Development and Performance Evaluation of High Insulation Box Type Solar Cooker

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ABSTRACT

This paper presents the design, development and performance evaluation of high insulation box type solar cooker. The solar cooker is capable of boiling food for five persons per day. Stagnation test and the water boiling test of the solar cooker were performed during April, 2017. The resulting values of first figure of merit (F_1), second figure of merit (F_2) and standardized cooking power (P_s) was 0.120^{0}C, 0.424 and 45 W, respectively, which categorized the cooker as class A. This high insulation solar cooker was found to have high values of F_1 and F_2 (F_1>0.12 and F_2>0.40) during different seasons of the year. The overall efficiency of the high insulation box type solar cooker was 26.5%. The cooker is estimated to save 1293.8 MJ of energy per year. The cost of the cooker is INR 4500.00. The payback period of the solar cooker as compared to firewood, electricity, coal, LPG and kerosene based cooking was estimated to be 1.49, 1.94, 2.42, 3.12 and 6.99 years, respectively. The high insulation box type solar cooker can reduce about 815.30 kg of CO_2 emission on annual basis.

Key words: *Solar cooker, High insulation 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. Solar cooking has proved to be one of the simplest, viable and attractive options for solar energy utilization and is also environment-friendly and cost effective . 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 (Elliott, 2004; Tingem and Rivington, 2009; Panwar *et al.,* 2011; Huttunen, 2009). The fuel wood requirement is 0.4 tons per person per year in India. In rural areas firewood crisis is far graver than that caused by a rise in oil prices. One third of India's fertilizer consumption can be met if cow dung is not burnt for cooking and instead it is used as manure. The arid and semi-arid parts of the country receive much more radiation as compared to rest of the country with 6.0 kWh m^{-2} day^{-1} mean annual daily solar radiation having 8.9 average sunshine hours a day at Jodhpur (Pande *et al.,* 2009). The solar irradiance available in cold desert region, such as Leh, was observed to be 5.53 kWh $m^{-2}day^{-1}$ on horizontal plane and 6.36 kWh $m^{-2}day^{-1}$ at a 35 degree south facing tilt indicating an excellent potential of solar energy in high altitude cold deserts of India (Jacobson, 2000).

Based on the principles of working, solar cookers can be classified into three broad categories (i) Reflector/ focusing type (ii) Heat transfer type and (iii) Hot box type. 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 (Negi and Purohit, 2005; Kumar, 2008; Harmim *et al.,* 2010 and Mahavar *et al.,* 2012). A double reflector based cooker was developed and improved by providing an additional reflector and by using transparent insulation material as reported in several literatures (Nahar, 2001). 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 high insulation 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 High Insulation Box type Solar Cooker

A double glazed high insulation box type solar cooker with reflector was designed and fabricated during February 2017 at the workshop of ICAR-Central Arid Zone Research Institute, Jodhpur, India. The cooker is based on hot box principle. The outer box was made of galvanized steel sheet (22 SWG) and the inner one was made of aluminum sheet (22 SWG). The dimensions of the outer box were 610x610x200 mm and that of the inner box were 355x355 mm with 80 mm height (Fig. 1).The space between the outer box and inner box was filled with glass wool insulation. The top side of the inner tray was painted black using black board paint. Two clear window glass planes of 4mm thickness were fixed over the same wooden 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 4mm thick plain mirror reflector was fixed over it. The reflector can be placed over the cooker and acts as a lid. The tilt of the reflector can be varied from 60^{o} to 120^{o} 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 0.126 m^2. Four cooking utensils each of 175 mm diameter aluminum/ stainless steel boxes with lid can be kept inside it for cooking four dishes simultaneously. The cooker is fixed on an angle iron stand.

Evaluation of Cooker

The on-site experiments on high insulation box type solar cooker were performed during 2017at the ICAR-Central Arid Zone Research Institute.

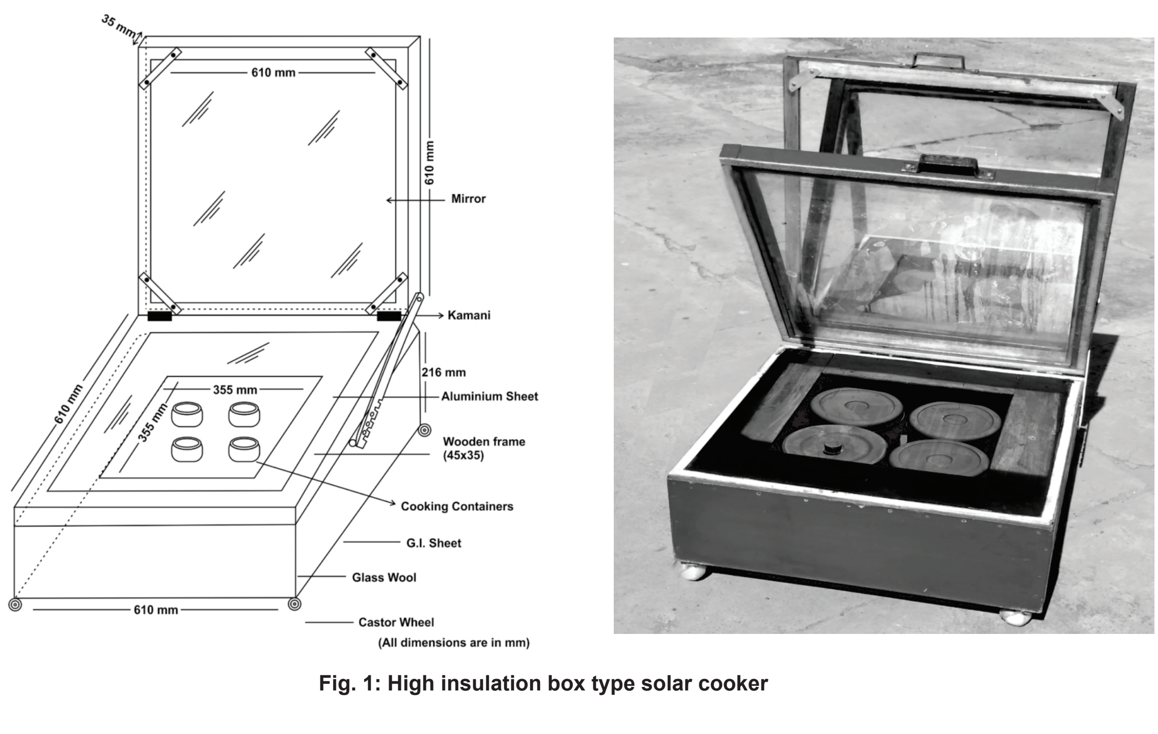

Fig. 1: High insulation box type solar cooker

In these experiments, the solar radiation intensity (G_s) on a horizontal surface was measured using a thermopile pyranometer. A thermometer with point contact thermocouples (accuracy 0.1°C) was used to measure the temperatures at different locations of the cooker, viz. the base plate, water temperature and cooking fluid. Ambient air temperature was measured using a mercury thermometer (accuracy 0.1°C), placed in an ambient chamber. The measurements of temperatures of different regions were carried out on clear sunny days at every 15 min interval for the duration of 10:00 to 14:30 Indian Standard Time (IST). Reflector was used whenever required as per test conditions.

Thermal performance and testing: The solar cooker was evaluated based on existing international testing standards. It included three major testing standards for solar cookers that are commonly employed in different parts of the world viz (i) American Society of Agricultural Engineers Standard (ASAE, 2003), (ii) Bureau of Indian Standards Testing Method (BIS 2000), and (iii) European Committee on Solar Cooking Research Testing Standard and others (ECSCR, 1994). Based on the existing international testing standards three tests were performed on the high insulation box type solar cooker; these were: first figure of merit F_1, second figure of merit F_2 and standardized cooking power (P_s). The first figure of merit (F_1) was determined by conducting the no-load test; second figure of merit (F_2) 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 high insulation 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 15 minutes interval in order to determine the first figure of merit F_1 and second figure of merit F_2 of the box type solar cooker. The reflector of high insulation box type solar cooker was shrouded with black cloth during the stagnation temperature test.

First Figure of Merit (F_1) without water load (Stagnation test): The first figure of merit (F_1) 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_o/U_L which is a unique cooker parameter can serve as a performance criterion. In stagnation test initially temperature of bare plate increases and after some time it gets stagnant. Higher values of F_1 would indicate better cooker performance (Mullick *et al.*, 1987):

$$F_1 = \frac{\eta_0}{U_L} = \frac{(T_{ps} - T_a)}{G_s} \qquad ...(1)$$

Where F_1 is first figure of merit, η_o is optical efficiency (%), U_L is overall heat loss coefficient of the cooker (W/m^2 °C), T_{ps} is maximum plate surface temperature (°C), T_a is ambient temperature (°C), and G_s is global solar radiation on a horizontal surface (W/m^2).

Second Figure of Merit (F_2) with water load (Sensible heat test): The second figure of merit, F_2, 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 ($\eta_o = \alpha\tau$) and heat capacity ratio (C_R). It can be expressed as (Mullick *et al.,* 1996):

$$F_2 = F'\eta_0 C_R = \frac{F_1 (MC)w}{A(t_2 - t_1)} ln \left[\frac{1 - \frac{1}{F_1}\left(\frac{T_{w1} - \bar{T}_a}{\bar{G}_s}\right)}{1 - \frac{1}{F_1}\left(\frac{T_{w2} - \bar{T}_a}{\bar{G}_s}\right)} \right] \qquad ...(2)$$

where F_2 is second figure of merit (°C m^2/W), $(MC)_w$ is product of the mass of water and its specific heat capacity (J/°C), A is aperture area of the solar cooker (m^2), t_1 is initial time (s), t_2 is final time (s), T_{w1} is initial water temperature (°C), T_{w2} is final water temperature (°C), G_s is average global solar radiation (W/m^2), and T_a is average ambient temperature (°C).

Cooking power estimation: Funk (2000) discussed two types of test variables for cooking power estimation. These are mainly uncontrolled variables e.g. weather parameters and controlled variables, e.g. design parameters of cooker. Wind, ambient temperature, pot contents temperature, insolation and solar altitude and azimuth are the uncontrolled variables while loading, tracking, temperature sensing are the controlled variables. From Funk's definition, cooking power (P) is defined as the rate of useful energy available during heating period. It may be determined as a product of the change in water temperature for each interval and mass and specific heat capacity of the water contained in the cooking utensil. Dividing the product by the time (600 seconds contained in a ten minute intervals according to American Society of Agricultural Engineers) contained in a periodic interval yields the cooking power in watts:

$$P = \frac{MC_W\ \mathrm{dT_w}}{dt} \quad \text{... (3)}$$

Where P is cooking power (W), M is mass of water (kg), C_w is specific heat of water (4186 (J/kg/°C), dT_w is temperature difference of water (°C) and dt is time interval (s).

Standardized cooking power (P_s): Funk (2000) also introduced the term standard or adjusted cooking power (P_s) which can be expressed as:

$$P_s = \frac{700\ MC_W\ \Delta\mathrm{T_w}}{600\ G_s} \quad \text{... (4)}$$

Where P_s is standard cooking power, ΔT_w is temperature difference of water load in every 10-minute intervals and G_s is average solar radiation on surface during this time period. As per this test protocol wind speed should be less than 1 m/s and water temperatures of the pots should be recorded in between 40 and 90°C. Ambient temperature and solar radiation should be in the range of 20-35°C and 450-1100 W/m^2, respectively (Funk, 2000). For the intercept area of a cooker 7 kg water/m^2 should be distributed evenly in the pots. The intercept area is defined as the sum of the reflector and aperture areas projected onto the plane perpendicular to direct beam radiation. For box type solar cooker intercept area has been found to be 0.448 m^2, so the water load for cooking power test has been taken 3.0 kg and distributed in four containers.

Temperature difference: This is the difference between ambient temperature for each interval and the average cooking vessel contents temperature for each corresponding interval:

$$T_d = T_w - T_a \quad \text{... (5)}$$

Where T_d is temperature difference (°C), T_w is water temperature (°C), and T_a is ambient temperature (°C).

Efficiency of the box type solar cooker (η): Performance of solar cooker was carried out extensively by measuring stagnation plate temperature and rise in water temperature in cooking utensils in known interval of time. The stagnation plate temperature was measured by putting four numbers of thermo-couples on the plate and on air inside cooking chamber and temperature of each was measured by the portable digital thermometer with suitable sensor (accuracy 0.1°C) and average of initial and final were taken. The initial temperature of cold water was measured. The final temperature of hot water and time interval was also measured. The efficiency of the cooker was determined by the following relations proposed by Nahar (2001 and 2009):

$$\eta = \frac{\left(MC_w + M_1C_u\right)\left(T_{w2} - T_{w1}\right)}{CA\int_0^t Gdt} \quad \text{... (6)}$$

Where A = Absorber area (m^2); C = Concentration ratio; C_u = Specific heat of cooking utensil (J/kg/°C); C_w = Specific heat of water (J/kg/°C); G = Solar radiation (W/m^2) ; M = Mass of water in cooking utensils (kg); M_1 = Mass of cooking utensils (kg); T_{w1} = Initial temperature of water (°C); T_{w2} = Final temperature of water (°C); t = Time interval (s) and η = Efficiency of box type solar cooker (%).

Statistical analysis: The paired-samples t-test of high and low insulation box type solar cookers was worked out by using the following relation (Kim, 2015)

$$t = \frac{(\Sigma D)/N}{\sqrt{\dfrac{\Sigma D^2 - \left(\dfrac{(\Sigma D)^2}{N}\right)}{(N-1)(N)}}}$$

Where ΣD = Sum of the differences of cooker; ΣD^2 = Sum of the squared differences of cooker and N= Number of observations.

Energy Saving and Economic Analysis of High Insulation Box type Solar Cooker

It has been assumed that the cooker will cook both meals if the duration of bright sunshine hours exceeds 9 h/day, while it will cook only one meal if the duration of bright sunshine hours is less than 9 h/day but more than 6 h/day. By analyzing 50 years data of the duration of bright sunshine hours measured at Jodhpur, India, it was found that the cooker will cook both meals for about 280 days and one meal per day for about 15 days in a year at Jodhpur. The energy for cooking per person is about 900 kJ of fuel equivalent per meal (Nahar, 2001). The developed solar cooker is capable of cooking for about five persons. The payback period and NPV (Net Present Value) of the high insulation box type solar cooker has been computed by considering the equivalent savings in alternate fuels, viz. firewood, coal, kerosene, liquid petroleum gas (LPG) and electricity. The payback period has been calculated by considering the compound annual interest rate, maintenance cost and inflation in fuel prices and maintenance cost per year. The payback periods and NPV (Net Present Value) for box type solar cooker was computed by using the following relations, respectively (Nahar, 2001 and Mahavar *et al.,* 2012):

$$N = \frac{\log\left[\frac{(E-M)}{(a-b)}\right] - \log\left[\left(\frac{E-M}{a-b}\right) - C\right]}{\log\frac{(1+a)}{(1+b)}} \quad \text{... (7)}$$

$$NPV = \frac{(E-M)}{(a-b)}\left[1 - \left(\frac{1+b}{1+a}\right)^n\right] - C \quad \text{... (8)}$$

Where, a = Compound interest rate per annum; b = Inflation rate in energy and maintenance per annum; C = Cost of the cooker (Rs.); E = Energy savings price for commonly used fuels such as firewood, coal, kerosene, LPG and electricity per year (Rs.); M = Maintenance cost of the system per year which increases at the rate of b every year, inflation in fuel price is assumed same to the rate of increasing maintains cost, n = number of years and N = Payback periods (yr). The economic evaluation and payback periods have been computed by taking interest rate (a) as 10%; maintenance (M) as 5% of the cost of solar cooker and inflation rate (b) as 5%. The cost of a solar cooker is only Rs 4500.00. The exact payback periods was computed from eq. (7) with respect to different fuels. .

CO_2 Emission Reduction Potential of Solar Cooker for Different Fuels

The carbon dioxide (CO_2) emission of various fuels was provided by the Renewable Energy System (Quaschning, 2015). The CO_2 emission on annual basis is dependent on the type of fuel and its consumption per annum. Calorific value and carbon content of the fuel are prime factors of CO_2 emission. The high insulation box type solar cooker seems to be a promising option for energy conservation and it also helps in cutting the CO_2 emission.

RESULTS AND DISCUSSION

First Figure of Merit (F_1) without water load (stagnation test): The thermal evaluation experiment to determine the stagnation temperature of the high insulation box type solar cooker was carried out during clear sky condition in April 2017. The stagnation temperature experiment test that is, no load test was started at 10:00 h. The plate temperature increased up to 100°C within half an hour and stagnated at about 140°C at around 13:00 h. The increase in stagnation temperature corresponding to the solar radiations is shown in Fig. 2. The highest temperature attained by plate was 145°C (T_a= 37.0°C, T_{ps}= 145°C, G_s= 900 W/m^2). This result for cooker with other box type solar cookers is given in Table 1. This table 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 (glass wool) to reduce thermal losses while maintaining the same absorber area. The enough insulation material indicates good thermal performance of the cooker.

Fig.2 also illustrates the variation of plate and ambient temperature with insolation. The stagnation temperature varied between 122°C and 145°C with the variation in insolation from 852 to 924 W/m^2. This figure also shows that the plate temperature remained around 121°C for more than 5 hours which is long duration for satisfactory cooking. The first figure of merit F_1 was calculated using Eq (1)

Table 1: Comparison of performance of present solar cooker at stagnation time with other box type solar cookers

Reference	Date of experiment	Time (IST)	Ambient temperature (°C)	Insolation value ($W.m^{-2}$)	Stagnation temperature (°C)
Negi and Purohit (2005)	March 2002	12:00	27	750	140
Kumar et al. (2008)	-	1:40	37	858	138
Mirdha and Dhariwal (2008)	-	1:30	37	-	163
Harmani *et al.* (2010)	23/7/2008	12:00	48	690	140
Purohit and Purohit (2009)	-	12:30	32	950	138
Mahavar *et al*. (2012)	17/6/2009	1:30	35	945	144
Present cooker	**29/4/2016**	**1:30**	**37**	**900**	**145**

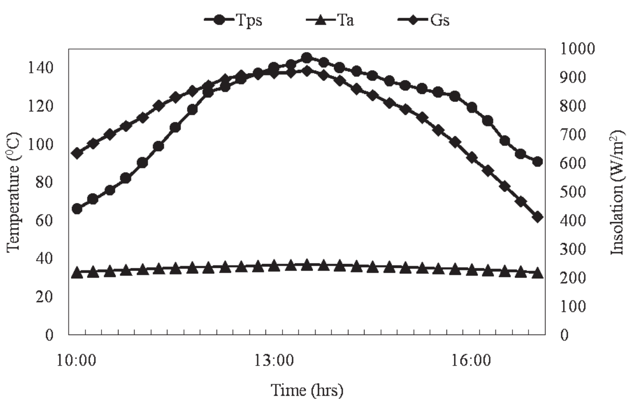

Fig. 2: Stagnation temperature of box type solar cooker for first figure of merit (F_1)

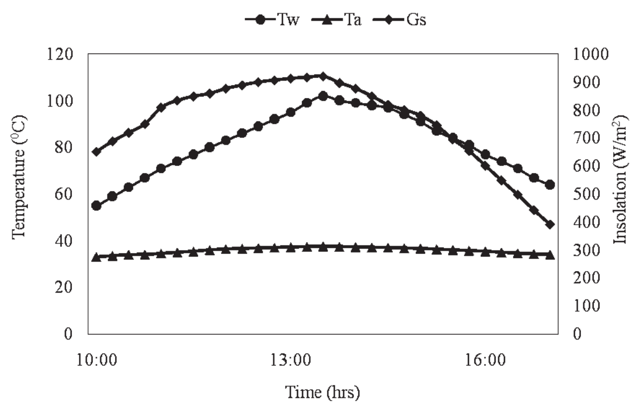

Fig. 3: Water heat up temperature of box type solar cooker for second figure of merit (F_2)

as per the stagnation thermal performance test. The first figure of merit (F_1) was found to be 0.120 (Table 2) 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).

Second Figure of Merit (F_2) with water load (Sensible heat test): To determine F_2, water heat up test was carried out with water load and without reflector in April, 2017 in a clear sky conditions as per IS test code. The base plate temperature reached 82°C within 45 min and it remained higher than this temperature for around 6 hours. The water temperature reached 82°C within 2 hours and remained higher than this for almost 5 hours, which is sufficient to cook two meals. The temperature profile of water, ambient condition and insolation during test are shown in Fig. 3. 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 (F_2) using Eq (2) was found to be 0.424 (using F_1 = 0.120, M = 1.2 kg, C = 4186 J/kg/°C, A = 0.126 m^2, T_{w1} = 71°C, T_{w2} = 102°C, $\overline{G_s G_s}$ = 840 W/m^2, $\overline{T_a T_a}$ = 36.5°C) which was within the recommended standard value in the range of 0.254-0.490.

The similar test was performed for autumn season during October, 2017. The maximum plate temperature (T_{ps}) at 13:30 PM was observed as 129°C when insolation (G_s) was observed to be 820 W/m^2 and ambient temperature (T_a) was 29°C. The value of F_1 came to be 0.121 and that of F_2 as 0.414. Similarly, in winter season in December, 2017, the maximum plate temperature (T_{ps}) at 13:00 PM was observed as 116°C when insolation (G_s) was observed to be 620 W/m^2 and ambient temperature (T_a) was 26°C. The value of F_1 came to be 0.145 and that of F_2 as 0.404 (Mullick *et al.,* 1987). F_1 and F_2 were found acceptable and satisfying the standards (ASAE and BIS) limits. The values of first and second figure of merit (F_2) of this cooker for different seasons are reported in Table 2.

The value of second figure of merit in different seasons is within the range of standard value which indicated good thermal performance of box type solar cooker. A high value of F_2 indicated good heat exchange efficiency factor F′ with number of pots and low heat capacity of the cooker interiors and vessels compared to the full load of water (Lahkar and Samdarshi, 2010). It was found that F_2 increased with load and this is because of an improvement in heat capacity ratio CR, as mass of water in the pots increased (Mullick *et al.,* 1996).

A paired-samples t-test was conducted to compare high and low insulation box type solar cookers. Since table value of t-test at degree of freedom (df) = 3 and probability level (p) = 5% is 3.182 and t-calculated is 2.231, which is less than t-table, there is a significant difference between the means (Table 3). These results suggested that high insulation cooker is more effective as compared to low insulation solar cooker.

Standardized cooking power (P_s): Cooking power experiment was conducted, based on international standard procedure, on May 1, 2017. Experiment was conducted for the load of 3.0 kg of water and distributed in four containers. Box type solar cooker was exposed to the sun light at 10.00 hour to14.00 hour, and initial temperature of water, final temperature of water, ambient temperature and solar insolation were recorded at 10-min intervals. From the data recorded equ. (3), (4), and (5) were used to calculate P, P_s, and T_d for each interval. Standard cooking power (P_s) was plotted against the difference between water temperature and ambient temperature (T_d) as shown in Fig.4.

A linear regression of the plotted points was used to find the relationship between the cooking power and the temperature difference in terms of intercept,

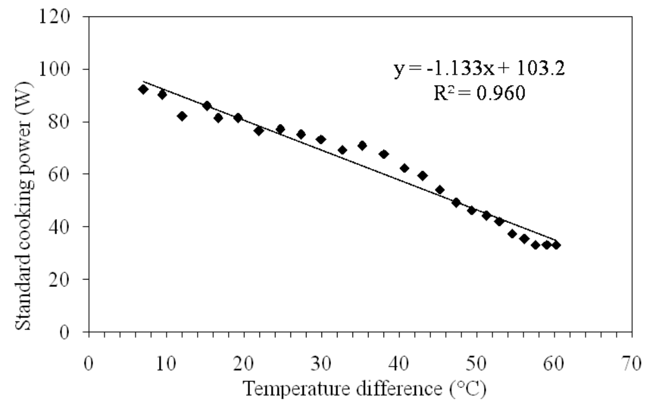

Fig.4. Relationship between the standard cooking power and the temperature difference

Table 2: Figures of merit F_1 and F_2 of cooker during different seasons.

S. No.	Parameters	April, 2017	October, 2017	December, 2017
1.	Ambient temperature (T_a)	37°C	29°C	26°C
2.	Plate temperature (T_{ps})	145°C	129°C	116°C
3.	Solar insolation (G_s)	900 W/m^2	820 W/m^2	620 W/m^2
4.	First figure of merit (F_1)	0.120	0.121	0.145
5.	Second figure of merit (F_2)	0.424	0.414	0.404

Table 3: Statistical analysis of two solar cookers

Time (h)	Temperature (°C)		(Difference)	(D^2)
	High insulation solar cooker	Low insulation solar cooker		
12:30	134	130	4	16
13:00	140	135	5	25
13:30	145	138	7	49
14:00	141	135	6	36
			ΣD = 22	ΣD^2 = 191

W, and the slope, (W°C^{-1}). From Fig. 4 following relation was deduced:

$$P_s = 103.3 - 1.133T_d \quad \text{... (6)}$$

The coefficient of determination (R^2) or proportions of variation in cooking power was found was 0.960 satisfying the ASAE International test standards. According to the ASAE International test standards, the coefficient of determination (R^2), should be better than 0.75 (Funk, 2000). The initial cooking power was found to be 103.3 within the range of the ASAE International test procedure. The standardized cooking power(P_s) was calculated using the regression equation and was 45 W, which is quite high in comparison to the other systems (Funk, 2000; El-Sebaii and Ibrahim, 2005 and Mahavar *et al.,* 2012). The loss coefficient from the slope of the regression line was found to be 1.133 °C/W. High initial cooking power and low heat loss coefficient revealed that the multilayer insulation is an efficient insulation for solar thermal appliances. These values also place the present cooker among small size, good insulation solar cookers as per International Standard (Funk, 2000).

Efficiency of the box type solar cooker (η): The maximum stagnation temperature was observed to be 141°C. The efficiency of the cooker was obtained by putting 750 g of water in each cooking utensils. There are four cooking utensils that can be accommodated in the cooker. Therefore, cooker was loaded with 3.0 kg of cold water. The initial temperature of water was 67°C and when it reached near to the boiling point temperature of water, the final temperature of hot water was 101°C. The efficiency of the box type solar cooker was calculated using the Eq (6) and it was found that 26.5 %. Thermal efficiency of the solar cooker depends on many factors such as solar radiation, mass of the loaded water, time taken to boil the water, control of the reflector etc. So, lots of experiments will be needed to fully understand their effects on thermal efficiency. The present box type solar cooker has shown the best performance and highest efficiency for the maximum load (3 kg) is an indication of better heat retention ability of the cooker as compared with others found in the literature.

Energy saving and economic analysis of high insulation box type solar cooker : The payback period of high insulation box type solar cooker in comparison to different fuels is given in Table 4. It is least, i.e. 1.49 year for firewood and maximum, i.e. 6.99 year for kerosene. Net present value (NPV) varied from 1530 to 19003 INR, according to the fuel type. The estimated life of this solar cooker is 10 years. From Table 4 it is quite obvious that the payback period of box type solar cooker with respect to various fuels is reasonably small. It also revealed that the value of NPV is very high for firewood i.e. these low efficiency cooking fuels which are purchased by poor mass population in urban areas are much more expensive in long run. The shorter payback period suggested that the use of box type solar cooker is economical.

Annual CO_2 emission : Box type solar cooker is in a position to replace 100 percent biomass and save about 815.30 kg of CO_2 on annual basis, if it replaces firewood, Table 5. Considerable amount of CO_2 reduction is also seen in comparison to coal (437.10 kg), kerosene (198.37 kg), LPG (136.07 kg) and electricity (368.79 kg).

The use of box type solar cooker would help in conservation of conventional fuels, such as firewood in rural areas of India, and LPG, kerosene, electricity

Table 4: NPV and payback periods of high insulation box type solar cooker

Type of fuel	Calorific value (MJ kg^{-1})	Efficiency (%)	Cost (INR/kg)	Energy saving (INR)	Net present value (INR) n = 10	Payback period (year)
Firewood	19.89	17.3	9.00	3384.0	19002.9	1.49
Coal	27.21	28.0	15.00	2547.0	12775.7	2.42
LPG	45.59	60.0	40.00	1892.0	7902.5	3.12
Kerosene	45.55*	48.0	17.5***	1035.5	1530.0	6.99
Electricity	3.6**	76.0	6.00 ****	2837.2	14934.5	1.94

MJ/l, **MJkWh^{-1}, * per l, **** kWh^{-1}*

Table 5: Annual CO_2 emission saving of box type solar cooker for various types of fuel

Type of fuel	Calorific value ($MJkg^{-1}$)	Annual fuel saving, kg	CO_2 emission ($kgMJ^{-1}$)	Annual CO_2 emission (kg)
Firewood	19.89	374.00	0.1096	815.30
Coal	27.21[1]	169.80	0.0946	437.1
Kerosene	45.55*	60.91 ***	0.0715	198.37
LPG	45.59	47.30	0.0631	136.07
Electricity	3.6**	472.87 ****	0.217	368.79

*MJ/l, **MJ/kWh, *** per l, **** kWh^{-1}

and coal in the urban areas. Conservation of firewood would help in preserving the ecosystem thereby increasing the forest area. It is evident from Table 5 that firewood is the highest CO_2 intensive fuel (815.30 kg CO_2 yr^{-1} of firewood) whereas, LPG is the lowest CO_2 intensive fuel (136.07 kg CO_2 yr^{-1} of LPG). Moreover, the use of the box type solar cooker would result in reduction of the release of CO_2 to the environment.

CONCLUSION

The experimental results showed that first figure of merit (F_1), second figure of merit (F_2) and standardized cooking power (P_s) satisfied the Bureau of Indian Standards (BIS) and American Society of Agricultural Engineers Standard (ASAE) and International standards for thermal performance testing of the high insulation box type solar cooker. The thermal efficiency of the high insulation box type solar cooker was 26.5% for the water load of 3.0 kg. The payback period varied between 1.49 to 6.99 years depending upon the fuel it replaced. High insulation box type solar cooker can result in CO_2 reduction in comparison to fuel wood (100%), coal (437.10 kg), kerosene (198.37 kg), LPG (136.07kg) and electricity (368.79 kg).

REFERENCES

Ahmad B. 2001. User and disusers of box solar cookers in urban India-Implications for solar cooking projects. Solar Energy, 69: 209-215.

ASAE. 2003. ASAE S580: Testing and reporting of solar cooker performance.

Bureau of Indian Standards. 2000. BIS standards on solar – box type cooker - IS 13429, Part I, II and III, Manak Bhavan, New Delhi, India.

ECSCR. 1994. Solar Cooker Test Procedure: Version 3.

Elliott D. 2004. Energy efficiency and renewables . Energy and Environment, 15: 1099–1105.

El-Sebaii A A; Ibrahim A. 2005. Experimental testing of a box-type solar cooker using the standard procedure of cooking power. Renewable Energy, 30: 1861-1871.

Funk L A. 2000. Evaluating the international standard procedure for testing solar cookers and reporting performance. Solar Energy, 68: 1-7.

Harmim A; Belhamel M; Boukar M; Amar M. 2010. Experimental investigation of a box type solar cooker with a finned absorber plate. Energy, 35: 3799-802.

Huttunen S. 2009. Ecological modernization and discourses on rural non-wood bioenergy production in Finland from 1980 to 2005. Journal of Rural Studies, 25: 239–247.

Jacobson A. 2000. Solar energy measurements for Ladakh, India. Proceedings of 24th National Renewable Energy Convention of Solar Energy Society of India. pp. 1-12.

Kim T K. 2015. T- test as a parametric statistic. Korean Journal of Anesthesiol, 68(6): 540-546

Kumar N; Agravat S; Chavda T; Mistry H N. 2008. Design and development of efficient multipurpose domestic solar cookers/dryers. Renewable Energy, 33: 2207-11.

Kumar S. 2008. Estimation of design parameters for thermal performance evaluation of box-type solar cooker. Renewable Energy, 30: 1117-26.

Lahkar P J; Samdarshi S K. 2010. A review of the thermal performance parameters of box type solar cooker and identification of their correlations. Renewable and Sustainable Energy Review, 14: 1615–1621.

Mahavar S; Sengar N; Rajawat P; Verma M; Dashora P. 2012. Design development and performance studies of a novel single family solar cooker. Renewable Energy, 47: 67-76.

Mirdha U S; Dhariwal S R. 2008. Design optimization of solar cooker. Renewable Energy, 33: 530-44.

Mullick S C; Kandpal T C; Kumar S. 1996. Testing of box type solar cooker: second figure of merit F_2 and its variation with load an number of pots. Solar Energy, 57: 409-413.

Mullick S C; Kandpal T C; Saxena A K. 1987. Thermal test procedure for box-type solar cookers. Solar Energy, 39: 353-360.

Nahar N M. 2001. Design, development and testing of a double reflector hot box solar cooker with a transparent insulation material. Renewable Energy, 23: 167-179.

Nahar N M. 2009. Performance and testing of a hot box storage solar cooker. Energy Conversion and Management, 44: 1323–1331.

Negi B S; Purohit I. 2005. Experimental investigation of a box type solar cooker employing a non-tracking concentrator. Energy Conversion and Management, 46: 577-604.

Pande P C; Nahar N M; Chaurasia P B L; Mishra D; Tiwari J C; Kushwaha H L. 2009. Renewable energy spectrum in arid region. *In*: Trends in Arid Zone Research in India (Ed. Amal Kar; B.K. Garg; M.P. Singh and S. Kathju), CAZRI, Jodhpur, India, pp: 210-237.

Panwar N L; Kaushik S C; Kothari S C. 2011. Role of renewable energy sources in environmental protection: A review. Renewable and Sustainable Energy Review, 15: 1513–1524.

Purohit I; Purohit P. 2009. Instrumentation error analysis of a box type solar cooker. Energy Conversion and Management, 50: 365-75.

Quaschning V. 2015. Specific carbon dioxide emissions of various fuels. Renewable energy system: Technology-calculation-simulation (ISBN: 978-3-446-44267-2), Carl Hanser Verleg, Munchen, 9th Edition, pp. 1-444. [Online Available]: http://www.volker-quaschning.de/datserv/CO2-spez/index_e.php 2015].

Tingem M; Rivington M. 2009. Adaptation for crop agriculture to climate change in Cameroon: Turning on the heat. Mitigation and Adaptation Strategies for Global Change, 14: 153–168.