# Thermal Performance Evaluation of Indian Standard Solar Box Cooker (SBC) with Retrofitted Radiative Control

**Md. Rahbar Jamal, S. K. Samdarshi, P. S. Panja, Sandip Kumar Maurya, and Santosh Tigga**

## *Nomenclature*

| | |
|---|---|
| SBC | Solar box cooker |
| TPPs | Thermal performance parameters |
| COR | Cooker opto-thermal ratio |
| $F_1$ | First figure of merit |
| $F_2$ | Second figure of merit |
| PCM | Phase change material |
| $\eta_0$ | Optical efficiency |
| $U_l$ | Over all heat loss factor (W/ ($m^2$ °C)) |
| $T_{ps}$ | Absorber plate saturation temperature (°C) |
| $T_a$ | Ambient temperature (°C) |
| M | Mass of load (kg) |
| $C_p$ | Specific heat capacity of load (J $K^{-1}$ $kg^{-1}$) |
| ($t_2$-$t_1$) | Time interval during which water temperature rises from $T_{w1}$ to $T_{w2}$ (seconds) |
| $T_{w1}$ | Initial water temperature (°C) |
| $T_{w2}$ | Final water temperature (between 90–95 °C) |
| $\overline{G_T}$ | Average solar insolation during period of ($t_2$-$t_1$) (W/$m^2$) |

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## 1 Introduction

Affordable and clean energy for all, is one among the 17 sustainable development goals of the 2030 agenda for sustainable development adopted by all united nations member countries in 2015 [1, 2]. Solar cooking, due to the equitable nature and free availability of solar energy, could be pivotal to achieve this goal, mainly in developing nations where solar insolation is in abundance [3, 4]. Researcher and solar cooking enthusiasts around the globe are continuously working to design and develop new systems; and also making the existing system better to meet the need of the user. Through a detailed literature survey, it could be concluded that solar box cookers are being made better each passing day by optimizing the cooker design [5–8], employing different pot designs [9–11], integrating thermal storage systems [8, 12] and better radiation augmentation arrangements [7, 8, 13, 14]. Prior to all these, selection of a stable as well as user friendly opto-thermal performance parameter and test procedure are also necessary for satisfactory and acceptable evaluation; and mass propagation of solar cooking for its acceptance. Mullick et al. presented thermal performance parameter in term of figures of merit which are used.

For thermal performance evaluation of SBC [15]. Other thermal performance parameters associated with its performance evaluation are standard cooking power [16], characteristic and specific boiling time [17], utilizable efficiency [17], thermal efficiency [18], effective concentration ratio [19] and cooker opto-thermal ratio (COR) [20]. Buddhi et al. [8] designed and tested the performance of a solar box cooker with three reflectors and a cooking vessel with latent heat storage arrangement. They reported successful late evening (20.00 h) cooking with 4 kg of PCM charged during sunshine period. Coccia et al. [13] designed and tested a prototype SBC with multiple reflectors arrangement (of high concentration ratio) and reported high value of figures of merit and a steady value of cooker opto-thermal ratio for different quantities of load. Mirdha et al. [7] theoretically investigated various designs of box cooker with different arrangements of booster mirror to get an optimum design. Based on these, an improved design was finalised and fabricated with north and south facing booster mirror and a better performance was reported in comparison to conventional box cooker fabricated out of the same material. Sagade et al. [11] developed and tested hybrid cooking pot with glass lid and reported an improvement in the value of COR and an increase in the typical value of maximum achievable temperature in comparison to conventional cooking pot. Vengadesan et al. [10] investigated the effect of adding fins of varying lengths to the lid of cooking vessel. They reported a better performance of finned vessel compared to conventional vessel and best performance was reported for the longest fin and ascribed it to the high contact area between load and fin. Ali [5] fabricated and tested an SBC for Sudanese condition using internal as well as external reflector and reported a better thermal performance (figures-of-merit) in comparison to same cooker performance without reflectors' arrangement. Amer [6] introduced a modified solar cooker in which bottom insulation of conventional solar cooker's absorber plate was removed and was exposed to solar radiation through an arrangement of the reflectors. The achievable temperature was predicted

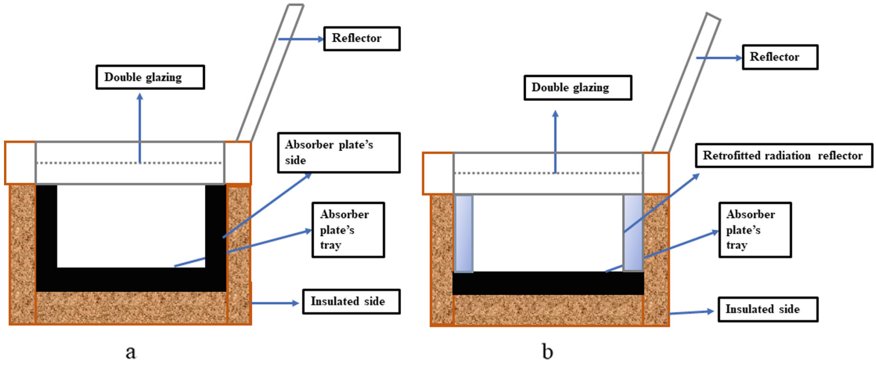


**Fig. 1** Schematic of **a** Indian conventional solar box cooker (SBC) **b** retrofitted solar box cooker (SBC)

with the help of energy balance equation and it agreed well with the measured value with a very low variance. Maximum achievable temperature of absorber plate and oven air was 165 and 155 °C, respectively. Tawfik et al. [14] constructed and evaluated the thermal performance of cooker with tracking type bottom reflector and reported a higher value of the mean cooker opto-thermal ratio, effective concentration ratio, first figure of merit and an average reduced cooking time in comparison to the performance of the same cooker without assembling of tracking type bottom reflector.

In present work retrofitting has been done to Indian standard solar box cooker as shown in Fig. 1a. Herein the sides of absorbing plate have been replaced by an anodized aluminium reflecting sheet of dimension equal to the specifications of the absorber plate's sides. Figure 1 schematically shows the specifications of testing cooker with two different conditions taken into account. Part (a) shows the conventional SBC's construction and its parts, and part (b) shows the retrofitting arrangement within conventional design.

Figure 2a shows the one side of retrofitting done as per the reflector's shape and size, Fig. 2b shows SBC after retrofitting has been done, and Fig. 2c schematically shows absorber plate structure (top view). Tests are performed on the aforementioned cooker with different arrangements and is discussed in the following sections.

## 2 Experimental Procedure

As stated, many TPPs are available to test thermal performance parameter of solar box cooker, namely, figures of merit, standard cooking power, thermal efficiency, utilizable efficiency, specific and characteristic time and COR. Among all these available TPPs, Bureau of Indian Standards has accepted figures of merit to rate the thermal performance of a solar box cooker. $F_1$ tests the performance through

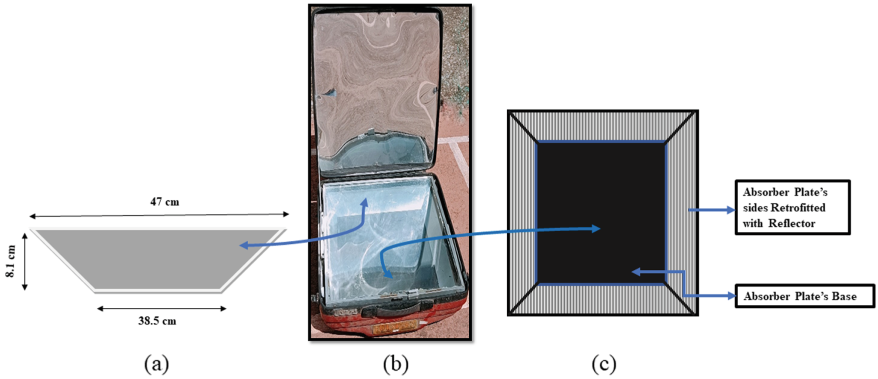


**Fig. 2** **a** Reflector sheet with specification (side view), **b** retrofitted solar box cooker, and **c** schematic of retrofitted absorber plate (top view)

stagnation temperature test of absorber plate and the second figure of merit, obtained through sensible heating test of a test load, predicts the performance based on the rate of heat transfer to the load in the cooking pot. In this work test procedure of Bureau of Indian Standards IS13429 part 3 [21] has been followed. All the tests have been performed between 1 h 30 min before and after solar noon (around11:50 am) at Central university of Jharkhand, Ranchi (23.34°N,85.30°E). For the $F_1$ calculation ambient temperature, solar insolation at the cooker aperture level and temperature of the absorber plate measured at the mid-point between its centre and edge at an interval of 5 min each. $F_1$ is calculated for steady state condition of SBC. Steady state is defined as a duration of 15 min around which variation in plate temperature is ± 1 °C, solar radiation is ± 20 w/m$^2$, and ambient temperature is ± 0.2 °C. $F_1$ is defined as the ratio of optical efficiency to heat loss coefficient.

$$F_1 = \frac{\eta_0}{U_l} = \frac{T_{PS} - T_a}{G_t} \tag{1}$$

For the calculation of $F_2$ [15, 21] cooker is loaded with cooking pot with a mass equivalent to 8-L of water per square metre of aperture area. Solar insolation, ambient temperature, and water temperature are measured at an interval of 5 min each. Data is recorded till water temperature reaches 95 °C. $F_2$ is calculated from equation given as

$$F_2 = \frac{F_1 (MC)_w}{A(t2 - t1)} \ln \frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - \overline{T_a}}{\overline{G_T}}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - \overline{T_a}}{\overline{G_T}}\right)} \tag{2}$$

## 3 Result and Discussion

Experimental data of the performance tests are given in Tables 1 and 2. The tests for first figure of merit were performed for two different conditions:

1. Condition A: test on conventional solar box cooker, and
2. Condition B: same cooker with retrofitted absorber plate's sides with reflector (radiative control).

Hereafter, these conditions have been mentioned as condition A and condition B. Average value of $F_1$ without retrofitting i.e., condition A, the recorded value is 0.09, whereas with retrofitting i.e., condition B, the recorded value is 0.0942 and at the same time for condition B temperature of plate rose by about 8 °C in comparison to the condition A. A clear gain of 4.67% in the value of $F_1$ is found for condition B w.r.t condition A.

Average ambient temperature and solar insolation for condition A was 34.40 °C, 1046.54 W/m$^2$ and for condition B was 35.93 °C, 1057 W/m$^2$, respectively. The geographical and environmental parameters involved in the calculation of $F_1$ are average solar insolation ($\overline{G_t}$) and average ambient temperature ($\overline{T_a}$). And $F_1$ is directly proportional to difference of average plate stagnation temperature and ambient temperature ($\overline{T_{ps}} - \overline{T_a}$) and inversely proportional to average solar insolation ($\overline{G_t}$). So, logically a test condition with a low value of $\overline{T_a}$ and $\overline{G_t}$ (within acceptable

**Table 1** Data and test result of test condition A

| Date | $\overline{T_p}$ | $\overline{T_a}$ | $\overline{G_t}$ | $F_1$ |
|---|---|---|---|---|
| 15/3/2022 | 130.67 | 31.07 | 1113 | 0.089 |
| 16/3/2022 | 126.6 | 31.7 | 1067 | 0.089 |
| 30/03/2022 | 131.67 | 34.97 | 1053.33 | 0.092 |
| 01/4/2022 | 124.67 | 35.87 | 996 | 0.089 |
| 02/4/2022 | 128 | 36.7 | 1014.33 | 0.09 |
| 04/4/2022 | 130.2 | 36.1 | 1035.6 | 0.091 |
| Average | | | | 0.09 |

**Table 2** Data and test result of test condition B

| Date | $\overline{T_p}$ | $\overline{T_a}$ | $\overline{G_t}$ | $F_1$ |
|---|---|---|---|---|
| 14/3/2022 | 135.25 | 28.58 | 1130.84 | 0.093 |
| 05/4/2022 | 136.5 | 36.35 | 1059 | 0.095 |
| 12/4/2022 | 136.33 | 37.83 | 997.33 | 0.094 |
| 14/4/2022 | 134.67 | 39.17 | 1019.67 | 0.094 |
| 25/4/2022 | 140 | 37.7 | 1078.25 | 0.095 |
| Average | | | | 0.0942 |

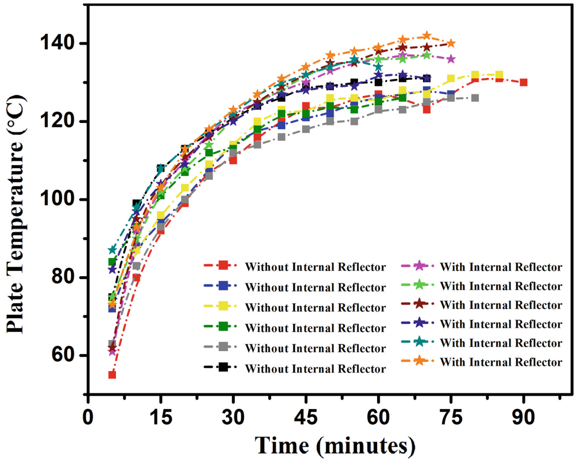


**Fig. 3** Plate temperature versus time graph

range, $\geq$ 600 $W/m^2$) has a more favourable conditions to expect better performance. But contrary to the expectations the result is otherwise. It clearly indicates a positive additionality in performance due to the retrofitting.

Further, from Fig. 3, it is more evident that time taken to reach stagnation temperature is lesser and at the same time average stagnation plate temperature is higher in condition B compared to condition A. It indicates a faster heating rate too. All these favourable gains could be attributed to retrofitted internal absorber reflector or radiative control, as it produces internal concentrating effect within the enclosure. In a very first appearance a higher stagnation temperature and lesser heating time collectively indicate towards lesser need of insulation to the side wall after retrofitting. Furthermore, the cleaning requirement in this case is limited to the glass cover only. A more detailed study is being carried to support this claim. So, as of now it could be summarised that overall impact of retrofitting is encouraging. A detailed study of result with two more parameters $F_2$ and COR will give more insight to the results. The results of COR will be crucial one as it will impart a holistic opto-thermal performance of the cooker and retrofitting arrangement.

## 4 Conclusion

An attempt to achieve a better performance and operational advantage, a hybrid of box cooker and concentrating solar cooker was designed through minimal changes and addition to the cost of the existing box cooker. Retrofitting of radiative control arrangement was made out of anodized aluminium reflector sheet by fixing it to the sides of an SBC. Outcome of retrofitting showed an enhancement in the performance of SBC. $F_1$ increased by 4.67% and the mean stagnation temperature of plate rose by about 8 °C and at a faster rate, in comparison to the same SBC without any radiative control. More tests are being performed for a better and clear opto-thermal analysis of retrofitting. It promises fairly good carbon reduction potential.

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