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Research Article

THERMAL PERFORMANCE EVALUATION AND ECONOMIC ANALYSIS OF NON-TRACKING SOLAR COOKER

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Abstract: This research paper presents the design, development, thermal performance evaluation, efficiency and payback period of non-tracking solar cooker. Length to width ratio of the cooker was designed as 3.8:1 so that maximum reflected radiation falls on the glass window at any time in a day. It led to removal of azimuthal tracking which is a must for hot box solar cooker. The overall efficiency of the non-tracking solar cooker is 25.2%. During testing in April, 2019, the highest plate stagnation temperature, under no-load condition, approached 138°C. The developed non-tracking solar cooker was tested as per different test procedures as standardized by American Society of Agricultural Engineers (ASAE) and Bureau of Indian Standards (BIS). Stagnation and water boiling test of the solar cooker were performed during April, 2019 to determine the first figure of merit (F_1), second figure of merit (F_2) and standardized cooking power (P_s). Experimental evaluation showed these criteria (F_1, F_2 and Ps) as 0.121, 0.401 and 46.50 W, which indicate that the developed cooker falls under category "A", as per standard. The cooker saves 2587.5 MJ of energy per year. The cost of the cooker is ₹ 9000.00 (1.0 US$ = ₹67.16). The payback period of the solar cooker was calculated as compared to firewood, electricity, charcoal, LPG and kerosene-based cooking. The payback period was 1.58 yrs when compared to firewood.

Keywords: *Thermal performance, Non-tracking solar cooker, Efficiency, Economic analysis*

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Introduction

The need for energy is increasing at a fast rate due to growth of population and industries. If the rate of energy consumption continues to be the same as its present rate, total energy resources of the world will be exhausted in next 50 to 100 years. Therefore, there is need to harness alternate energy sources *e.g.*, solar energy, wind energy, biofuels *etc.* for future energy security. Solar cooking proved to be one of the simplest, viable and attractive options for solar energy utilization and was also found environment friendly and cost effective. Even the solar cooker is very useful 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.*, fuelwood, agricultural waste, cow dung, kerosene *etc.* The environmental effects of fuel wood burning have been reported in several literatures [1-5]. Keeping in mind these environmental problems of fuelwood, a transition towards low polluting energy sources for cooking purpose is required, which will also be very apt for mitigating climate change [6]. Therefore, there is huge potential to replace these non-renewable sources of energy for cooking purpose by solar based cooking devices. Moreover, solar energy is abundantly available in many parts of India, particularly the arid and semi-arid parts of India capture substantial amount of solar insolation (6.0 kWh m^{-2} day^{-1}) with approximately 8.9 average sunshine hours per day at Jodhpur, India [7].

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, which are briefly described below. The hot box type solar cooker in which most of the defects of above two types of solar cookers have been rectified [8-12]. In the box type solar cooker, solar energy is trapped inside an insulated box and 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 [13-18].

Although the performance of these box type solar cooker was found very good, however, it requires tracking towards sun every 30 minutes. Moreover, the box type solar cookers have also been found too bulky and costly. To eliminate the requirement of tracking completely, a non-tracking solar cooker was further designed and fabricated. The length to width ratio of the non-tracking solar cooker was fixed as 3.8:1 to capture maximum amount of reflected radiation by the vertically aligned mirror reflector in addition to direct radiation received on horizontally aligned top glass surface. It removed the need for azimuthal tracking of solar cooker, as the length to width ratio of the cooker was optimized. By using the non-tracking solar cooker one can save about 30-40% of fuel requirement. However, for wide scale adoption of the non-tracking solar cooker, there is need for evaluation of its thermal performance. For this purpose, experiments were carried out at Jodhpur, Rajasthan India with a non-tracking solar cooker in which different standard test parameters recommended by American Society of Agricultural Engineers [19] and Bureau of Indian Standards [20,21] *e.g.*, first figure of merit (F_1), second figure of merit (F_2) and standardized cooking power (P_s) were evaluated following standard methods [22]. Net present value (NPV) and payback periods for the developed cooker with respect to the various fuels such as fuel wood, charcoal, kerosene, LPG and electricity have also been presented.

Materials and Methods

Design of Non-tracking solar cooker

Double-glazed non-tracking solar cooker with reflector was designed and fabricated at the workshop of ICAR-Central Arid Zone Research Institute, Jodhpur, India. The cooker is based on hot box principle with dimensions of 1090×285×150 mm. The cooker was designed in such a way that the length to width ratio of the cooker has optimized so that maximum amount of radiation falls on the glass window any time during the day.

The availability of reflected radiation depends on length width ratio of solar cooker which are given as 20%, 33%, 40% and 42% for length to width ratio 1, 2, 3 and 4 respectively [23]. A second order polynomial relationship was established between length width ratio and available reflected radiation which is given as $Y = -2.75\ x^2 + 21.05 + 1.75$ ($R^2 = 0.999$) [Fig-1], which was optimized by putting $dy/dx = -5.5\ x + 21.05 = 0$ and solved for $x = 3.8$ for maximum reflected radiation. As the value of $d^2y/dx^2 = -5.5$ found negative, it is evident that the most suitable value of length width ratio is 3.8 for getting maximum reflected radiation. As far as fabrication is concerned the outer box is made of galvanised steel sheet (22 SWG) and inner of aluminium (22 SWG). The space between the outer box and inner box was filled with glass wool insulation. The inner tray is painted black using black board paint. Two horizontal glass covers (4 mm thick) fixed on a removable angle iron-wooden frame were provided over it. The spacing between the two glass covers was maintained at 15 mm to avoid thermal losses. A 4 mm thick plain mirror reflector is fixed over it. The tilt of the reflector can be varied from 0° to 120° depending upon the season and its tilt is fixed once in a fortnight. The reflector was folded on the cooker while the device is not in use. The aperture area of the solar cooker is 0.30 m². Four cooking utensils of aluminium/stainless steel boxes with lid can be kept inside it for cooking four dishes simultaneously. The cooker is fixed on an angle iron stand. Actual installation of the non-tracking solar cooker is shown in [Fig-2].

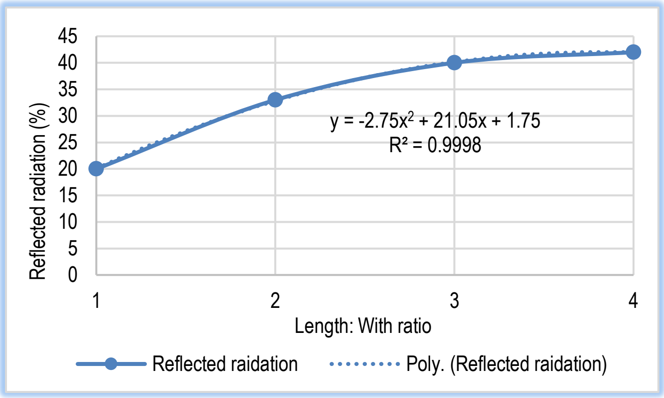

Fig-1 Reflected radiation as affected by length width ratio of solar cooker

Fig-2 Installation of the non-tracking solar cooker

Experimental procedure

The on-field experiments at the ICAR-Central Arid Zone Research Institute, Jodhpur, India (26°18'N and 73°04'E) were carried out using the non-tracking solar cooker during the month of April, 2019 in clear sky condition. In these experiments, the solar radiation intensity (Gs) on a horizontal surface was measured using a thermopile pyranometer. DTM-100 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 thermal performance of the non-tracking solar cooker was carried out in terms of first figure of merit, F_1, second figure of merit, F_2 and standardized cooking power (P_s).

Thermal Performance without Water Load (Stagnation test)

According to Bureau of Indian Standards (2000) and Mullick *et al.* (1987) the first figure of merit (F_1) is determined through the stagnation test. In this test the temperature of bare plate, without reflector is recorded along with the insolation and ambient temperature. In stagnation test initially temperature of bare plate increases and after some time it gets stagnant, at stagnation F_1 is obtained through the following relation (BIS, 2000 and Mullick *et al.*, 1987). It is defined as the ratio of optical efficiency, (η_0), and the overall heat loss coefficient, (U_L) given as below:

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

Where,

F_1 = First Figure of Merit, η_0 = Optical Efficiency, %, U_L = Overall heat loss coefficient of the cooker, W.m^{-2} °C, T_{ps} = Maximum plate surface temperature, (°C), T_a = Ambient temperature, (°C) and G_s = Global solar radiation on a horizontal surface, W.m^{-2}.

Thermal performance with water load (Sensible heat test)

The second figure of merit, F_2, of non-tracking solar cooker is evaluated under full-load condition (water load), without using reflector and is defined as the product of the heat exchange efficiency factor (F'), optical efficiency $\eta_0 = \alpha\tau$) and heat capacity ratio (C_R). It can be expressed as Mullick *et al.*, 1996 [24]:

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

Where,

F_1 = First Figure of Merit, $(MC)_w$ = Product of the Mass of water and its Specific heat capacity, J.°C^{-1}, A = Aperture area of the solar cooker, m², t_1 = Initial time (s), t_2 = Final time (s), T_{w1} = Initial water temperature, °C, T_{w2} = Final water temperature (°C), G_s = Average global solar radiation, W.m^{-2}, and T_a = Average ambient temperature, (°C)

Cooking power estimation

Funk (2000) discussed two types of test variables for cooking power estimation. From Funk's definition, cooking power, P, is defined as the rate of useful energy available during heating period. It is obtained by multiplying the change in water temperature for each time interval by them as sand by the specific heat capacity of the water contained in the cooking pot according to American Society of Agricultural Engineer (ASAE) which is given as below:

$$P = MC_w\, dT_w / dt \qquad (3)$$

Where,

P = Cooking power, W, M = Mass of water, kg, C_w = Specific heat of water, 4186 J^{-1}.kg^{-1}. °C^{-1}, dT_w = Temperature difference of water, (°C), and dt = Time interval, s.

Standardized Cooking Power (Ps)

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

$$Ps = 700\ MC_w\, \Delta T_w / 600\ G_s \qquad (4)$$

Where,

P_s = Standard cooking power, W, ΔT_w = Temperature difference of water load in every 10-minute intervals, °C, and G_s = Average solar radiation on surface during this time period, W.m^{-2}.

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. The range of ambient temperature and insolation are 20-35°C and 450-1100 W/m², respectively. For the non-tracking solar cooker aperture area was 0.30 m², so the water load for cooking power test was taken 3.0 kg.

Temperature difference

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

$$T_d = T_w - T_a \quad (5)$$

Where, T_d = Temperature difference, °C, T_w = Water temperature, °C, and T_a = Ambient temperature, °C.

Cooker Efficiency (η)

The efficiency of the non-tracking solar cooker was determined by measuring stagnation plate temperature and rise in water temperature in cooking utensils in known interval of time. The inside plate temperature was recorded using four numbers of thermocouples on the plate and on air inside cooking chamber. The temperature was measured by a portable digital temperature recorder (Make DTM-100), and the average reported. The initial and final water temperature were measured, whereby thermal efficiency of the cooker is expressed mathematically proposed by Poonia *et al*., (2017 and 2019) as follows:

$$\eta = \frac{(MC_w + M_1 C_u)(T_{w2} - T_{w1})}{CA\int_0^t G dt} \quad (5)$$

Where,

A = Absorber area, m^2, C = Concentration ratio, C_u = Specific heat of cooking utensil, J.kg^{-1}°C^{-1}, C_w = Specific heat of water, J.kg^{-1}°C^{-1}, 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 non-tracking solar cooker (%).

Energy Saving and Economic Analysis

The people's acceptability of the developed system among the common users depends on economic viability, like payback period and its net present value (NPV) with respect to traditional cooking fuels. The comparative study of the energy-saving amount and its economics for different cooking fuels was done. By analyzing 50 years data of the duration of bright sunshine hours measured at Jodhpur, 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 [25]. The cooker is capable of cooking for about 10 persons, and it will save 50% of cooking fuel per meal. Therefore, it will save 9 MJ of energy per meal and 2587.5 MJ of fuel equivalent per year. The payback period and NPV (net present value) of the cooker was computed by considering the equivalent savings in alternate fuels, *viz*. firewood, charcoal, kerosene, liquid petroleum gas (LPG) and electricity. The payback period was 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 of the cooker was computed by the following relations proposed by Nahar, 2001; Poonia *et al*., 2019:

$$PP = \frac{\log\left|\frac{(E-M)}{(a-b)}\right| - \log\left|\left(\frac{E-M}{a-b}\right) - C\right|}{\log\frac{(1+a)}{(1+b)}} \quad (6)$$

$$NPV = \frac{(E-M)}{(a-b)}\left[1 - \left(\frac{1+b}{1+a}\right)^n\right] - C \quad (7)$$

Where,

a = Compound interest rate per annum, b = Inflation rate in energy and maintenance per annum, C = Cost of the cooker, ₹, E = Energy savings price per year, ₹, M = Maintenance cost of the system annum, ₹, n = number of years, and PP = Payback periods (yr).

The economic evaluation and payback periods have been computed by considering the following: Interest rate a = 10%; maintenance M = 5% of the cost of solar cooker and inflation rate b = 5%. The cost of a solar cooker is only ₹9000.00. The exact payback periods have been computed from eq. (6) with respect to different fuels.

Results and Discussion

Commercially available box type solar cookers are about 80% costlier, of lower capacity and needs frequent orientation towards the sun. The present cooker was designed in such a way that the length to width ratio of the cooker was optimized so that maximum amount of radiation falls on the glass window any time during the day.

Stagnation Temperature Test

The cooker was placed on horizontal surface at empty condition with reflectors shrouded with black cloth for the stagnation temperature test. During stagnation temperature experiment test that is, no load test was started at 10:00 hour and observation were taken till the maximum plate temperature (138°C) was achieved at 13.30 hour. The increase in stagnation temperature corresponding to the solar radiations is shown in [Fig-3]. The highest temperature attained by plate was 138°C (T_a= 36.6°C, T_{ps}= 138°C, Gs= 850 W/m^2). 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 first figure of merit F_1 was calculated using Eq. (1) as per the stagnation thermal performance test. The first figure of merit (F_1) was found 0.121 and this value is acceptable as per BIS, 1992, 2000; Mullick *et al*., 1996. Whereas, as per standard F_1 test, if the value of F_1 is greater than 0.12, the cooker is marked as A-Grade and if F_1 is less than 0.12 the cooker is marked as a B-Grade solar cooker. The constructed non-tracking solar cooker is marked as a A-Grade solar cooker. The higher values of first figure of merit indicate good thermal performance of solar cooker as per Poonia *et al*., 2019.

Water Test

Water heat up test experiment of the non-tracking solar cooker was conducted in order to determine the second figure of merit (F_2). The test was carried out in April, 2019 in a clear sky conditions as per International Standard Procedure. As per BIS the full load, *i.e*., 8.0 kg water per meter square aperture area must be equally distributed in all cooking pots. For the aperture area of non-tracking solar cooker (0.30 m^2), full water load was found to be about 2.8 kg; this water load was evenly distributed in four containers during the test. For the full load test water temperatures for T_{w1}= 66°C and T_{w2}= 101°C were chosen. The temperature profile of water, ambient condition and insolation during test are shown in [Fig-4]. The trend of water temperature curve shows that as the time of day progressed, the water temperature increased with increasing solar insolation. The base plate temperature reached 101°C within 45 min and it remained higher than this temperature around 6 h. The water temperature reached 101°C within 3 h and remained higher than this for almost 5 h, which is sufficient time to cook two meals.

For the computation of F_2, the following values were used: F_1 = 0.121, M = 2.8 kg, A = 0.30 m^2, C = 4186 J.kg^{-1}.°C^{-1}, $t_2 - t_1$= 180 min (10800 s), T_{w1} = 66°C, T_{w2} = 101°C, Gave = 850 W.m^{-2}, T_{ave} = 36.4°C. Using Eq (2) second figure of merit F_2 was determined to be 0.401, which was within the recommended standard value in the range of 0.254-0.490 as per Mullick *et al*., 1987. The value of second figure of merit in different seasons is within the range of standard value which indicates good thermal performance of non-tracking solar cooker. High value of F_2 indicates good heat exchange efficiency factor F' and lower heat capacity of the inside surface and vessels compared to the full load of water [26]. It was found that F_2 increased with load, and this occurred because of an improvement in heat capacity ratio CR with increase in mass of water in the pots.

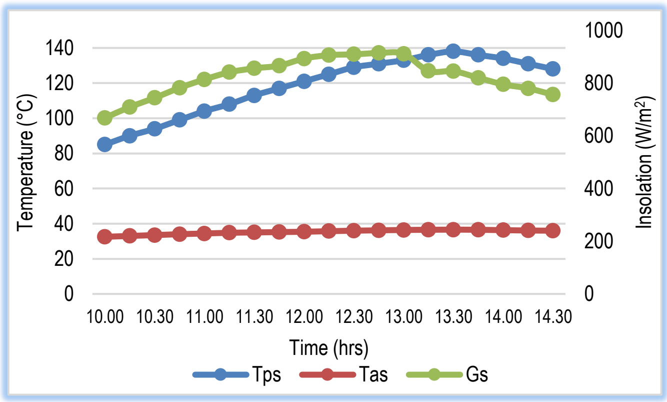

Fig-3 Stagnation temperature test of non-tracking solar cooker for F_1

Table-1 *NPV and payback periods of high insulation box type solar cooker*

Type of Fuel	Calorific Value (MJ kg^{-1})	Efficiency (%)	Cost (₹)	Energy saving (₹)	Net present value (₹) n = 10	Payback period (yr.)
Firewood	19.89 MJ kg^{-1}	17.3	9.00 kg^{-1}	6768	38006	1.58
Coal	27.21 MJ kg^{-1}	28.0	15.00 kg^{-1}	5094	25552	2.19
Kerosene	45.55 MJ L^{-1}	48.0	17.50 L^{-1}	2071	3060	6.00
LPG	45.59 MJ kg^{-1}	60.0	40.00 kg^{-1}	3784	15805	3.12
Electricity	3.6 MJ kWh^{-1}	76.0	6.00 kWh^{-1}	5674	29869	1.93

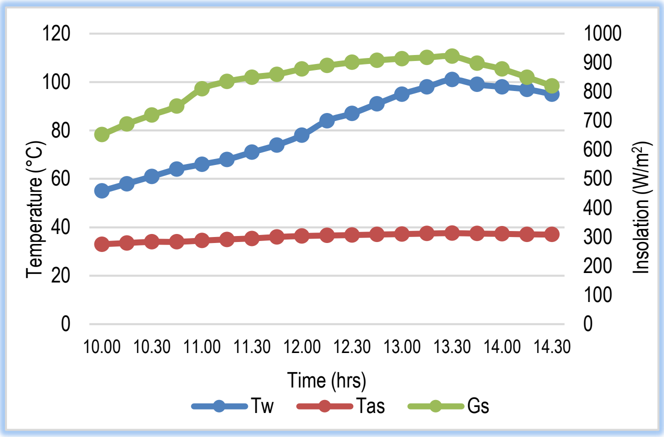

Fig-4 Water heat up test of non-tracking solar cooker for F_2

Cooking Power

Cooking power experiment was conducted based on international standard procedure on April, 2019. Experiment was conducted for the load of 2.8 kg of water and distributed in four containers. Non-tracking solar cooker was exposed to the sun at 10:00 hour to 14:00 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 Eq. (3), (4), and (5) were used, to calculate P, P_s, and T_d for each interval. Relationship between standard cooking power (P_s) and difference between water temperature and ambient temperature (T_d) was established [Fig-5].

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, W, and the slope, (W°C^{-1}). From [Fig-6] the cooking regression equation is:

$$P_s = 102.6 - 1.118T_d \qquad (6)$$

The coefficient of determination (R^2) or proportions of variation in cooking power was found was 0.950, satisfying the ASAE International test standards to be better than 0.75 (Funk, 2000). The initial cooking power was found to be 102.6, and within the range of the ASAE International test procedure. The standardized cooking power (P_s) was calculated using the regression equation to be 46.50 W, which was in comparison to the other systems. The loss coefficient from the slope of the regression line was found to be 1.118°C/W. High cooking power and reduced heat loss coefficient ensured good insulation. These parameters conform to International Standard. [Fig-5] shows that as the temperature difference increased, the standard cooking power decreased. It is, therefore available to cook optimum quantity [27,28].

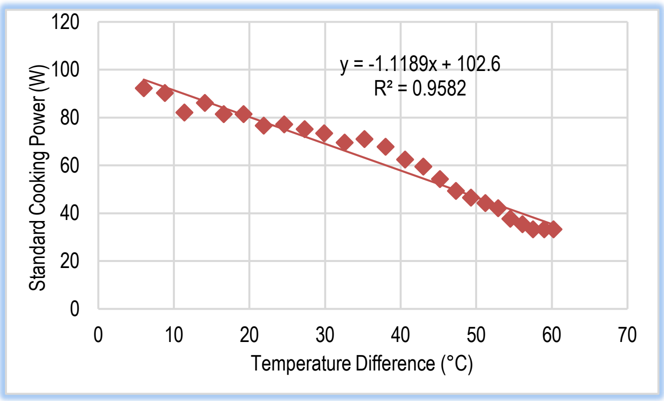

Fig-5 Standard cooking power variations with temperature difference

The maximum stagnation temperature was observed 138°C. The efficiency of the cooker was determined by using 0.7 kg of water in each cooking utensils. There are four cooking utensil that can be accommodated in the cooker. Therefore, cooker was loaded with 2.8 kg of cold water. The initial temperature of water was 55°C, and the final temperature of hot water was 100°C. The efficiency of the non-tracking solar cooker was calculated using the Eq. (6) and was 25.2 %. Thermal efficiency of solar cooker depends upon factors like solar radiation, mass of loaded water, time taken to boil the water, control of the reflector, *etc*. The non-tracking solar cooker demonstrated good performance and highest efficiency at the maximum load of 2.8 kg of water, indicating better heat retention ability of the cooker as compared with some other designs found in the literature [29-30].

Economic Viability of Cooker

The payback period is least, *i.e.*, 1.58 year, with respect to firewood and maximum, *i.e.*, 6.00 year, with respect to kerosene and net present value (NPV) varies 3060 to ₹38006, according to the fuel type [Table-1]. The payback periods are in increasing order with respect to fuel: firewood, electricity, charcoal, LPG and kerosene. The estimated life of this solar cooker is more than 15 years. From [Table-1] it is quite obvious that the payback period of cooker with respect to various fuels is reasonably small. It also reveals 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 suggests that the use of cooker is economical.

The use of non-tracking solar cooker would help in conservation of conventional fuels, such as firewood, animal dung cake and agricultural waste in rural areas of India, and LPG, kerosene, electricity and coal in the urban districts. Conservation of firewood help in preserving the ecosystems and animal dung cake could be used as fertilizer, which could aid in the increase of production of agricultural products. Moreover, the use of the non-tracking solar cooker would result in reduction of the release of CO_2 to the environment.

Conclusion

The non-tracking solar cooker had an operation area (aperture area) of 0.30 m^2 with optimized length: breath ratio of 3.8:1 for receiving maximum reflected radiation and eliminating the tracking requirements. The experimental results showed that first figure of merit (F_1), second figure of merit (F_2) and standardized cooking power (P_s) were 0.121, 0.401 and 46.50 W, respectively, which indicated that the developed cooker is marked as a A-Grade solar cooker as per ASAE and BIS standards. The thermal efficiency of the animal feed solar cooker was 25.2%. The payback period varies between 1.58 to 6.00 years depending upon the fuel it replaces and is in increasing order with respect to the following fuels: firewood, electricity, charcoal, LPG and kerosene. The non-tracking solar cooker seems to be a promising option for energy conservation and also helps cut the CO_2 emission.

Application of research:

The length to width ratio of the non-tracking solar cooker was optimized as 3.8:1 to capture maximum amount of reflected radiation. It removed the need for azimuthal tracking of the cooker, which is very essential for a simple hot box solar cooker. The present cooker has shown the best performance and highest efficiency for the maximum load. Solar cooking promotes the use of renewable solar energy and represents the simplest application of solar thermal energy and has a potential to reduce the consumption of conventional fuels and CO_2 emission, which will help combat desertification.

Research Category: Renewable resources, Alternative energy sources

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Cultivar / Variety / Breed name: Nil

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Ethical Committee Approval Number: Nil

References

[1] Elliott D. (2004) *Energy Environment,* 15, 1099-1105.
[2] Tingem M. and Rivington M. (2009) *Mitigation and Adaptation Strategies Global Change*, 14, 153-168.
[3] Panwar N.L., Kaushik S.C. and Kothari S.C. (2011) *Renewable and Sustainable Energy Review*, 15, 1513-1524.
[4] Huttunen S. (2009) *Journal of Rural Studies*, 25, 239-247.
[5] Poonia S., Singh A.K., Santra P., Nahar N.M. and Mishra D. (2017) *Journal of Agricultural Engineering*, 54(1), 33-43.
[6] Budzianowski W.M. (2012) *Energy*, 41, 280-297.
[7] Poonia S., Singh A.K., Santra P. and Jain D. (2019) *Agricultural Engineering Today*, 43(1), 1-10
[8] Funk P.A. (2000) *Solar Energy*, 68(1), 1-7.
[9] Ahmad B. (2001) *Solar Energy*, 69, 209-215.
[10] Rao A.V.N. and Subramanyam S. (2003) *Solar Energy*, 75, 181-185.
[11] Rao A.V.N. and Subramanyam S. (2005) *Solar Energy*, 78, 19-22.
[12] Kumar S. (2005) *Renewable Energy*, 30, 1117-1126.
[13] Nahar N.M. (1986) *Proc. 7th Miami International Conference on Alternative Energy Sources. Hemisphere Publishing Corporation, New York* 1, 431-439.
[14] Nandwani S.S., Steinhart J., Henning H.M., Rommel M. and Wittwer V. (1997) *Renewable Energy*, 12, 1-20.
[15] Negi B.S. and Purohit I. (2005) *Energy Conversion and Management*, 46, 577-604.
[16] Kumar S. (2008) *Renewable Energy*, 30, 1117-26.
[17] Harmim A., Belhamel M., Boukar M. and Amar M. (2010) *Energy*, 35, 3799-802.
[18] Mahavar S., Sengar N., Rajawata P., Verma M. and Dashora P. (2012) *Renewable Energy*, 47, 67-76.
[19] American Society of Agricultural Engineers. (2003) *ASAE S580: Testing and Reporting of Solar Cooker Performance, ASAE, 2950 Niles Road, St. Joseph, MI, USA*, 825-826.
[20] Bureau of Indian Standards (1992) *BIS standards on solar cooker IS 13429: 1992, Part I, II and III, Manak Bhavan, New Delhi, India*, 1-10.
[21] Bureau of Indian Standards (2000) *BIS standards on solar-box type cooker - IS 13429: Part I, II and III, Manak Bhavan, New Delhi, India*, 1-3.
[22] Mullick S.C., Kandpal T.C. and Saxena A.K. (1987) *Solar Energy*, 39(4), 353-360.
[23] Pande P.C. and Thanvi K.P. (1988) *International Journal of Energy Research*, 12, 539-545.
[24] Mullick S.C., Kandpal T.C. and Kumar S. (1996) *Solar Energy*, 57(5), 409-413.
[25] Nahar N.M. (2001) *Renewable Energy*, 23, 167-179.
[26] Lahkar P. J. and Samdarshi S. K. (2010) *Renewable and Sustainable Energy Review*, 14(6), 1615-1621.
[27] Folaranmi J. (2013) *Journal of Renewable Energy*, 184352, 1-8.
[28] Hermelinda S.C. and Mauricio G.A. (2014) *Energy Procedia*, 57, 1573-1582.
[29] Nahar N.M., Gupta J.P. and Sharma P. (1996) *Renewable Energy*, 7(1), 47-50.
[30] Currin C., Nandwani S.S. and Marvin A. (1994) *In: Proceedings of the Second World Conference on Solar Cookers, Heredra Costa Rica*, 149-158.