Study of Performance of Wooden Box Type Solar Cooker

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ABSTRACT

This paper presents the design, development and performance evaluation of wooden box type solar cooker. The Stagnation test and the water boiling test of the solar cooker were performed during April, 2022. The resulting values of first figure of merit (F1), second figure of merit (F2) and efficiency (η) was 0.135 , 0.307 and 32.89%, respectively, which categorized the cooker as class A grade. This wooden box solar cooker was found to have high values of F1 and F2 (F1 >0.12 and F2 >0.40). The cost of the cooker is INR 3000.00.

Key words: Solar cooker, wooden box type solar cooker, Thermal efficiency

INTRODUCTION

In order to keep pace with the development there is rise in energy use but it has adverse effect on greenhouse gas emissions due to burning of fast depleting fossil fuels. In this context, we need to harness and use more and more renewable forms of energy, especially solar energy that is plentiful in most parts of the country [1]. Solar cooking offers an effective method of utilizing solar energy for meeting a considerable demand for cooking energy and, hence, protecting the environment. Considerable efforts have gone into the development and performance testing of a variety of solar cookers and their suitability for cooking different foods [2]. Solar cookers are mainly of two types: box types and concentrating types. Box type solar cookers are simple and suitable for limited cooking due to their relatively low heat collection capacity, while concentrating type solar cookers are capable of generating higher temperatures and can efficiently be used for a variety of cooking applications. However, the latter require continued adjustment of the orientation of the concentrator to reflect the incident solar radiation on the focus where the cooking pot is placed.

The solar cooker is very useful even for common people in developing world specifically because of its low drudgery. A major portion of total available energy resource in rural areas of developing world is utilized for cooking and is mainly supplied by non-renewable energy sources e.g. fuel wood, agricultural waste, cow dung, kerosene etc. The environmental effects of fuel wood burning have been reported in several literatures [3-6]. In India, half a million box type solar cookers have been propagated in the country through the popular schemes launched by the Ministry of Non-conventional Energy Sources, Government of India [7].

In the box type solar cooker, solar energy is trapped inside an insulated box and the food items are kept inside the box for cooking purpose. Different types of box type solar cookers have been designed, developed and tested in different parts of the world [8-11]. Different designs of solar cookers reported in the literature have separate provisions for energy collection and the cooking units. The box type solar cooker is the most popular one due to its simple design and easy handling requirements [12]. Conducted extensive experimental studies and developed a test procedure for performance evaluation and standardization of box type solar cookers [13].The performance of a box type solar cooker largely depends on selection of materials for various components viz. glazing, insulation, casing and absorber tray. For improving the efficiency of box type solar cookers, a wooden box type solar cooker was designed and evaluated for its use as a domestic solar cooker for small families in the current social conditions.

MATERIALS AND METHODS

Development of wooden Box type Solar Cooker

A wooden box type solar cooker with reflector was designed and fabricated during March 2022 at the physics department, S. M. B. S. Thorat College of Arts, Science & Commerce, Sangamner, Dist. Ahmednager (M.S.) India. The cooker is based on hot box principle. The outer box was made of silver wood and the inner one was made of galvanized steel sheet of thickness 0.5 mm. The dimensions of the outer box were 495 x 495 x 140 mm and that of the inner box were 44x44x7 cm (Fig. 1). The space between the outer box and inner box was filled with Black foam (Insulation) depth 15 mm. The top side of the inner tray was painted black using black board paint. Two clear window glass planes (K. G. Tuff Toughened glass) of 3.5 mm thickness were fixed over the wooden box and has no need of separate frame. The spacing between two glass

covers was 15 mm to avoid thermal losses. A rubber gasket was provided between the tray and the wooden frame to make it leak proof. A 5 mm thick plain mirror reflector of size 443 mm x 437 mm was fixed over it. The reflector can be fitted to wooden lid and placed over the cooker and acts as a lid. The tilt of the reflector can be varied from 60^0 to 120^0 depending upon the season. The tilt is fixed once in a fortnight. The reflector could be folded on the cooker while the device is not in use. The aperture area of the solar cooker was 0.1599 m^2 . The four cooking utensils of 298.42 gm, 296.25 gm, and 297.55 gm and 296.20 gm weight. Stainless steel boxes with lid can be kept inside it for cooking four dishes simultaneously.

Figure 1 wooden box type solar cooker

Evaluation of Cooker

The on-site experiments on wooden box type solar cooker were performed during April, 2022 at the physics department, S. M. B. S. Thorat College of Arts, Science & Commerce, Sangamner, Dist. Ahmednager (M.S.) India. In these experiments, the solar radiation intensity (Gs) on a horizontal surface was measured using a Sun meter. A thermometer with point contact thermocouples was used to measure the temperatures at the base plate, water temperature and cooking fluid. The ambient air temperature was measured using a mercury thermometer, placed in an ambient chamber. The measurements of temperatures of different regions were carried out on clear sunny days at every 5 min interval for the duration of 10:00 to 1:15 Indian Standard Time (IST). Reflector was used whenever required as per test conditions.

Thermal performance and testing:

The solar cooker was evaluated based on Bureau of Indian Standards Testing Method (BIS 2000). Based on the existing testing standards three tests were performed on the wooden box type solar cooker; these were: first figure of merit F1, second figure of merit F2 and standardized cooking power (Ps). The first figure of merit (F1) was determined by conducting the no-load test; second figure of merit (F2) was determined by load test in which known amount of water was heated in solar cooker and cooking power was estimated. The efficiency of the wooden box type solar cooker was obtained by measuring the rise in temperature of a known quantity of water in a specified time as proposed by the method of calculation of efficiency (η) of the solar cooker by Nahar (2001 and 2009). The solar radiation, ambient air temperature, base plate temperature and water temperature were taken at a 5 minutes interval in order to determine the first figure of merit F1 and second figure of merit F2 of the box type solar cooker. The reflector of wooden box type solar cooker was surrounded with black cloth during the stagnation temperature test.

First Figure of Merit (F1) without water load (Stagnation test):

The hot junction of the thermocouple should be fixed at the midpoint of tray with proper thermal contact and without protruding out. The no load test shall be carried out on a clear day in following steps.

a) Place the solar cooker without pot in open sun condition.
b) Cover the reflector of the solar cooker with black cloth.
c) Monitor the cooker tray temperature at an interval of 5 min. continuously. Also measure intensity of total solar radiation, ambient temperature and wind speed at the level of glazing's of solar cooker; and
d) When the cooker tray temperature has reached a quasi-steady state note down the final steady cooker tray temperature (Tpx) and the corresponding outside ambient air temperature (Taz) along with the solar radiation (Gs) at that time.

The first figure of merit (F1) is defined as the ratio of optical efficiency, (η_0), and the overall heat loss coefficient, (U_L). A quasi-steady state (stagnation test condition) is achieved when the stagnation temperature is attained. High optical efficiency and low heat loss are desirable for efficient cooker performance. Thus, the ratio η_0 / U_L which is a unique cooker parameter can serve as a performance criterion. In stagnation test initially temperature of

$$F_1 = \frac{T_{pz} - T_a}{G_s} \quad \text{..... (1)}$$

bare plate increases and after some time it gets stagnant. Higher values of F1 would indicate better cooker performance (Mullick et al., 1987):

Where F1 is first figure of merit, Tpz is maximum plate surface temperature (^{0}C), Taz is ambient temperature (^{0}C), and Gs is global solar radiation on a horizontal surface (W/m^2).

Second Figure of Merit (*F*2) with water load (Sensible heat test):

Weight the empty cooking pots and then fill with 8 litters of water per square meter of aperture area. Water at ambient temperature is equally distributed in all the cooking pots if they are of the same size. If sizes are different, then water quantity in each cooking pot shall be in proportion to their bottom area. Reweight and calculate the exact mass of water. Place the pots in the cooker from which the mirror has either been removed or covered with cloth. Place temperature probe of thermocouple in the largest of the cooking pots with the measuring tip submerged in the water. The temperature probe lead shall be sealed where it leaves the cooking pots and the cooker. The ambient temperature and wind speed at the level of glazing's of solar cooker are measured throughout the test. The test shall start in the morning between 10:00 h to 10:30 h of local solar time. If the radiation and temperature are measured by spot checks, these shall be no more than 5 min apart. Constant monitoring at 30 s intervals or or less is desirable with averages of radiation recorded over 2 min intervals.

The second figure of merit, F2, of box type solar cooker is evaluated under full-load condition (water load), without reflector and can be defined as the product of the heat exchange efficiency factor (F′), optical efficiency ($\eta_0 = \alpha t$) and heat capacity ratio (C_R). It can be expressed as (Mullick et al., 1996).

$$F_2 = \frac{F_1 (MC)_w}{A(t_2 - t_1)} \ln \frac{\left[1 - \left(\frac{T_{w1} - T_a}{F_1 G}\right)\right]}{\left[1 - \left(\frac{T_{w2} - T_a}{F_1 G}\right)\right]} \quad \text{.....(2)}$$

where F2 is second figure of merit (^{0}C m^2 /W), (MC)w is product of the mass of water and its specific heat capacity (J/ ^{0}C), *A* is aperture area of the solar cooker (m^2), t_1 is initial time (s), t_2 is final time (s), Tw_1 is initial water temperature (^{0}C), Tw_2 is final water temperature (^{0}C), Gs is average global solar radiation (W/m^2), and Ta is average ambient temperature (^{0}C).

Efficiency of the box type solar cooker (η):

The overall thermal efficiency of the solar box cooker is expressed mathematically by [15, 16] and reported by [14] as follows:

$$\eta_u = \frac{M_w c_w}{I_{av} Ac} \frac{\Delta T}{\Delta t} \quad (3)$$

Where η_u represents overall thermal efficiency of the solar cooker; M_w, mass of water (kg); C_w, Specific heat of water (J/kg/°C); ΔT, temperature difference between the maximum temperature of the cooking fluid and the ambient air temperature; A_c, the aperture area (m^2) of the cooker; Δt, time required to achieve the maximum temperature of the cooking fluid; I_{av}, the average solar intensity (W/m^2) during time interval Δt.

RESULTS AND DISCUSSION

First Figure of Merit (F1) without water load (stagnation test):

The thermal evaluation experiment to determine the stagnation temperature of the wooden box type solar cooker was carried out during clear sky condition in May 2022. The stagnation temperature experiment test that is, no load test was started at 10:00 h. The plate temperature increased up to 95 °C within half an hour and stagnated at about 137 ^{0}C at around 3:00 h. The increase in stagnation temperature corresponding to the solar radiations is shown in Fig. 2. The highest temperature attained by plate was 137 ^{0}C (Taz = 36.5 ^{0}C, Tpz= 137 ^{0}C, Gs = 741.84 W/m^2). This shows that although this cooker is small in size, its thermal performance is comparable with the solar cookers developed by the other researchers. The plate temperature indicated that the present cooker provided enough insulation material (black foam) to reduce thermal losses while maintaining the same absorber area. The enough insulation material indicates good thermal performance of the cooker. Fig.2 illustrates the variation of plate temperature with time. Fig.3 illustrates the variation of solar intensity with time. The stagnation temperature varied between 70 ^{0}C and 120 ^{0}C with the variation in insolation from 400 to 960 W/m^2 . This figure also shows that the plate temperature remained around more than 120 ^{0}C for more than 5 hours which is long duration for satisfactory cooking. The first figure of merit F1 was calculated using Eq (1) as per the stagnation thermal performance test. The first figure of merit (F1) was found to be 0.135 and this value is acceptable as per BIS (2000) and Mullick et al. (1996). The constructed box type solar cooker is marked as A-Grade solar cooker. The higher values of first figure of merit indicated good thermal performance of box type solar cooker (Mahavar et al., 2012).

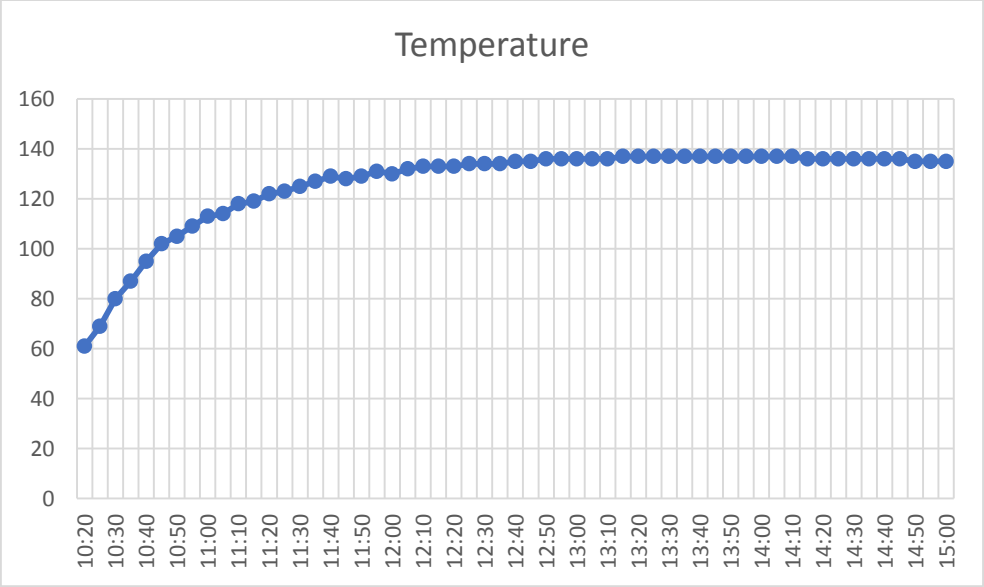

Fig. 2 Variation of plate temperature with time.

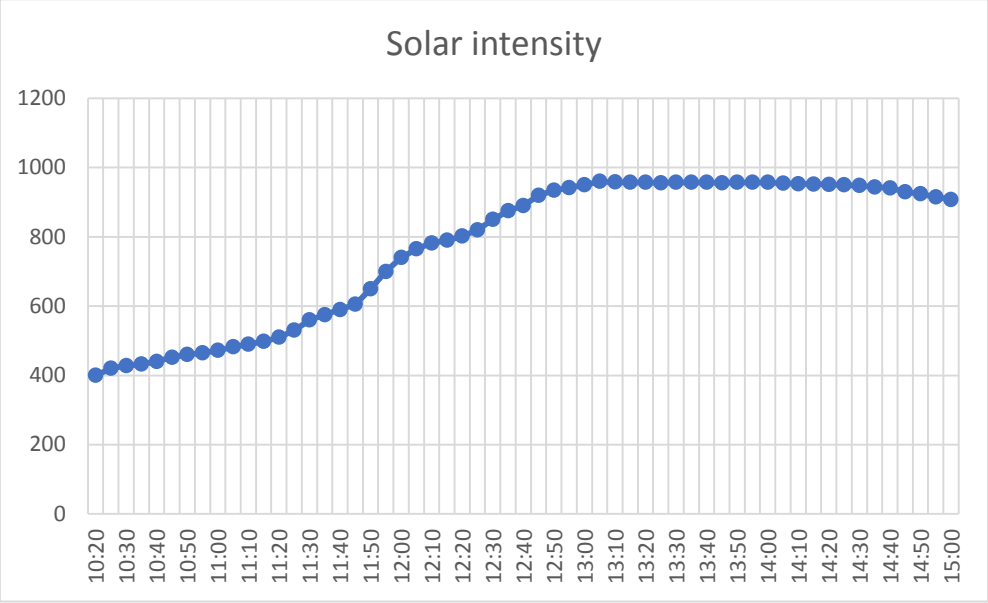

Fig.3 variation of solar intensity with time

Second Figure of Merit (*F*2) with water load (Sensible heat test):

To determine F2 , water heat up test was carried out with water load and without reflector in May, 2022 in a clear sky conditions as per BIS (2000) test code. The base plate temperature reached 80° C within 45 min and it remained higher than this temperature for around 6 hours. The water temperature reached 90 ^{0}C within 3 hours and remained higher than this for almost 4 hours, which is sufficient to cook two meals. Fig.4 illustrates the variation of water temperature with time. Fig.5 illustrates the variation of solar intensity with time. The trend of the water temperature curve shows that as time of day progressed water temperature increased with increasing solar insolation. The value of second figure of merit (F2) using Eq (2) was found to be 0.307 (using F1 = 0.135, M = 1.2 kg, C = 4186 J/ kg/°C, A = 0.1599 m^2 , Tw1 = 61 ^{0}C, Tw2 = 90 ^{0}C, Gs= 657.87 W/m^2 , Ta = 36.5°C, t1= 10.30, t2 = 13.00) which was within the recommended standard value in the range of 0.254- 0.490.

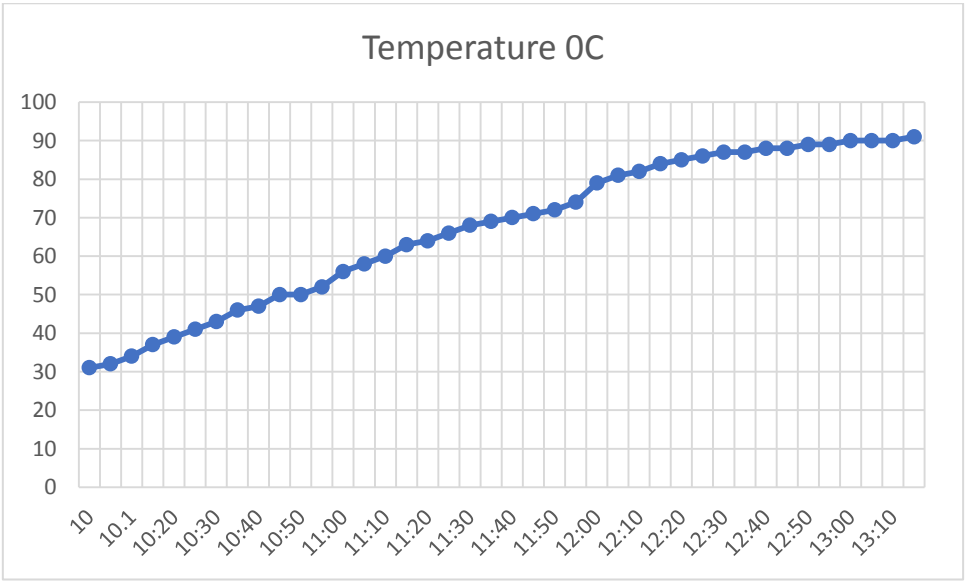

Fig. 4 variation of water temperature with time.

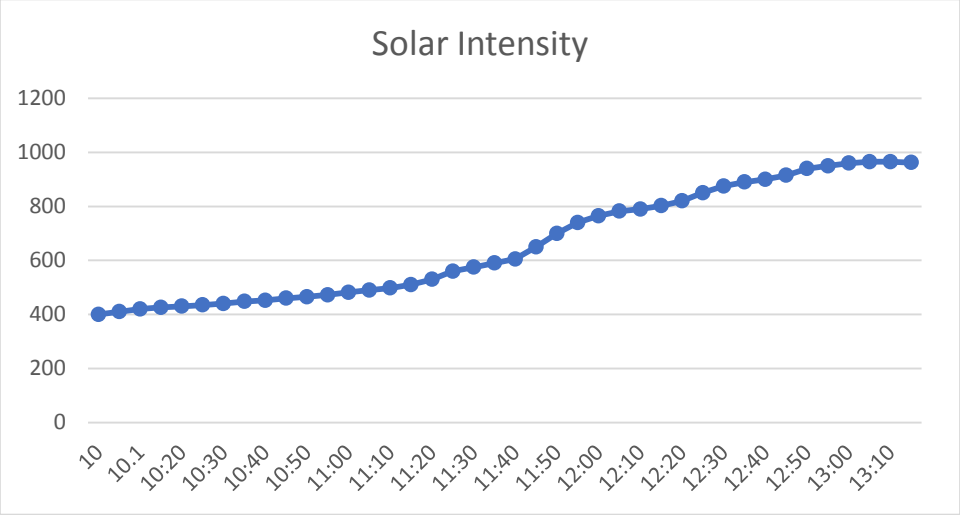

Fig. 5 variation of solar intensity with time.

Efficiency of the box type solar cooker (η):

Cooker was loaded with 1.2 kg of cold water. The initial temperature of water was 37°C and solar intensity 410 W/m^2 and the final temperature of hot water was 99 ^{0}C and solar intensity 962 W/m^2. The efficiency of the box type solar cooker was calculated using the Eq (3) and it was found that 32.89 % (Where A_c = 0.1599 m^2; C_w = 4186 J/kg/^{0}C; I_{av} = 657.87 W/m^2 ; M_w = 1.2 kg; ΔT_w = 62 ^{0}C, $\bigtriangledown t$ = 9000s). The present box type solar cooker has shown the best performance and highest efficiency for the maximum load (1.2 kg) is an indication of better heat retention ability of the cooker as compared with others found in the literature.

CONCLUSION

The experimental results showed that first figure of merit (F1), second figure of merit (F2) satisfied the Bureau of Indian Standards (BIS) and International standards for thermal performance testing of the wooden box type solar cooker. The thermal efficiency box type solar cooker was 32.89% for the water load of 1.2 kg.

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