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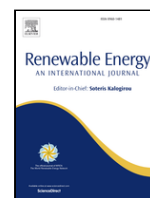3 PUBLICATIONS   1 CITATION

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Experimental determination of the thermal performance of a solar box cooker with a modified cooking pot

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ABSTRACT

The performance improvement of the solar box cookers is possible using different techniques and design changes. One of them is new or advanced designs of cooking utensil/pot. New designs of the cooking pot enhance the heat transfer to the food leading to reduced cooking time. The present work depicts the performance of a Solar Box Cooker (SBC) using a modified cooking pot (MCP). The SBC is tested with new design of the cooking pot equipped with top glazed lid. The COR is used as a thermal performance parameter (TPP) and determined experimentally using heating and open sun cooling tests. The inter-cooker performance comparison of the SBC is done using a newly designed MCP and a conventional cooking pot (CCP).It is shown that the thermal performance of a solar box cooker (SBC) improves with a modified cooking pot (MCP) because of reduction in heat loss with the additional benefit of visualization of the solar cooking activity.

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1. Introduction

Many designs of solar box cookers (SBCs) have been designed, fabricated and investigated to enhance their thermal performance using different techniques. Some of them are alterations in the geometries of SBCs and cooking pots; addition of booster mirrors in SBCs; heat augmentation techniques for SBCs and heat storage arrangements using different materials. Some studies focus on the modified or advance design of cooking pots. In the case of SBCs, one or more pots are kept at the center of the absorber plate/tray to achieve the desired and effective contact between the pots/vessels and the absorber plate/tray in order to increase the rate of heat transfer by conduction between the absorber plate and the cooking vessels and transfer it to the food being cooked. Generally, conventional cylindrical or rectangular shaped cooking pots/vessels made of aluminium or copper are preferred for the cooking in a SBC, although any type of them can be used in SBCs. The surface of pots/vessels is generally coated/painted black to enhance the opto-thermal performance. The number of vessels can be varied according to the quantity and nature of food. The heat transfer into the cooking pot in different designs of solar cookers has been the subject of several experimental and theoretical studies (Grupp et al. [1]; Binark and Turkmen [2]; Nahar, 2001 [3]; Amer, 2003 [4]; Ekechukwu and Ugwuoke [5]; Narasimha Rao and Subramanyam [6]; N and Purohit [7]; Petela [8]; Sagade et al. [9]; Bhave and Thakare [22] and Rekha and Sukhchi [23]). The results of these studies indicate that typical cooking times in the case of the SBCs are ~ 2–3 h and 1–2 h for the solar concentrating cookers (SCCs). Thus, the heat augmentation to the food item being cooked in a typical design of a solar cooker is possible using the modifications in the shape/geometries of the cooking pot/vessel leading to a reduction in the reference cooking time. Gaur et al. [10] investigated a SBC using a cooking vessel provided with a concave lid. Their results showed a reduction of 10–13% in the cooking time compared to conventional cooking vessel under the same conditions. Narasimha Rao and Subramanyam [11] showed that the cooking time can be reduced by increasing the effective area of heat transfer into the food item using a central annular cavity cooking pot. Harmim et al. [12] used a finned cooking pot to reduce the cooking time of a double exposure SBC. Sethi et al. [13] reported the comparative performance SBC with a conventional and parallel piped cooking vessel.

Although several studies have been reported in the literature, it can be seen that the cooking pot design changes were incorporated and studied at low temperature (~100 °C) using the relevant thermal performance parameters (TPPs). Also the evidence of using modified cooking pots with metallic container-glass/glazed lids for solar cooker and their detailed analysis is scarce as reported in re-

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cent literature. Thus, the objective of the present study is to investigate amodified design of the conventional cooking pot with a glass lid for the SBC with the motive to i) increase heat gain and heat transfer to the food item in the solar box cooker; ii) study the possibility of reducing the heat loss characteristics and reference cooking time for a particular design of solar cooker; iii) impact on the TPP value of the solar cooker to enable performance rating.

2. Basic theory

Glass is transparent in the solar range and opaque to infrared radiation (Duffie and Backman, [14]). Thermal properties of the glass cover such as absorptance, transmittance, and reflectance are functions of wavelength, angle of incidence of the incoming solar radiation etc. Thus glass can be used as a lid for cooking pot, because it absorbs almost all the infrared radiation re-emitted by the inner part of the cooking pot, it is expected to result in an enhancement of the thermal efficiency of the cooking pot (Khoukhi and Maruyama [15]). Hence the proposed design of cooking pot with the glass lid–metallic container allows the advantages of the conventional cooking pot too.

It is also expected that the proposed modified design of the cooking pot may enable the reduction in heat loss by keeping the heat gain constant. Because, glass has certain properties like the effective transmission of the shorter wavelength solar radiation and blocking the longer wavelength re-radiation from the cooking pot. In the case of a SBC, the radiation falling on the top of the lid will be trapped and directly absorbed by the food item kept in the cooking pot. Thus, the conduction and radiative heat loss will be reduced. It also reduces the heat loss by convection from the cooking item in the cooking pot. Another advantage of having such designs is that the visualization of the cooking activity. It will facilitate the person to observe the condition of the food being cooked. However, the disadvantage of cracking of glass can be minimized by using toughened/tempered glass (Goswami et al., [16]).

2.1. Modified design of cooking pot/s

In the present work, an advance design of the cooking pot is designed and fabricated. Here, the container of CCP (made up of stainless steel cooking pot) is kept metallic and top/lid is replaced with a glass as shown in the Figure 1c The middle portion of the metallic lid of CCP is cut and retrofitted with a single glass top of 3.5 mm thickness and sealed properly using an appropriate high temperature sealant (Urja Sealants Pvt. Ltd, India). It makes them workable at low (~100 °C) as well as intermediate to high temperatures (120–300 °C).

This configuration increases the possibility of i) direct addition of heat from solar radiation to the food item placed in the cooking vessel ii) reduced heat losses and iii) visualization of the solar cooking activity. Also, use of two cooking pots in aSBC enables the inter-cooker thermal performance comparison.

This design of a modified cooking pot (hereafter denoted as MCP) with the metallic container maintains the advantage of conventional cooking pot (hereafter denoted as CCP) also. In the case of a SBC-CCP combination, the food item kept in the cooking pot is heated from the side and top of the container by the hot air trapped in the cooker interior. The bottom of the cooking pot receives heat from the absorber plate by conduction.

In the process of cooking, the food being cooked is converted to semi solid state after the initial phase of heat distribution. A temperature gradient is set up in the food and temperature will be high at the wall of the cooking pot. As the process of cooking progresses, the temperature decreases as the distance of food from the wall increases and even may reach a level which is insufficient to carry forward the cooking process (Narasimha Rao and Subra-
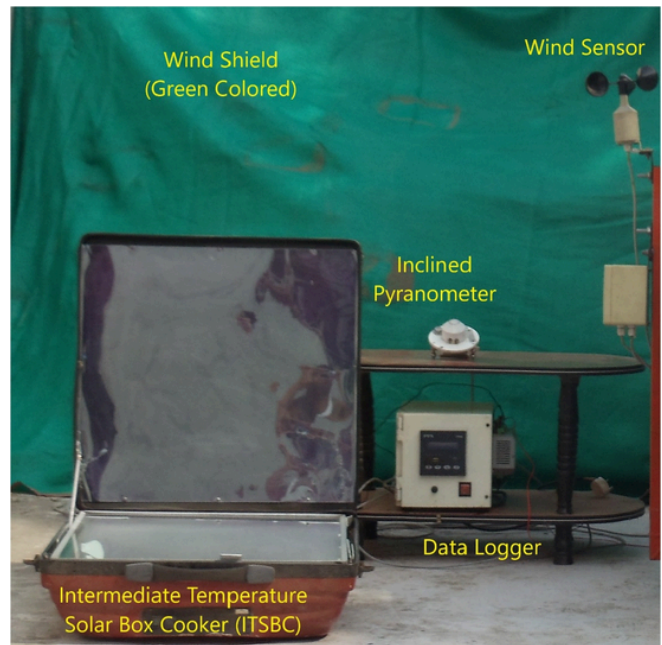

Fig. 1a. Experimental test setup for the SBC.

Fig. 1b. Conventional Cooking Pot with the metallic lid.

manyam, [11]). Thus, the use of the MCP with a glass lid may avoid this difficulty partially. The glass will help to absorb heat energy directly from the source and the entire food material will get an equal amount of heat. Condensation of vapor on the glass top of the lid may limit the transmissivity of glass during the final stages of cooking (Tiwari, [17])

3. Experimental details

In the present experiments, the SBC used previously by Sagade et al. ([9,18,19]), has been tested with modified cooking pot (MCP) with glass lid. Open sun cooling tests (Sagade et al., [19]) were conducted to determine the realistic value of the thermal performance parameter (TPP), i.e. Cooker Opto-Thermal Ratio (COR). Also, thermal heating tests (Sagade et al., [18]) were conducted to verify the results. Glycerin (Sagade et al. [18,19]) was used as an intermediate temperature test load and loaded in single a MCP only. As suggested by Sagade et al. [19], a standard specific ther-

mal load (SSTL) of 10.46 kJ/$^{\circ}$C of Glycerin per m^2 of the cooker aperture area is used for the experiments. The mean value of COR was used to interpret the inter-cooker performance comparison.

Temperatures of the test load, absorber plate and ambient air were measured using J-type temperature sensors. Solar radiation and wind velocity were measured using a pyranometer (Dynalab, India) and wind sensor (Dynalab, India), respectively. All the measuring instruments were wired to a data logger (Unilog, India) and measurements were recorded at an interval of 90 s. During tests, the SBC was manually oriented according to azimuth in order to collect the maximum of solar radiation on the cooker aperture area.

The experimental data was used to find the value of $\dot{Q}''$ using equation (1) (Lahkar et al., 2012; Sagade et al. [19]) as

$$\pm \dot{Q}'' = \frac{\left(M_f C_{pf}\right)'_f \ \left(T_{f2} - T_{f1}\right)}{A_p \Delta t} \tag{1}$$

where, $+\dot{Q}''$ is the rate of useful heat gain (for heating tests) and $-\dot{Q}''$ is rate of heat loss (for open sun cooling tests), respectively, by the test load in the case of heating test and cooling test, respectively per unit aperture area of the SBC.

The experimental data was used to plot exponential and linear plots of temperature of the test load (T_{Gly}) vs. Time and $\frac{Q''}{\bar{G}_T}$ vs. $\frac{\left(T_{m(Gly)} - \bar{T}_a\right)}{\bar{G}_T}$, respectively, for the heating test and temperature of the test load (T_{Gly}) vs. Time and $-\frac{Q''}{\bar{G}_T}$ vs. $\frac{\left(T_{m(Gly)} - \bar{T}_a\right)}{\bar{G}_T}$, respectively, for the open sun cooling test on the SBC-MCP combination. Here, the exponential relation, generated through a fit between temperature of the test load and time, is used in the eq.(1). Thereafter, the diffrence between T_{f1} and T_{f2} for a time interval Δt is taken from the generated relation/plot to calculate Q" value for that time interval and mean of the same T_{f1} and T_{f2} (i.e. $T_{m(Gly)}$) is used in the further analysis using relevant plot. The value intercept, $F'\eta_o$ and slope, $F'U_l/C$ of the each linear plot was used to estimate value of COR for the SBC. The value of COR was used to estimate the values of the COR dependent objective parameters, reference time (τ_R), highest achievable load temperature (T_{fmax}) and heat retention time (τ_{hr}) for the SBC at a given location on a typical experimental day.

The experiments were conducted at a location (17.66°N; 75.32°E) around $\pm$ 90 min of the local solar noon; under test conditions as $\bar{G}_T \geq$ 700 W/m^2, 20 $^{\circ}$C $\leq \bar{T}_a \leq$ 40 $^{\circ}$C and wind velocity $\leq$1.5 m/s. The average of the ambient air temperature ($\bar{T}_a$) and the total solar radiation ($\bar{G}_T$) was taken for the complete duration of the heating tests or open sun cooling i.e. for the entire period of the experiment on a typical day at a location and used in the calculations. Fig. 1a depicts the experimental test setup and Fig. 1b and c shows the conventional and modified cooking pot, respectively, used with the SBC in the present experimentation and Table 1 indicates the values of different parameters used in the determination of TPP, COR.

4. Results and discussions

Fig. 2a and b depict the plots of temperature of test load (T_{Gly}) vs. Time and corresponding linear fit of $\frac{Q''}{\bar{G}_T}$ vs. $\frac{\left(T_{m(Gly)} - \bar{T}_a\right)}{\bar{G}_T}$ for the open sun cooling tests. It is to be noted that the Y-axis of both Fig. 2a and b is set to offset (stack lines with constant) to avoid the overlapping of curves or lines. The experimental results of five typical experimental days at a location are shown here.

It is seen that the mean values of the $F'\eta_o$, $F'U_l/C$ and COR for SBC - MCP combination using the cooling test are estimated to be 0.805 $\pm$ 0.059, 5.453 $\pm$ 0.463, and 0.147 $\pm$ 0.0027 respectively,

Fig. 1c. Modified Cooking Pot (MCP) with the glass lid.

Table 1
Values of parameters used in the determination of TPP (COR) for SBC.

Parameter	Value for SBC
Mean value of Inclined aperture area of SBC (A_p) (m^2)	0.37
Area of Cooking Pot (A_{pot}) (m^2)	0.06
Glazed Area of Solar Cooker (A_{glz}) (m^2)	0.23
Geometric Concentration Ratio (C)	1.44 to 1.75
Effective Concentration Ratio (ECR) (Sagade et al., [9])	1.33
Material for Cooking Pot	Stainless Steel
Specific heat of Conventional Cooking Pot (CCP) (J/(kgK))	510
Specific heat of Modified Cooking Pot (MCP) (J/(kgK))	534
Specific heat of Glycerin (C_{pGly}) (J/(kgK))	3014
Mass of Glycerin in CCP (kg)	1.3
Mass of CCP (kg)	0.54
Mass of Glycerin in MCP (kg)	1.22
Mass of MCP (kg)	0.92

with percentage standard deviation of 7.31%, 8.49% and 1.83%, respectively and depicted in Table 2.

It is important to note that the detailed analysis of heating tests and open sun cooling tests with conventional cooking pot (CCP) were reported in the earlier work, Sagade et al. [18,19], respectively, therefore the repetition is avoided in the present work.

The value of the COR, determined experimentally from the cooling test is used to estimate the theoretical value of the heat retention time (τ_{hr}) (COR dependent objective parameter) on a typical experimental day at a location. τ_{hr} is dependent on the meteorological conditions of a location on a typical experimental day and seasonal variation is expected in their values. The details of the theoretical equation of τ_{hr} are given in Appendix A.

The typical theoretical value of τ_{hr} (using equation (A.4)) for a typical experimental day at a location is estimated to be 24 min.

Also, simple experiments were conducted for the experimental determination of heat retention time (τ_{hr}) for SBC – MCP combination as suggested by Sagade et al. [19]. A typical experimental value of τ_{hr} is seen to be 26 min. on a typical experimental day at a location., -
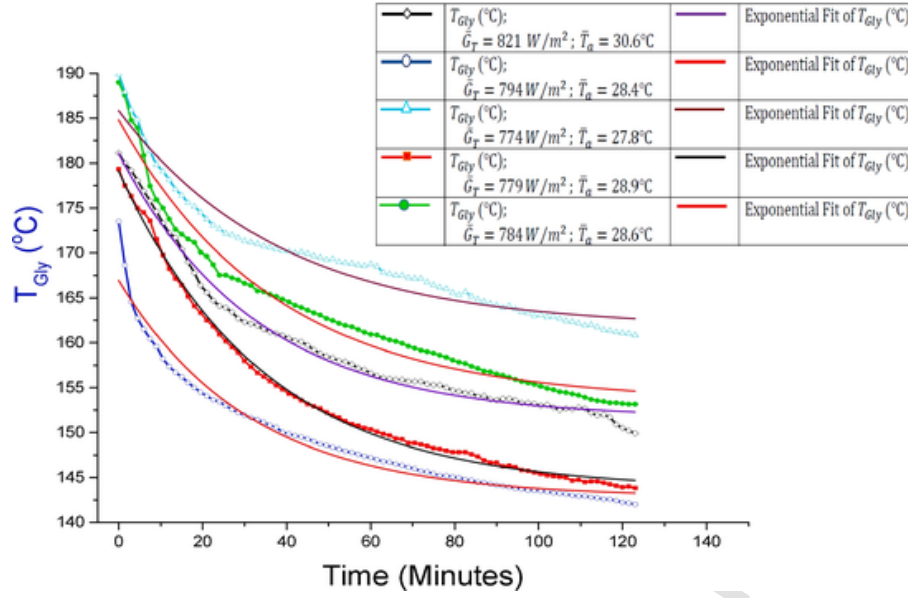
Fig. 2a. Plot of T_{Gly} vs. Time for the SBC- HPC with the glass lid for open sun cooling tests.
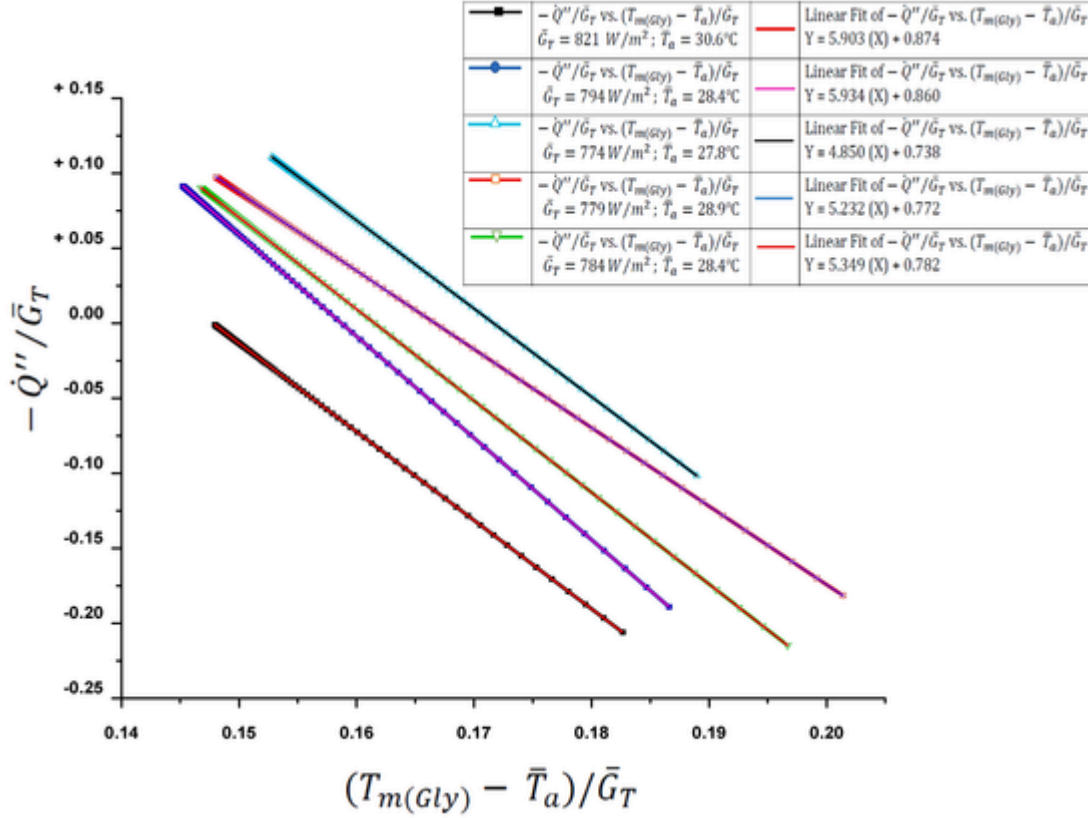
Fig. 2b. $-\dot{Q}''/\bar{G}_T$ vs. $\left(T_{m(Gly)} - \bar{T}_a\right)/\bar{G}_T$ plot for the SBC- HPC with the glass Lid for open sun cooling tests.

4.1. Heating tests for inter-cooker performance comparison

In order to confirm the test results of open sun cooling tests and design change, the experiments were conducted using the heating tests as reported earlier by Sagade et al., [18]. Although, an apprehension related to the heating tests was kept in the mind that the solar cooker may not always reach the desired high temperature stagnation in small window of three hours during the so-

lar noon on a typical experimental day at a location which is required for determination of the COR for an intermediate temperature solar cookers (Sagade et al. [18]). Also, the impact of fluctuation in the solar radiation level more than desirable due to cloud cover etc. for small the interval makes this case becomes realistic for any design of a solar cooker while evaluating the TPP (i.e. COR) using the heating tests. But it is expected that the COR may be able to identify and confirm the design change.

Table 2
Results of SBC using Cooling Tests.

Parameter	Results of the SBC using Cooling Test	
	MCP with a Glass Lid	CCP with a Metallic Lid (Sagade et al. [19])
Mean Value of $F'\eta_o$	0.805 ± 0.0589	0.867 ± 0.110
Mean Value of $F'U_l/C$	5.453 ± 0.463	6.258 ± 0.763
Mean Value of COR	0.147 ± 0.0027	0.138 ± 0.0011
Typical Value of T_{fmax} (°C)	152.2	143.4
Typical Theoretical Value of τ_{hr} (minutes)	26	22.4
Typical Experimental Value of τ_{hr} (minutes)	29	24

Fig. 3a and b shows the plots of the temperature of the test load (T_{Gly}) vs. Time and the corresponding linear fit of $\frac{Q''}{G_T}$ vs. $\frac{(T_{m(Gly)} - \bar{T}_a)}{\bar{G}_T}$ for the heating tests. It is to be noted that the Y-axis of both Fig. 3a and b is set to offset (stack lines with constant) to avoid the overlapping of curves or lines. It is seen that the mean values of the parameters $F'\eta_o$, $F'U_l/C$ and COR for the SBC-MCP combination using the heating test are estimated to be 0.254 ± 0.0171, 1.69 ± 0.118, and 0.150 ± 0.003 respectively, with percentage standard deviation of 6.73%, 6.95% and 1.88%, respectively. Table 3 depicts the comparison of experimental results for the SBC using both the cooking pots (MCP and CCP) and utilizing the heating tests (Sagade et al. [18]). The mean value of COR for the SBC-MCP is compared with that one for the SBC-CCP combination to gain an insight on the inter-cooker performance (Table 3). From Table 3, it can be seen that the COR is able to predict and confirm the design change precisely using heating tests too, although the change in the mean value is small.

The value of the COR, determined experimentally from the heating tests is used to estimate the two COR dependent objective parameters, highest achievable load temperature (T_{fmax}) and Reference Temperature (τ_R) on a typical experimental day at a location. These parameters are dependent on the meteorological conditions of a location on a typical experimental day and seasonal variation is expected in their values. The details of theoretical equations of T_{fmax} and τ_R and are given in Appendix A.

The typical value of T_{fmax} (determined using equation (A.2)) for the SBC-MCP combination is 162.1 °C. A percentage standard deviation of 3.73% is seen in the typical values of T_{fmax}. Also, the theoretically determined (using equation (A.3)) and experimentally observed values of τ_R are seen to be 48 and 47 min, respectively at a location on a typical experimental day. A percentage standard deviation in the typical values of τ_R is seen to be 6.38% (theoretical) and 9.51% (experimental), respectively. Thus, the heating test too confirms the improvement in the performance of the cooker with proposed design modification in the cooking pot. It can be seen from the typical values of objective parameters T_{fmax} and τ_R given in Table 3. The typical values of τ_R and T_{fmax} are less in the case of the SBC-MCP combination as compared to SBC-CCP combination. Thus, the heating tests confirm the results of open sun cooling tests and able to predict the inter-cooker performance comparison with reasonable accuracy.

5. Comparison of inter-cooker performance of the SBC

The present results of ITSBC - MCP combination are compared with the results of the SBC-CCP combination tested previously (Sagade et al. [18] and Sagade et al. [19]). The values of different experimental parameters, $F'\eta_o$, $F'U_l/C$, COR, T_{fmax}, τ_R and τ_{hr} determined for the ITSBC – MCP (present work) and the SBC - CCP with the metallic lid combination (Sagade et al. [18,19]) are compared to reach the conclusions on the inter-cooker performance comparison of the ITSBC.

From the analysis and comparison of the results of the cooling tests (Table 2) and the heating tests (Table 3), it is seen that the mean value of $F'U_l/C$ is lowered in the case of the SBC - MCP with the glass lid combination as compared to the SBC - CCP with the metal lid combination. This may be due to property of glass which blocks the longer wavelength re-radiation from the cooking pot. Moreover, a glass lid reduces the convective and conduction loss from the pot. The CCP with the metal lid absorbs a complete range of the spectrum, but has high conductivity, thus having more mean value of the $F'U_l/C$ than that for MCP with the glass lid.

Interestingly, contrary to expectation, an opposite picture is seen in the case of the $F'\eta_o$. It is less in the case of the SBC-HPC combination as compared to the SBC-CCP combination using both heating and cooling tests. It may be ascribed to the glass top of MCP which transmits only the shorter wavelength solar radia-
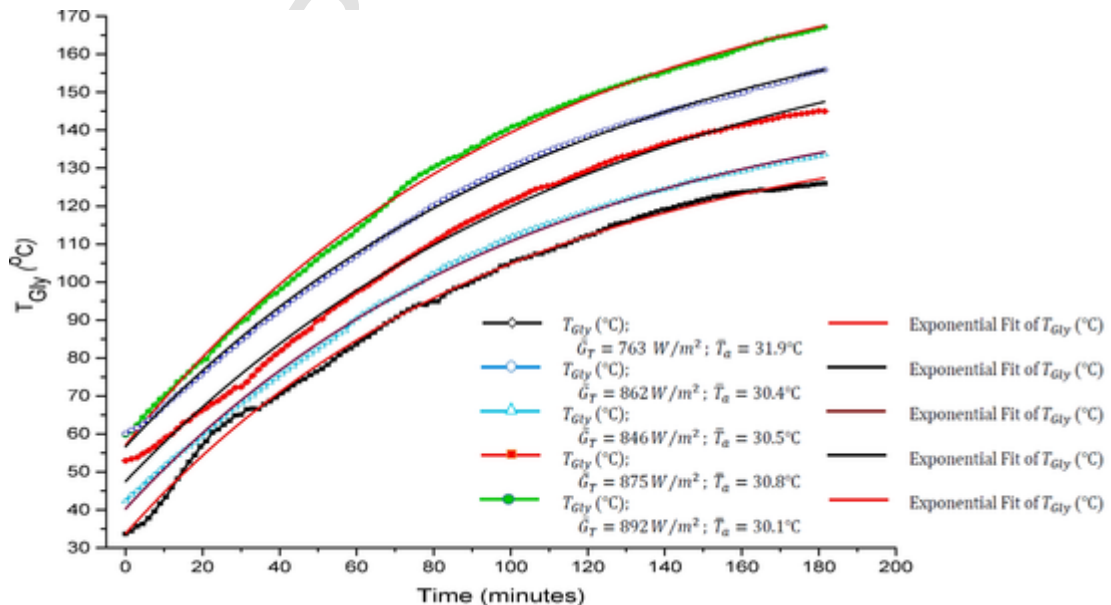
Fig. 3a. Plot of T_{Gly} vs. Time for SBC- HPC with Glass lid for heating tests.
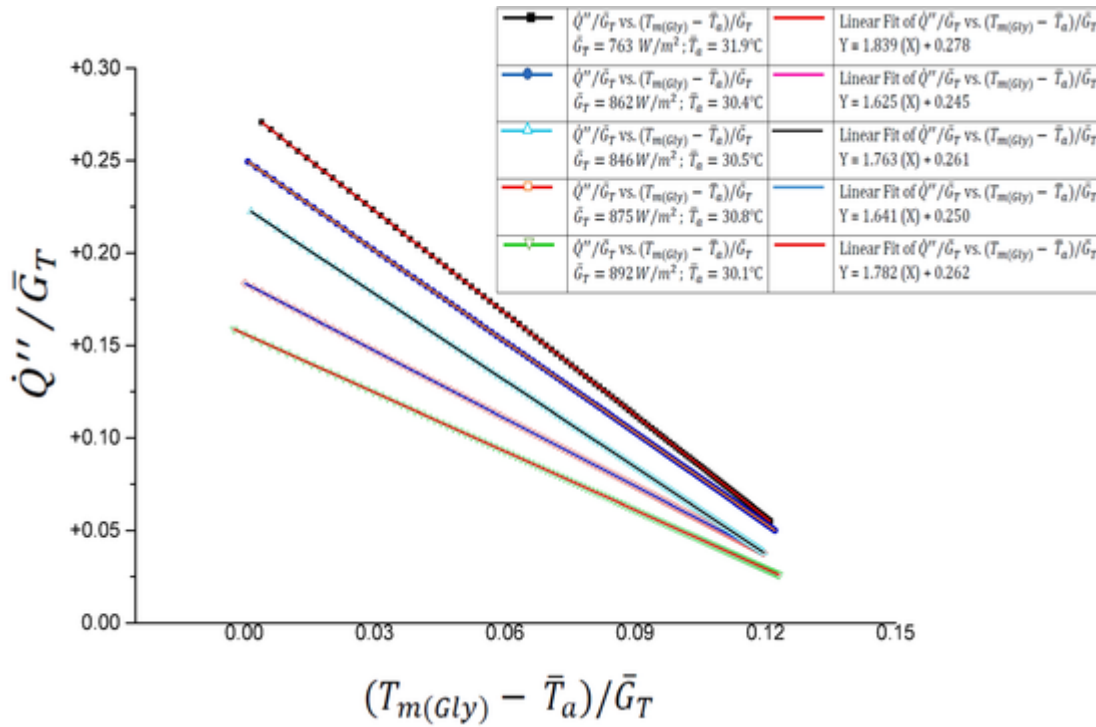
Fig. 3b. $\dot{Q}''/\bar{G}_T$ vs. $\left(T_{m(Gly)} - \bar{T}_a\right)/\bar{G}_T$ plot for SBC- HPC with Glass Lid for heating tests.

Table 3
Results of the heating tests.

Parameter	Results of theSBC using the Heating Tests	
	MCP with a Glass Lid	CCP with a Metallic Lid (Sagade et al. [18])
Mean Value of $F'\eta_o$	0.254 ± 0.0171	0.316 ± 0.030
Mean Value of $F'U_l/C$	1.696 ± 0.118	2.112 ± 0.220
Mean Value of COR	0.150 ± 0.003	0.148 ± 0.0015
Typical Value of T_{fmax} (°C)	162.9	157.3
Typical Theoretical Value of τ_R (minutes)	48	51
Typical Experimental Value of τ_R (minutes)	47	49

tion to pot. But low value of the $F'U_l/C$ in MCP with the glass lid more than compensates the loss in the $F'\eta_o$.

The small improvement in the performance of the cooker with proposed design modification in the pot can be seen from the three objective parameters given in Table 2 and 3. The typical value of the reference time, τ_R is less in the case of the SBC-MCP combination as compared to the SBC-CCP combination. The impact of a lower value of the $F'U_l/C$ is clearly visible for both the heating and the cooling tests. But the $F'\eta_o$ has minimum effect on the performance of the cooker in comparison to $F'U_l/C$. It has a positive impact on heat retention time (τ_{hr}) also. T_{fmax} is also higher in the SBC - MCP combination. As shown in Tables 2 and 3, the mean value of the COR for the SBC- MCP with the glass lid is higher as compared to the SBC - CCP with the metal lid for the heating as well as the cooling tests. Interestingly, the value of COR for the SBC-MCP combination utilizing the heating and the cooling tests is seen to approximately equal. It may be because of the lowered value of the $F'U_l/C$. Hence COR seems to be sufficient to reflect small design intervention in a solar cooker and able to predict the inter-cooker performance comparison as well.

5.1. Significance of combined linear fit of heating and open sun cooling tests in the case of SBC-MCP combination

The linear fit (Fig. 2b) plotted from the experimental data of the cooling test yields the higher values of $F'\eta_o$ in the present case too. Thus the sample combined linear fit plot of the heating and open sun cooling tests is plotted as suggested by Sagade et al. [19] to gain an insight on this issue. Fig. 4 depicts the sample combined linear fit plot for the SBC-MCP combination. From this plot the mean values of the parameters $F'\eta_o$, $F'U_l/C$ and COR are estimated to be 0.288 ± 0.011, 2.142 ± 0.010 and 0.134 ± 0.0034, respectively, for the SBC-MCP combination. The detailed analysis of combined linear fit was described earlier [19], hence avoided in the present case. It can be seen that the resultant mean values of the COR estimated from the combined linear fit plot and cooling tests for the SBC-MCP remains within an acceptable deviation of 10.66%. The resultant values of the parameter set $F'\eta_o$ and $F'U_l/C$ are also reasonably within an acceptable limit and near to that one with the heating tests (Table 3). It clearly indicate that the combined linear fit enables the realistic solution to the higher values of $F'\eta_o$ derived from the cooling test in the present case too. Also, the mean values of the COR estimated from combined linear fit plots in the present case (COR = 0.134 ± 0.0034 (SBC-MCP)) and earlier one (COR = 0.129 ± 0.0011 (Sagade et al. [19])) are compared in order to gain an insight on the inter-cooker performance. It can be seen that the both the values of COR satisfactorily differs from each other and able to provide sufficient information on inter-cooker performance comparison of SBC with two different pots i.e. MCP and CCP.

6. Conclusions

The new pot design shows marked improvement in the performance of the SBC. The efficient thermal barrier between the glass lid of the cooking pot and the surface above the test load in the pot obstructs the heat rejection through the glass lid from the pot inte-
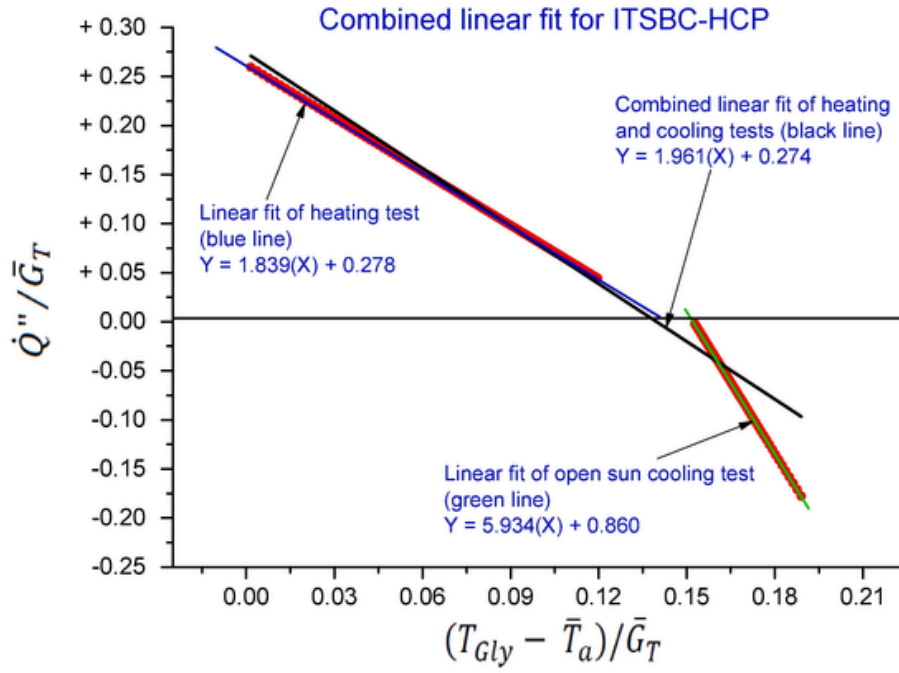
Fig. 4. Sample combined linear fit of heating and cooling test for the SBC with MCP.

rior. This is useful for the MCP having a glass lid as the heat loss is reduced. Even with very high test load temperatures the major factor is the low test load-glass temperature difference. Although a high test load temperature leads to higher evaporation, the low temperature difference results in a significantly reduced total energy transfer. Total energy transfer from the MCP may be further reduced by decreasing the value of thermal conductance of air in between the glass, but the combined effects of radiative and convective heat transfer across the air gap make it almost the same. This may be the reason which improves the performance of the cooker using the MCP.

Thus, two important conclusions may be drawn. One with regards to cooker performance improvement due to the pot lid design and another capability of the both test procedures (heating and cooling tests) and TPP to respond to design change; a) improvement in the performance of the cooker using MCP with glass lid is demonstrated; b) both heating and open sun cooling tests has been successfully used to unambiguously and explicitly quantify the improvement in cooker performance due to improvement in design of one of the components of the cooker.

These experiments provided some additional important information such as i) A glass lid may improve the performance of other such designs of the solar cookers as well; ii) Heating and cooling tests and the COR as a TPP may be used for the purpose of carrying out and studying the design modification in the solar cookers and the inter-cooker performance comparison.

CRediT author statement

Atul A. Sagade: Conceptualization, Methodology, Investigation, validation, formal analysis, Writing- Original draft preparation.

S.K.Samdarshi: Conceptualization, Methodology, Supervision, formal analysis, Writing- Reviewing and Editing.

P.J. Lahkar: Conceptualization, Methodology, Investigation, formal analysis, Data curation.

Narayani A. Sagade: Visualization, Investigation, Writing- Reviewing and Editing, Data curation.

Declaration of competing interest

We have no conflict of interest to declare.

Appendix - A.

Definition of Cooker Opto-Thermal Ratio (COR)

COR is defined as a ratio of product of optical efficiency and concentration ratio of a given design of the solar cooker to the heat loss factor and expressed by eq. (A.1) (Lahkar et al. [20],). COR is derived from the HWB equation at the apparent stagnation temperature of the test load under meteorological conditions of a location.

$$COR = \frac{\eta_0 C}{U_l} \tag{A.1}$$

Highest achievable load temperature (T_{fmax})

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} on a typical experimental day at a location can be determined for the solar cookers using equation (A.2) (Lahkar et al., [20]).

$$T_{fmax} = \bar{T}_a + COR \ (\bar{G}_T) \tag{A.2}$$

Reference Time (τ_R)

Reference Time, τ_R may be defined 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 (A.3) (Lahkar et al. [20], Sagade et al. [18],) which gives the theoretical time taken by the fluid to heat up from lower to upper limit of temperature under given meteorological conditions of a specified loca-

tion.

$$\tau_R = \frac{\left(M_f C_{pf}\right)'_f}{A_p F' \eta_o} \times COR \times \ln\left[\frac{\bar{G}_T - \frac{T_{f1} - \bar{T}_a}{COR}}{\bar{G}_T - \frac{T_{f2} - \bar{T}_a}{COR}}\right] \tag{A.3}$$

Heat retention time (τ_{hr}):

Heat retention time (τ_{hr}) is the duration for which temperature of the test load/food item is maintained between two (upper and lower) reference temperatures under sudden uncontrolled reduction in clearness and radiation at the location. It characterizes the heat retention and storage capacity of a particular design of solar cooker in terms of duration of heat retention between the defined temperature ranges for ensured cooking.

The **Heat Retention Time** (τ_{hr}) of the typical design of solar cooker can expressed using equation (A.4) (Lahkar et al. [21], Sagade et al. [19],)

$$\tau_{hr} = \frac{\left(M_f C_{pf}\right)'_f}{A_p F' \eta_o} \times COR \times \ln\left[\frac{\bar{G}_D - \frac{T_{ref.Upper} - \bar{T}_a}{COR}}{\bar{G}_D - \frac{T_{ref.Lower} - \bar{T}_a}{COR}}\right] \tag{A.4}$$

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Nomenclature and abbreviations:

$\dot{Q}''$: Rate of heat gain/loss per unit aperture area of SBC (W/m^2)
$\bar{G}_T$: Average total solar irradiance (W/m^2)
$\bar{G}_D$: Average diffuse solar irradiance (W/m^2)
η_o: Optical efficiency
F': Heat exchange efficiency factor
Δt: Time interval (seconds) (unless otherwise specified)
$\bar{T}_a$: Average ambient air temperature (℃)
$T_{m(GLY)}$: Mean temperature of Glycerin (℃)
T_{fmax}: Highest achievable load temperature (℃)
T_{f1}: Initial temperature of test load or food item (℃)
T_{f2}: Final temperature of test load or food item (℃)
M_f: Mass of test load (kg)
C_{pf}: Specific heat of test load (J/kgK)
A_p: Effective inclined aperture area of SBC (m^2)
A_{pot}: Area of cooking pot (m^2)
C: Concentration ratio of the SBC
$\left(M_f C_{pf}\right)'_f$: Sum of the heat capacity of the test load and the cooking pot
τ_R: Reference Time (minutes)
τ_{hr}: Heat retention time (minutes)

Abbreviations
SBC: Solar Box Cooker
COR: Cooker Opto-Thermal Ratio
ECR: Effective Concentration Ratio
MCP: Modified Cooking Pot (with the glass lid)
CCP: Conventional Cooking Pot (with the metallic lid)