Development and evaluation of multi-reflector foldable type solar cooker

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Abstract: A multi reflector foldable type solar cooker using locally available material was developed and evaluated for its thermal and cooking performance. It facilitates the wider utilization and adoption of solar energy for cooking the food in the household sector as well as in the outdoor during the picnics, parties, outings etc due to its foldable nature and light in weight (2 kg). The thermal performance indicators of the solar cooker in term of figures of merits were measured. The first figure of merit and second figure of merit were found to be 0.093 and 0.232 respectively. The time required for cooking the commonly used food item was found to be 75 to 110 minutes (Ambient temperature was –32℃ and solar intensity was –715 W/m^2). The results obtained were competitive with standard box type solar cooker.

Keywords: multi reflector, folding solar cooker, stagnation test, figures of merits, India

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1 Introduction

Cooking is the most important energy consuming operation in the domestic sector. In India more than 90 percent of the total house hold energy in rural areas is consumed in kitchen by burning the 133 million tones of firewood (Pohekar, Kurhekar and Gupta, 2003). The energy consumption for cooking constitutes half of India's total energy consumption and no other form of energy has greater impact on the environment or is more crucibles for human survival. Box type solar cooker is the most viable option for utilization of solar energy through solar thermal mode (Sharan, 1999). The wide diffusion of the box type solar cooker depends on political, cultural, historical, economic and technical factors. One of disadvantage of box type solar cooker is its weight, high cost and skill required for manufacturing of cooker. The high weight of solar cooker restricts its utilization in the outdoor during the picnics, parties, outings etc (Garg and Prakash, 1997). Many scientists from the different parts of the world are working on the box type solar cooker for cooking. The instrumentation required for testing of the solar cooker was described by Dubey (2001). Ekechukwn and Ugwonke (2003) explained the augmentation of the plane reflector used in the box type solar cooker. The construction details of the box type solar cooker are simple but scientific backup is needed for better performance in the field (Sharan and Mania, 2005). The thermal performance of the box type solar cooker is carried out in terms of figures of merit as per standard test procedure (Mullick, Kandpal and Saxena, 1987). Mullick, Khan and Chourasia (2005) described the importance of the second figure of merit in the evaluation of thermal performance of the box type solar cooker. The importance of the multi-reflectors for the temperature gain suitable for the solar cooking were described by Singh and Yadava (1998) and Rathore and Kothari (2003). Keeping this in view, a low cost multi reflector foldable type solar cooker using locally available materials has been designed and developed.

2 Materials and methods

The low cost multi reflector foldable type box cooker was designed and developed using the locally available

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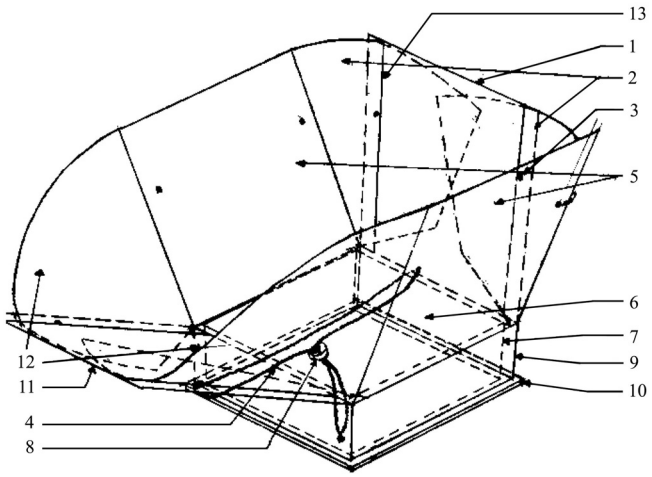
material (Figure 1). The pictorial view of solar cooker is shown in Figure 2.



1. Main reflector 2. Corner reflector 3. Holes of thread (Dia 5 mm) 4. Thread 5. Side reflector 6. Geletin paper 7. Inner box 8. Stopper 9. O ter box 10. Base 11. Secondary main reflector 12. Corner reflector 13. Shutter adjustment

Figure 1 Schematic view of foldable solar cooker

Figure 2 Pictorial view of foldable solar cooker

The main aim of development of the foldable solar cooker was its wider utilization during the picnics, outing camps and easy in transportation. The base plate made up of cardboard (40×40 cm) pasted with 3 mm thermacol sheet on the bottom reverse side was used to hold the side walls of the solar cooker and to act as a insulator. The thermocol is provided to act as an insulator to reduce the conduction losses from the cooker to the ground. Removable foldable side walls made of 2 mm thick cardboard with adjustable reflectors was used to hold the solar cooker in vertical position. The adjustable multi reflector coated with aluminum foil facilitates the concentration of incident solar radiations on the aperture area of solar cooker. The higher number of aluminum reflectors (04) concentrated the solar radiations in the inner absorber box to achieved the desired temperature for cooking. The position of the reflector was adjusted with the help of threads and fiber stopper at the desired angle (17°45′N latitude and 73°20′E longitude) to facilitate the incident angle of solar radiations. The foldable inner frame made up of card board (34×34×9.5 cm) was used to tighten the sidewalls and to hold the cooker in the standing position. The inner side of base plate and side walls and inner frame was painted dull black using black board paint to act as an absorber of solar energy. The removable transparent single plastic sheet fitted in the wooden frame was used as glaze for the solar cooker to allow the solar radiations to fall on the absorber plate and for loading and unloading of the cooking pots. The detail specification of material used for development of solar cooker was depicted in Table 1.

Table 1 Specifications of material used for development of foldable solar cooker

S N	Particulars	Specifications	Material used
1	Base plate/cm	40×40	Card board
2	Inner box/cm	34×34×9.5	Card board
3	Outer box/cm	35×35×11	Card board
4	Transparent cover/cm	34×34	Gelatin paper
5	Reflector/cm	4 numbers×40	Aluminum foil pasted on cardboard
6	Cooking container,	2 numbers, 1 lit. each	Aluminum
7	Thread/m	4	Cotton
8	Stoppers	4 numbers	Plastic

The developed solar cooker was extensively tested as per IS 13429 (Part3): 1992 code of testing (Anonymous, 2006). The stagnation temperature and heat up condition test was carried out to determine the first figure (F_1) and second figure (F_2) of merits respectively. Placing the empty cooker on horizontal surface with reflectors shrouded with black cloth carried out the stagnation temperature test. The temperature of center of the absorber plate was measured at an interval of 5 minutes continuously using K-type thermocouple with digital temperature indicator. The first figure o f merit (F_1) as ratio of optical efficiency to heat loss coefficient was determined as

First figure of merit,

$$F_1 = \alpha.\tau / U_l$$
$$= T_{ps} - T_{as} / G_s$$

The heat up condition test was carried out by keeping 450 gm of water (48.5℃) in each blackened aluminum cooking pot as per test procedure described by IS 13429 (Part3): 1992. The constant monitoring of water temperature at an interval of 30 seconds with average of radiations was recorded over two minutes' interval with the help of RTD and pyranometer. The second figure of merit (F_2) was determined as

$$F_2 = \frac{F_1(MC)w}{A(t_2 - t_1)} Log_e \frac{[1-(T_{w1} - T_a)/F_1.G_s]}{[1-(T_{w2} - T_a)/F_1.G_s]}$$

In addition to the thermal performance test, cooking test was carried out to confirm the performance of solar cooker. The commonly used food material like rice, pulses, potato and eggs was cooked with food to water ratio of 2:1 in the solar cooker. The cooking time required for cooking the material was recorded.

3 Results and discussion

The thermal performance and cooking performance of multi reflector foldable box type solar cooker was carried out to evaluate the overall suitability. The developed solar cooker was tested at dapoli (17°45′N latitude and 73°20′E longitude). The stagnation temperature test i.e. no load test was started at 10.00 till the maximum plate temperature was achieved. The reflectors of cooker were shrouded with black cloth during the test. Figure 3 illustrates the diurnal variation in stagnation temperature in an empty solar cooker with reflector shrouded with black cloth.

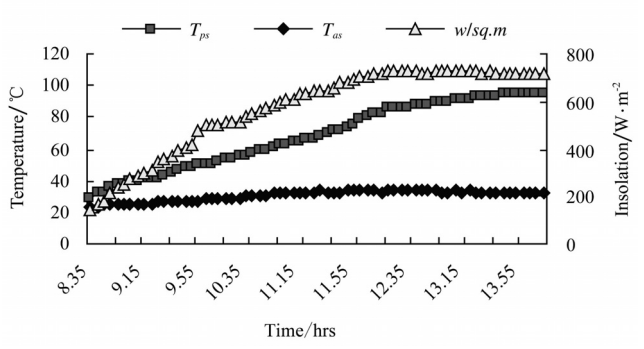


Figure 3 Stagnation temperature test of solar cooker for the first figure of merit (F_1)

The maximum absorber plate temperature attained was about 95.2℃, which corresponds to the first figure of merit (F_1) worked out to be 0.093. The increase in stagnation temperature corresponding to the solar radiations is shown in Table 2.

Table 2 Stagnation temperature test for first figure of merit (F_1)

Time/hrs	Plate Temperature/℃	Ambient Temperature/℃	Solar radiations /W·m^{-2}	Value of F_1 by calculation
8.35 a.m.	29.0	22.5	139.11	
9.00 a.m.	38.0	25.5	249.28	
9.30 a.m.	43.0	26.0	354.43	
10.00 a.m.	50.0	27.5	498.58	
10.30 a.m.	56.0	29.0	533.73	
11.00 a.m.	63.0	31.5	608.51	T_{ps}=95.2℃
11.30 a.m.	68.5	32.0	646.18	T_{as}=32.0℃
12.00 noon	79.0	33.5	706.95	G_s=715 W/m^2
12.30 p.m.	86.5	33.5	722.98	F_1= 0.093
13.00 p.m.	90.3	33.5	728.05	
13.30 p.m.	93.3	33.0	728.69	
14.00 p.m.	95.2	33.0	718.94	
14.30 p.m.	93.7	33.0	717.40	

The first figure of merit (F_1) was found to be at the lower side as compared to commercial box cookers (0.12 for 'A' cooker and 0.11 for 'B' cooker (Anonymous 2006)). The low value of first figure indicated the higher convection and radiation losses from the side walls made of cardboard and low insulation quality of 3 mm thermacol sheet. The sensible water heating test of solar cooker was carried out by placing the known quantity of the water in the cooking pots and placing the solar cooker in open space facing due south. The variation in water temperature in a loaded cooker with reflectors during the heat up condition test is shown in Figure 4.

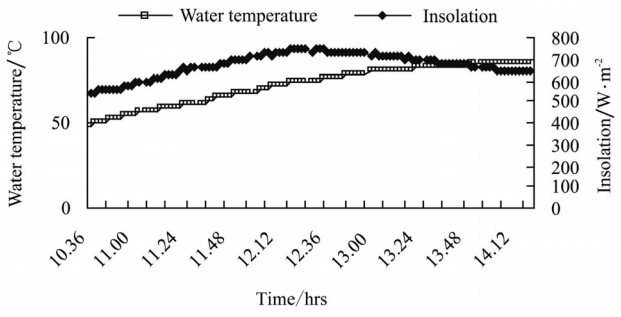


Figure 4 Water heat up test of solar cooker for the second figure of merit (F_2)

The initial temperature and final temperature /time data pair was selected from the data of water heating in

solar cooker as per IS test code. The time duration for raising water temperature from 60.8℃ to 84.5℃ was about 158 minutes which corresponds to the second figure of merit (F_2) worked out to be 0.232. The increase in water temperature corresponding to the solar radiations during the heat up condition test is shown in Table 3. The second figure of merit was found to be comparable with the commercial box type solar cooker (F_2>0.25).

Table 3 Heat up condition test for second figure of merit (F_2)

Time /hrs	Water temperature /℃	Ambient Temperature /℃	Solar radiations /W · m^{-2}	Value of F_2 by calculation
10.36	48.5	29.3	538.36	
11.00	55.1	30.2	587.42	G_s=710 W/m^2
11.30	60.5	31.6	659.02	$(MC)_w$=3771 J/℃
12.00	68.35	32.3	709.83	A=0.16 m^2
12.30	74.72	32.8	741.31	T_{w1}=60.8℃
13.00	79.84	32.3	723.73	T_{w2}= 84.5℃
13.30	82.31	32.2	690.02	(t_2-t_1)=11.31 to14.10 hrs =158 minutes
14.00	84.12	32.9	657.89	T_a=32.01℃
14.10	84.50	32.9	656.81	F_2=0.232
14.30	84.49	32.9	645.21	

The field performance of the solar cooker for the cooking of commonly food items was carried out on a clear sunny day. The cooking performance of the developed solar cooker is shown in Table 4.

Table 4 Cooking performance of solar cooker

Sr.No.	Food material cooked	Quantity /gm	Mixing water /gm	Cooking time Required/min
1.	Rice	100	200	70
2.	Potato	200	400	80
3.	Eggs	5 no.	200	85
4.	Pulses(Tur dal)	100	200	110

It is observed that, the commonly used food items like rice, pulses, potatoes and eggs required 70 to 110 minutes for cooking which is comparable with the time required for cooking in the commercial box type solar cooker. The folding nature of the solar cooker facilitates the easy for carrying in a polythene bag during the picnics and outing camps. The wide utilization of the solar cooker saves the considerable amount of energy and provides availability of cooking energy in the rural area, in the field and remote places.

4 Conclusions

The multi reflector foldable box type solar cooker provide the availability of cooking energy in the household as well as during the picnic and outing camp due to its foldable nature and easy in carrying. The figures of merits (F_1 = 0.093 and F_2 = 0.232) indicates the performance of solar cooker comparable with the commercial box type solar cooker. The cooking time required for commonly used items were comparative with the commercial box cooker.

Nomenclature

F_1 First figure of merit

F_2 Second figure of merit

α Absorvitivity of cooking tray

τ Transmitivity of glass/ cover

U_l Heat loss coefficient of solar cooker, W/m^2 K

T_{ps} Absorber Plate temperature, ℃

$T_{as,}$ T_a Ambient air temperature, ℃

G_s Global solar radiation incident on horizontal surface, W/m^2

$(MC)_w$ Product of mass of water and specific heat, J/K

A Aperture area of cooker, m^2

T_{w1} Initial temperature of water, ℃

T_{w2} Final temperature of water, ℃

$(t_2 - t_1)$ Time taken to heat the water from T_{w1} to $T_{w2,}$ Seconds

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