. http://dx.doi.org/10.1016/j.apenergy.2012.09.002.

Domanski, R., El-Sebaii, A.A., Jaworski, M., 1995. Cooking during off-sunshine hours using PCMs as storage media. Energy 20, 607–616. http://dx.doi.org/10.1016/0360-5442(95)00012-6.

Ekechukwu, O.V., Ugwuoke, N.T., 2003. Design and measured performance of a plane reflector augmented box-type solar-energy cooker. Renew. Energy 28, 1935–1952. http://dx.doi.org/10.1016/S0960-1481(03)00004-1.

El-Sebaii, A.A., Domanski, R., Jaworski, M., 1994. Experimental and theoretical investigation of a box-type solar cooker with multi-step inner reflectors. Energy 19, 1011–1121.

Esen, M., 2004. Thermal performance of a solar cooker integrated vacuum-tube collector with heat pipes containing different refrigerants. Sol. Energy 76, 751–757. http://dx.doi.org/10.1016/j.solener.2003.12.009.

Esen, M., Hazar, H., Esen, H., 2005. Experimental investigation of a solar cooker using collector with heat pipes. J. Eng. Nat. Sci. 1, 114–122.

Farooqui, S.Z., 2013. A vacuum tube based improved solar cooker. Sustain. Energy Technol. Assess. 3, 33–39. http://dx.doi.org/10.1016/j.seta.2013.05.004.

Funk, P.A., Larson, D.L., 1998. Parametric model of solar cooker performance. Sol. Energy 62, 63–68. http://dx.doi.org/10.1016/S0038-092X(97)00074-1.

Geddam, S., Dinesh, G.K., Sivasankar, T., 2015. Determination of thermal performance of a box type solar cooker. Sol. Energy 113, 324–331. http://dx.doi.org/10.1016/j.solener.2015.01.014.

Haraksingh, I., Mc Doom, I.a., Headley, O.S.C., 1996. A natural convection flat-plate collector solar cooker with short term storage. Renew. Energy 9, 729–732. http://dx.doi.org/10.1016/0960-1481(96)88387-X.

Harmim, A., Boukar, M., Amar, M., 2008. Experimental study of a double exposure solar cooker with finned cooking vessel. Sol. Energy 82, 287–289. http://dx.doi.org/10.1016/j.solener.2007.10.008.

Harmim, A., Merzouk, M., Boukar, M., Amar, M., 2012. Performance study of a box-type solar cooker employing an asymmetric compound parabolic concentrator. Energy 47, 471–480. http://dx.doi.org/10.1016/j.energy.2012.09.037.

http://www1.lsbu.ac.uk/water/water_unexpected.html.

Hussein, H.M.S., El-Ghetany, H.H., Nada, S.A., 2008. Experimental investigation of novel indirect solar cooker. Energy Convers. Manage. 49, 2237–2246. http://dx.doi.org/10.1016/j.enconman.2008.01.026.

Joshi, S.B., Jani, A.R., 2015. Design, development and testing of a small scale hybrid solar cooker. Sol. Energy 122, 148–155. http://dx.doi.org/10.1016/j.solener.2015.08.025.

Kaushik, S.C., Gupta, M.K., 2008. Energy and exergy efficiency comparison of community size and domestic size paraboloidal solar cooker performance. Energy Sustain. Dev. 9 (3), 60–74.

Kim, Y.S., Balkoski, K., Jiang, L., Winston, R., 2013. Efficient stationary solar thermal collector systems operating at a medium-temperature range. Appl. Energy 111, 1071–1079. http://dx.doi.org/10.1016/j.apenergy.2013.06.051.

Kumar, S., 2004. Thermal performance study of box type solar cooker from heating characteristic curves. Energy Convers. Manage. 45, 127–139. http://dx.doi.org/10.1016/S0196-8904(03)00103-1.

Kumar, R., Adhikari, R.S., Garg, H.P., Kumar, A., 2001. Thermal performance of a solar pressure cooker based on evacuated tube solar collector. Appl. Therm. Eng. 21, 1699–1706. http://dx.doi.org/10.1016/S1359-4311(01)00018-7.

Kumar, N., Chavda, T., Mistry, H.N., 2010. A Truncated pyramid non-tracking type multipurpose domestic solar cooker/hot water system. Appl. Energy 87, 471–477. http://dx.doi.org/10.1016/j.apenergy.2009.06.031.

Kumar, S., Kandpal, T.C., Mullick, S.C., 1993. Heat losses from a paraboloid concentrator solar cooker: Experimental investigations on effect of reflector orientation. Renew. Energy 3, 871–876. http://dx.doi.org/10.1016/0960-1481(93)90044-H.

Kumar, S., Kandpal, T.C., Mullick, S.C., 1994. Effect of wind on the thermal performance of a paraboloid concentrator solar cooker. Renew. Energy 4 (3), 333–337.

Kumar, S., Kandpal, T.C., Mullick, S.C., 1996. Experimental test procedures for determination of the optical efficiency factor of a paraboloid concentrator solar cooker. Renew. Energy 7 (2), 145–151.

Kundapur, A., 1998. Review of solar cooker designs. TIDE 8, 1–37.

Kurt, H., Deniz, E., Recebli, Z., 2008. An Investigation into the effects of box geometries on the thermal performance of solar cookers. Int. J. Green Energy 5, 508–519. http://dx.doi.org/10.1080/15435070802498473.

Lahkar, P.J., Samdarshi, S.K., 2010. A review of the thermal performance parameters of box type solar cookers and identification of their correlations. Renew. Sustain. Energy Rev. 14, 1615–1621. http://dx.doi.org/10.1016/j.rser.2010.02.009.

Lahkar, P.J., Bhamu, R.K., Samdarshi, S.K., 2012. Enabling inter-cooker thermal performance comparison based on cooker opto-thermal ratio (COR). Appl. Energy 99, 491–495. http://dx.doi.org/10.1016/j.apenergy.2012.05.034.

Lecuona, A., Nogueiram, J.I., Ventas, R., Rodrguez-Hidalgo, M del, C., Legrand, M., 2013. Solar cooker of the portable parabolic type incorporating heat storage based on PCM. Appl. Energy 111, 1136–1146. http://dx.doi.org/10.1016/j.apenergy.2013.01.083.

Lof, G.O.G., 1963. Recent investigations in the use of solar energy for cooking. Sol. Energy 7, 125–135.

Lokeswaran, S., Eswaramoorthy, M., 2012. Experimental studies on solar parabolic dish cooker with porous medium. Appl. Solar Energy 48 (3), 169–174. http://dx.doi.org/10.3103/S0003701X12030097.

Mahavar, S., Sengar, N., Rajawat, P., Verma, M., Dashora, P., 2012. Design, development and performance studies of a novel Single Family Solar Cooker. Renew. Energy 47, 67–76. http://dx.doi.org/10.1016/j.renene.2012.04.013.

Mahavar, S., Sengar, N., Rajawat, P., Verma, M., Dashora, P., 2015. Evaluating the optimum load range for box-type solar cookers. Renew. Energy 74, 187–194. http://dx.doi.org/10.1016/j.renene.2014.08.003.

Mirdha, U.S., Dhariwal, S.R., 2008. Design optimization of solar cooker. Renew. Energy 33, 530–544. http://dx.doi.org/10.1016/j.renene.2007.04.009.

Mullick, S.C., Kandpal, T.C., Saxena, A.K., 1987. Thermal test procedure for box-type solar cookers. Sol. Energy 39, 353–360. http://dx.doi.org/10.1016/S0038-092X(87)80021-X.

Mullick, S.C., Kandpal, T.C., Kumar, S., 1991. Thermal test procedure for a paraboloid concentrator solar cooker. Sol. Energy 46, 139–144. http://dx.doi.org/10.1016/0038-092X(91)90087-D.

Nahar, N.M., 2003. Performance and testing of a hot box storage solar cooker. Energy Convers. Manage. 44, 1323–1331. http://dx.doi.org/10.1016/S0196-8904(02)00113-9.

Nahar, N.M., Marshall, R.H., Brinkworth, B.J., 1994. Studies on a hot box solar cooker with transparent insulation materials. Energy Convers. Manage. 35, 787–791. http://dx.doi.org/10.1016/0196-8904(94)90107-4.

Öztürk, H.H., 2004. Experimental determination of energy and exergy efficiency of the solar parabolic-cooker. Sol. Energy 77, 67–71. http://dx.doi.org/10.1016/j.solener.2004.03.006.

Ozturk, H.H., 2007. Comparison of energy and exergy efficiency for solar box and parabolic cookers. J. Energy Eng. 133, 53–62.

Sagade, A.A., Samdarshi, S.K., Panja, P.S., 2018. Experimental determination of effective concentration ratio for solar box cookers using thermal tests. Sol. Energy 159, 984–991.

Sardeshpande, V.R., Chandak, A.G., Pillai, I.R., 2011. Procedure for thermal performance evaluation of steam generating point-focus solar concentrators. Sol. Energy 85, 1390–1398. http://dx.doi.org/10.1016/j.solener.2011.03.018.

Sharma, S., Buddhi, D., Sawhney, R., 1999. Accelerated thermal cycle test of latent heat-storage materials. Sol. Energy 66, 483–490. http://dx.doi.org/10.1016/S0038-092X(99)00045-6.

Sharma, S.D., Buddhi, D., Sawhney, R.L., Sharma, A., 2000. Design, development and performance evaluation of a latent heat storage unit for evening cooking in a solar cooker. Energy Convers. Manage. 41, 1497–1508. http://dx.doi.org/10.1016/S0196-8904(99)00193-4.

Sharma, S.D., Iwata, T., Kitano, H., Sagara, K., 2005. Thermal performance of a solar cooker based on an evacuated tube solar collector with a PCM storage unit. Sol. Energy 78, 416–426. http://dx.doi.org/10.1016/j.solener.2004.08.001.

Sharma, A., Tyagi, V.V., Chen, C.R., Buddhi, D., 2009. Review on thermal energy storage with phase change materials and applications. Renew. Sustain. Energy Rev. 13, 318–345. http://dx.doi.org/10.1016/j.rser.2007.10.005.

Singh, H., Gagandeep, Saini, K., Yadav, A., 2015. Experimental comparison of different heat transfer fluid for thermal performance of a solar cooker based on evacuated tube collector. Environ. Dev. Sustain. 17, 497–511. http://dx.doi.org/10.1007/s10668-014-9556-3.

Sonune, A.V., Philip, S.K., 2003. Development of a domestic concentrating cooker. Renew. Energy 28, 1225–1234. http://dx.doi.org/10.1016/S0960148102001878.

Stumpf, P., Balzar, A., Eisenmann, W., Wendt, S., Ackermann, H., Vajen, K., 2001. Comparative measurements and theoretical modelling of single- and double-stage heat pipe coupled solar cooking systems for high temperatures. Sol. Energy 71, 1–10. http://dx.doi.org/10.1016/S0038-092X(01)00026-3.

Suhail, Z.F., 2013. A gravity based tracking system for box type solar cookers. Sol. Energy 2013 (92), 62–68.

Suharta, H., Abdullah, K., Sayigh, A., 1998. The solar oven: Development and field-testing of user-made designs in Indonesia. Sol. Energy 64, 121–132. http://dx.doi.org/10.1016/S0038-092X(98)00096-6.

Tiwari, G.N., Yadav, Y.P., 1986. A new solar cooker design. Energy Convers. Manage. 26 (1), 41–42.

Zamani, H., Moghiman, M., Kianifar, A., 2015. Optimization of the parabolic mirror position in a solar cooker using the response surface method (RSM). Renew. Energy 81, 753–759. http://dx.doi.org/10.1016/j.renene.2015.03.064.