Comparative study of single and double exposure Box-type solar cooker

K. Saravanan*, B. Janarathanan+

Abstract— In the present work, an attempt has been made to compare the Figure of merit F1,figure of merit F2 and the performance of single and double exposure solar cooker. Aluminium and copper base cooking vessels have been used in both cookers to cook various food stuff in the local climate condition in Coimbatore, Tamilnadu, India. Experiments have been conducted with the two cookers in the months of April and May 2013 in the Department of Physics, Karpagam University, Coimbatore, Tamilnadu, India. The F1 and F2 values of double exposure solar cooker is comparable with the BIS values and suitability of the cooker in the location has been discussed.

Index Terms— Absorber plate, Copper vessels, Double exposure solar cooker , figure of merit , single exposure solar cooker, solar energy , solar thermal energy.

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1 Introduction

Sun is the major source of heat and light and energy from the sun can be harnessed in to useful form by thermal method and photovoltaic method. Among these methods, thermal method has shown immense potential in domestic and industrial sector to fulfill the thermal energy demand. There are many thermal applications of solar energy and one of the thermal applications i.e., solar cooker has attracted the attention of many researchers. Various designs of solar cookers have been developed in many countries and classified into three type's viz, (i) Box type solar cooker (ii) Parabolic concentrating solar cooker (iii) Multi reflectors solar oven.

Among these types of solar cooker, box-type cooker has significant impact in India for domestic applications. Tiwari and Yadav [1] have designed new box type solar cooker with double glass cover and reflector and tested. It has been found that the cooker is more efficient than the conventional solar cooker. Khalifa *et al.* [2] have studied the heat transfer in the cooking process as an approach to develop outdoor and indoor cookers. Mullick *et al.* [4] has tested the second figure of merit F2 and its variation with load and number of pots. It is inferred that F2 increases with number of pots.

Mullick *et al.* [3] have found the figure of merit F1 and F2 of a box type solar cooker and presented. Channiwala and Doshi [5] have presented a correlation for the determination of the top loss coefficient in terms ofcooker configuration, optical properties and wind velocity.

*Research scholar, Department of Physics, Karpagam University,Coimbatore-641021, E-mail: saravananperumal32@gmail.com

+Assistant Professor, Department of Physics, Karpagam University,Coimbatore-641021, E-mail: bjanarthanan2002@yahoo.co.in
Tel: +91 422 2611146 & Fax: +91 422 2611043

Sunita Mahavar *et al.* [9] designed a Single family solar cooker and its thermal and cooking performance F1 and F2. Arezki Harmim *et al.* [6] have proposed a finned cooking vessel in order to increase efficiency of solar cookers and reduced cooking time. Theoretical and experimental analysis of double exposure solar cooker using triple glass cover has been done by Emad H.Amer [7] and the results have been presented.

Nehi and Purohit [8] has developed and analyzed a non-tracking concentrator type solar cooker to find the value of F_1 and F_2. Further, many researchers have presented the detailed design, test, and theoretical and experimental analysis of developed box type solar cookers (Mohamed Ali [12], Khalifa, Taha and Akyurt [13], Mullick, Kandpal and Kumar [14], Kumar [15], Sengar and Dashoraand Mahavar [16] , Ishan Purohit [17], Funk [18], Harmim, Belhamel, Boukar and Amar [21].

Ismail *et al* [19]has developed comparative analysed an solar cooking using box type solar cooker and finned cooking pot.

In the present study, an experimental study of single and double exposure solar cooker have been carried out to compare the performance of the cookers. Two important thermal parameters; first figure of merit (F1) and second figure of merit (F2) which are suggested by Bureau of Indian Standards (BIS) [11] for solar cookers, have been determined by the experimental studies. Cooking time to cook various food items using single and double exposure solar cooker has been found and discussed.

2 Design of Single and Double exposure Solar Cooker

The photograph and schematic diagram of the double exposure solar cooker are shown in the Figs. 1 and 2. The double exposure solar cooker box consists of a

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rectangular box of inner and outer enclosure of dimensions .52 x .84 x .30 m and .44 x .75 x .30 m has been made with the help of plywood. The gap (.05 m) between inner and outer enclosure has been filled with glass wool to minimise the heat losses through the sides of the cooker. Copper plate of thickness .005 m with a dimension of .35 x .60 m has been used as the absorber plate. Copper plate is painted black with matt black paint to increase its absoptivity and has been fixed at adistance of 15cm from the top edge of the box. Tray shaped reflectors are fixed on the inner sides of the cooker with a tilt angle of 30° on two sides of the cooker. The glass cover of thickness .004 m has been used at the bottom side of the cooker which is .15 m from the absorber plate. The lid of the cooker has been made as a frame with the glass cover by using plywood with a dimension of .45 × .85 m and fixed at the top side of the cooker.

Fig.1 Photograph of box type double exposure solar cooker

Cylindrical shaped Aluminium and Copper base cooking vessels with diameter and depth of .15 m and .10 m has been used to cook various food stuff. The bases of the cookers are flat to obtain good thermal contact with the absorber plate. The corners and edges of the box were well covered with silicon sealant to prevent any air leakage and infiltration.

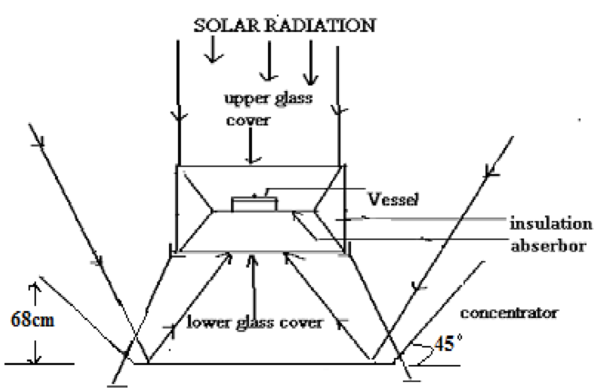

Fig.2 Schematic diagram of box type double exposure solar cooker in below,

Three Diffuse reflectors are placed beneath the lower side of the cooker out of which two are tilted at an angle of 45° on either side of the flat reflector to reflect radiation towards the solar cooker through the glass cover.

Fig.3 Photograph of single exposure box type solar cooker

Fig. 3 shows the photograph of the single exposure box-type solar cooker and it has been fabricated with the same design parameters of double exposure solar cooker.

3 Experimental methods

Experiments have been conducted at Karpagam University, Coimbatore (11.00ºN latitude and 76º56'E longitude), India with both single and double exposure solar cooker simultaneously to determine the figure of merit F_1 and F_2 during the month of April and May, 2013. The investigations have been done for several days and one of the typical experimental days has been used for calculation.

Calibrated copper-constantan thermocouples are used to measure the temperature elements of the two cookers. In double exposure solar cooker, solar radiation is transmitted through the top glass cover and radiation reflected from the bottom side beneath the cooker has been reflected towards the absorber plate after transmission through the bottom side glass cover. Hence the absorber plate is doubly exposed to solar radiation and it is absorbed as heat.

Thermocouple wire is fixed at the center of the absorber plate to measure the temperature. Seven thermocouple wires are used to measure the temperature of cooking vessel, base of the cooking vessel, cooking fluid, stagnant air between cooking fluid and lid of the vessel, lid of the vessel, stagnant air inside the cooker, top and bottom glass cover respectively. The intensity of solar radiation, wind speed and ambient temperature has been measured by using the solar radiation monitor, anemometer and digital thermometer respectively. In the case of single exposure solar cooker, seven thermocouple wires have been used for the measurement of temperature elements of the cooker.

3.1 Thermal Performance of Stagnation test

Figure of merit (F_1)

To evaluate the figure of merit F_1, both cookers are exposed to solar radiation without any load and time for the

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absorbers to achieve stagnation temperature has been observed. The first figure of merit (F_1) is calculated by using the expression [3, 11]

$$F_1 = \left(\frac{T_{PS} - T_{AS}}{H_s} \right) \quad (1)$$

Thermal performance of with load test (sensible test)

Experiments have been performed with the two proposed cookers with water load and the second figure of merit F_2 is calculated by using expression [3, 11]

$$F_2 = \frac{F_1 (mc)_w}{A\tau} \ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - T_A}{H} \right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - T_A}{H} \right)} \right] \quad (2)$$

4 Results and discussion

4.1 Analysis of Stagnation temperature

Experimental observations including the absorber plate temperature of single and double exposure cookers without load and intensity of solar radiation and ambient temperature with respect to time has been depicted in Fig. 4 for one of the typical days in the month of May 2013. It has been observed that the solar radiation and ambient temperature gradually increases from 9 am and reaches the maximum of 1122 W/m² and 37.5°C. The absorber plate temperature of the cookers have reached the stagnation temperature of 115°C and 102°C.

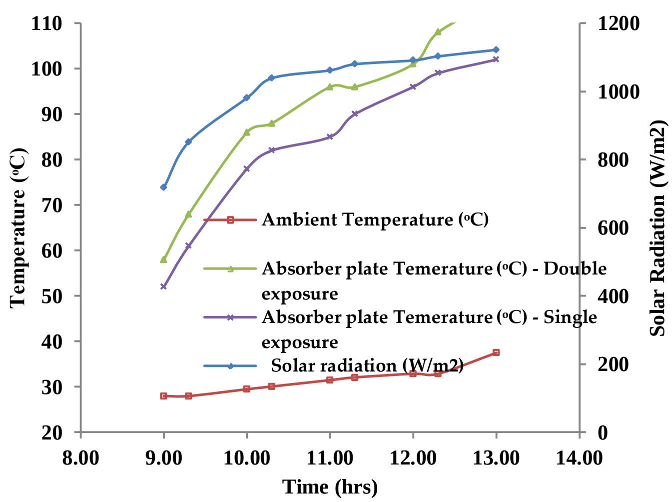

Fig.4. Variation of absorber plate temperature (single and double exposure cooker), solar radiation and ambient temperature

From the stagnation temperature test of the cookers without load inferred that, the absorber plate temperature of double exposure solar cooker is always higher than the single exposure solar cooker during the testing hours. This is due to the exposure of absorber plate by solar radiation transmitted through the upper glass cover and radiation reflected towards the absorber plate by the reflector assembly. In the case of single exposure solar cooker, the absorber plate absorbed the solar radiation transmitted through the glass cover only.

4.2 Analysis of temperature elements of the cookers

Figs. 5 and 6 shows the variation of glass covers temperature, air temperature inside the cooker, absorber plate temperature, ambient temperature and intensity of solar radiation on the typical day for the cookers without load. On the experimental days of the cookers it has been observed that the intensity of solar radiation and ambient temperature have same trend. Hence both the cookers can be treated simultaneously to analyze the temperature elements.

From Fig. 5 it is seen that the bottom glass cover temperature (Glass cover temperature 2) of double exposure solar cooker is zero in the beginning and started increasing throughout the working hours. This is due to the fact that during morning hours the amount of solar radiation reflected by the reflectors towards the glass cover is minimum and gradually increases depending on the increase of intensity of solar radiation.

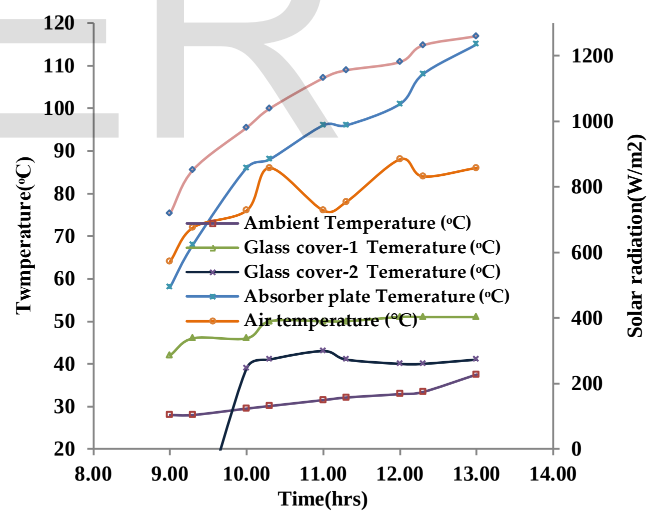

Fig.5. Variation of temperature elements of double exposure cooker and ambient temperature and solar radiation

The top glass cover temperature (Glass cover temperature 1) have shown higher temperature than the bottom glass cover throughout the working hours of the cooker. Since the cooker's absorber plate is exposed doubly, the amount of solar radiation intercepted on the plate is higher compared to the single exposure solar cooker. The absorber plate has received the solar radiation continuously and reaches the stagnation temperature of 115°C with the time duration of 3.5 hrs.

From Fig. 6, it has been observed that the air temperature inside the cooker and absorber plate temperature has increasing trend lower than the double exposure solar cooker. The absorber plate temperature becomes stagnant in 3.5 hrs and reached a maximum of 102°C. Since the amount of solar radiation reaching the absorber plate is only through the lid of the cooker, the absorber plate intercepted smaller amount of solar radiation compared to the double exposure solar cooker.

From the above experiment, it is confirmed that double exposure solar cooker has shown better performance than the single exposure solar cooker. From the stagnation test, the F_1

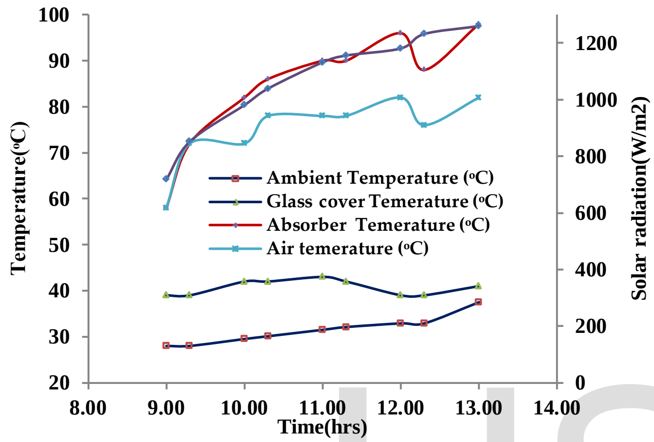

Fig.6. Variation of temperature elements of single exposure cooker and ambient temperature and solar radiation

Table. 1

Cooker type	F_1 (without load)
Single Exposure cooker	0.1131
Double exposure cooker	0.1504

The figure of merit F_1 for single and double exposure cooker are found to be 0.1131 and 0.1504 Km²/W respectively. It is found that the F_1 value for double exposure solar cooker meets the BIS values and found to be fit for the local climatic conditions in Coimbatore, Tamilnadu, India. The double exposure solar cooker has been tested for boiling of water (1 kg) by using Aluminium cooking vessel and it is found that the water reaches the boiling point after 180 minutes. The variation of the temperature of glass covers, water, air, ambient temperature and solar radiation intensity has been depicted in Fig. 7. Though the absorber plate is doubly exposed, water inside the aluminium cooking vessel has taken more time to reach the boiling point. The aluminium base transfers the heat energy to the water continuously due to high thermal conductivity.

Fig. 8 shows the variation of water temperature inside the copper base cooking vessel with air, ambient and glass covers temperature. When compared with aluminium cooking vessel, water in the copper base vessel reaches its boiling point in 80 minutes. This is due to the high specific heat capacity of copper than the aluminium. By using the experimental observations measured with load of 1kg of water in both aluminium and copper base cooking vessel, the figure of merit F_2 has been found to be 0.4422 and 0.4008. The F_2 values of both the vessels meet the standard for BIS values and can be recommended for using the vessels in double exposure solar cooker. Since the F_2 value of the cooker with copper base cooking vessel is higher than the aluminium base cooking vessel, experiments have been carried out with copper base cooking vessel to cook different food stuff.

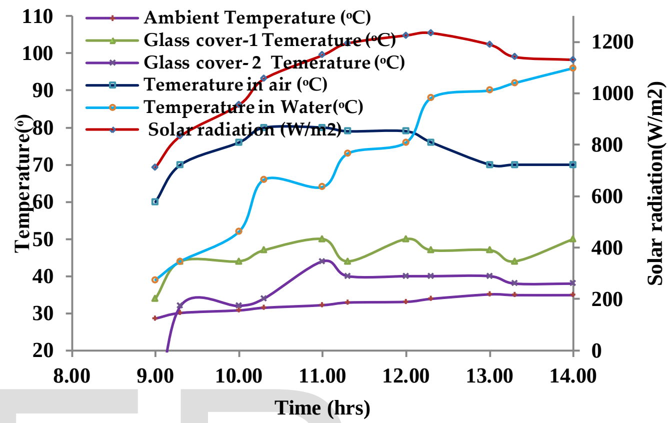

Fig.7.sensible test (F_2) of double exposure cooker by using aluminum vessels

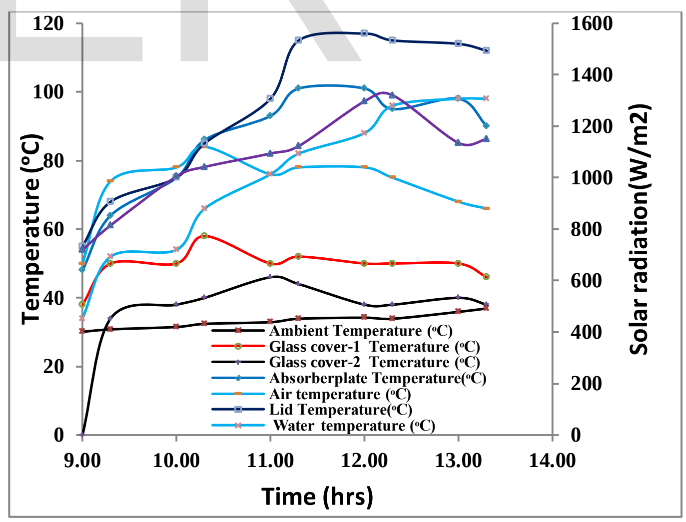

Fig.8. Sensible test (F_2) of double exposure cooker by using copper bottom vessels

In copper base cooking vessel, 1 kg of water has been taken tested in a typical sunny day and found that the water reaches the boiling point after 80 minutes. In the same vessel egg, wheat rava and dhal has been cooked and the cooking time is tabulated in Table. 2

Table. 2

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S.No	Food items	Cooking time (min)
1	1 liter of water	80
2	¼ kg rice + 1/2 kg water	85
3	4 Eggs + 1/2 kg water	60
4	¼ kg Dhal + ¼ kg water	120
5	Wheat rava ¼ + ¼ water	50

5 Conclusion

The performance of double exposure solar cooker is found to be satisfied with Bureau of Indian standards and calculated F_1 and F_2 values of the cooker has shown the potential of cooking different food items on a typical sunny day. It is also recommended that the cooker can be utilized in the local climatic conditions with less maintenance and found to be suitable for families in developing countries. The food cooked by the cooker has shown the presence of necessary nutrients without spoiling the odor and taste. The cooker is appropriate for commercialization to reduce the demand for conventional energy sources.

Nomenclature

A Aperture Area (m^2)
C Specific heat of water (J/kg/K)
Hs Solar radiation on horizontal surface (W/m^2)
H The average horizontal solar radiation over the interval τ.
M Mass of the water (kg)
τ Time(s) interval during which water temp rises from Tw_1 to Tw_2.
T_A Average Ambient temperature over the time interval (°C)
T_{W1} The average initial water temperature (°C)
T_{W2} The average final water temperature (°C)
F_1 Figure of merit 1 (without load)
F_2 Figure of merit 2 (with load)

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