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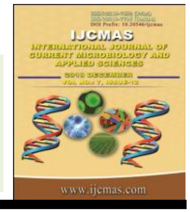

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Performance Evaluation and Cost Economics of Developed Box Type Solar Cooker

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Alternative energy sources are contributing major energy requirements especially solar energy of the world's population particularly in developing countries. In the present research work, a thermal performance of box type solar cooker was analysed according to the American Society of Agricultural Engineers (ASAE) international test procedure and Bureau of Indian Standards (BIS). The experiments were conducted in order to determine the first figure of merit (F_1), the second figure of merit (F_2) and standard cooking power (*Ps*). It was observed that two figure of merits (F_1, and F_2), standard cooking power (P_s) and thermal efficiency of solar cooker were 0.1084, 0.31, 58.41 watt, and 37.76%, respectively. The economic feasibility was determined by comparing it with LPG and fuel wood. The payback period was found 1.08 years and 0.49 year, respectively when LPG and fuel wood was replaced by developed box type solar cooker. Finally, the results indicated that the cooker has a good reliability for cooking food and boiling water.

Introduction

The majorly demand of energy is derived from fossil fuels. Due to the limited stock and depletion of these sources with time, balance between the demand and supply of energy seems to be degrading in the coming years. With the fossil fuel crisis it is polluting in nature. In order to maintain a balance between energy demand and supply of energy, there is a need to exploit renewable energy sources to the maximum limit possible thereby providing a clean, eco-friendly source of energy (Arunachala *et al.*, 2014). Solar cooking is reckoned as a technically and commercially viable option for pollution free cooking, especially in areas with abundant solar radiation. Solar cooking offers an effective method of utilizing solar energy for meeting a considerable demand of cooking energy and, hence protecting environments. The box type solar cooker, however, is still the preferred option for individual family needs, mainly because of its small size and simple handling and operational requirements. There are many designs of solar, electrical and mechanical cookers are available for drying and cooking applications and they are commercially available in the market. Nevertheless, the drying air characteristics in solar dryers and cookers depend on ambient conditions, due to the non-reliable nature of the solar energy. What can reduce the final product's quality and devices becomes less efficient most of the time. Major problems with the electrical dryers are non-availability of electricity and high capital investment which makes it unsuitable for use of rural producers (Chaudhari *et al.,* 2017). A hybrid box type solar cooker cum drying system can be used for cooking food and drying various agricultural products like spices, fruits and vegetables (Chaudhari *et al.,* 2018). There are more than half a million users of box type solar cookers in India (Annual Report, 2003). The box type solar cooker is a device which can utilize direct and diffuse solar radiation, having very little user intervention, easy and safe to use.

Materials and Methods

Experimental setup

The developed box type solar cooker consists of cooking chamber, cooking pots (no. 4) for holding food, reflector for reflecting the radiation showing in Figure 1. The box type solar cooker was made with following components, the frame structure was made from 5 mm thick plywood sheet for outer body, wood strips are used for support the reflector and body. The glass-wool was used as an insulation material; it is lighter in weight and economical for same thermal conductivity and resistance. To prevent the conduction heat losses from bottom and sides, insulation is provided between absorber plate and plywood sheet. The 5 mm glass sheet was used as a transparent cover; it was used to transmit as much solar energy to the absorber plate and to minimize convective heat loss from the absorber plate to the environment. The plane mirror type reflector was used to increase the aperture area of solar cooker. The function of cooking chamber is to put the cooking pot for cooking. The 1 mm thick aluminum sheet was used as an absorber and painted black (selective surface coatings) to increase the absorptivity of it. The aperture area of solar cooker was 0.275 m^2.

Performance evaluation procedure

The developed box type solar cooker was tested to know the thermal performance as well as economic feasibility for cooking at Department of Renewable Energy Engineering, College of Technology and Engineering, Udaipur during 18 to 29 Feb, 2016. The data were recorded at the interval of 30 minutes. The thermal performance tests were carried out in the form of first (no load) (F_1) and second (full load) (F_2) figure of merit as per Indian Standards (IS 13429 (Part 3): 2000.

The solar intensity, ambient temperature, water temperature were recorded to evaluate the test. For better accuracy, the thermal performance test was carried out three times and the average performance was calculated. The techno-economic analysis of the cooker was evaluated in term of net benefit and payback period of cooker.

First figure of merit test

The first figure of merit (F_1) is the stagnation test of solar cooker during no load condition. From the test to know the maximum temperature attained and temperature profile inside the cooker. It is giving as the ratio of optical efficiency, $F_{\eta o}$ and overall heat loss coefficient $F_{ul.}$ (Folaranmi, 2013);

$$F1 = \frac{\eta_o}{U_L} = \frac{T_{pz} - T_{az}}{I_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, $F_{\eta o}$ the system optical efficiency and F_{ul} is the overall heat loss coefficient. T_{pz} is the stagnation plate (tray) temperature (°C), T_{az} is the average ambient temperature (°C) and I_s is the solar radiation in w/m^2 on the aperture area of the cooker. Temperature of based plate of the oven without water load is recorded from 10:00 to 14:00 and simultaneously values of insolation and ambient temperature were also measured given in Table 1.

Second figure of merit test

The second figure of merit (F_2) is the water boiling test conducted to know the thermal performance during load condition of solar cooker. From the test to know the amount of water is sensibly heated in a solar cooker. It is given as below (Folaranmi, 2013);

$$F_2 = \frac{F_1 (MC)_w}{A_c\,(t_2 - t_1)} \ln \frac{\left[1 - \left(\frac{T_{w1} - T_a}{F_1 I_s}\right)\right]}{\left[1 - \left(\frac{T_{w2} - T_a}{F_1 I_s}\right)\right]} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

Where, M_w represent the mass of water in kg, C_{pw} is a specific heat of water in kJ/kg°C, A_c is an aperture area of cooker in m^2, (t_2 - t_1) is the time taken for heating from T_{w1} to T_{w2} in second, T_a is an average air temperature over time period (t_2 – t_1) in °C, I_s is an average radiation over time period (t_2 – t_1) in W/m^2.

Cooking power estimation

The 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 (Purohit, 2014);

$$p = (MC)_w \frac{(T_{w2} - T_{w1})}{T_{ab}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

Where, T_{w1} and T_{w2} represent temperatures of water respectively in at the beginning and end of time duration T_{ab} and T_a the ambient air temperature. The cooking power, P, is plotted against (T_w-T_a) for each pre-specified time interval.

Thermal efficiency of solar cooker

The efficiency has been found to be some important parameter established for evaluating the performance of solar cookers (Bello *et al.*, 2010). The efficiency of the solar box cooker was estimated using the relation (Adegoke and Fasheun, 1998).

$$\eta_c = \frac{(m_p c_p + m_w c_w)(T_w - T_a)}{A_c \times I_s \times t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where, M_p and M_w represent mass of pot (0.322 kg) and water (4.0 kg) respectively in kg, C_p and C_w represent the specific heat capacity of the material (here, aluminum 0.92 kJ/kg^{o}C and water 4.20 kJ/kg^{o}C) respectively, T_w and T_a stand for average water and ambient absolute temperatures respectively,

Techno-economics analysis of developed solar cooker

The economic viability of any system is calculated through economic analysis of the system. For the success and commercialization of any new technology, it is necessary to know whether the technology is economically viable or not.

Use of solar cooker can be replaced by the conventional cooking fuels such as LPG and fuel-wood. For the economic analysis the benefit and payback period was calculated when fuel replace by an LPG cylinder and fuel wood for cooking application.

Energy produced by solar cooker

The heat energy produced by the solar cooker per day can be calculated by using following formula (Singh, 2009);

= Family members x No. of meals x Percent of meal can cook x Heat required for cooking for single person (kJ)

Energy content of an lpg cylinder

Assuming when an LPG cylinder replace by solar cooker, equivalent energy production can be calculated by using following formula (Singh, 2009);

= cylinder's total useful energy / energy produced by cooker per day

The useful energy content of an LPG cylinder can be calculated by using following formula (Singh, 2009);

Useful energy per cylinder =

Total energy from cylinder $\times$ useful energy (0.6)

Payback period of solar cooker replace by LPG cylinder.

$$= \frac{\text{Cost of developed solar box cooker } (Rs)}{\text{Cost of energy saved per year } (Rs)}$$

Energy content of a fuel-wood

Assuming when fuel-wood replace by solar cooker for cooking, Payback period of solar cooker was calculated by using following formula (Garba, 2014);

Payback period =

$$\frac{\text{Cost of developed solar box cooker } (Rs)}{\text{Cost of energy saved per year}}$$

Results and Discussion

The developed solar cooker was evaluated for its technical as well as economic feasibility for cooking system. The experimental data of the thermal performance of cooker at no load and full load test were recorded such as solar intensity, ambient temperature, water temperature. The techno-economic feasibility of the developed system was evaluated in term of net present worth, benefit-cost ratio, and payback period.

For avoiding the errors during experiment the test was conducted in clear weather, and also solar radiation was exceeded 600 w/m^2 during test. For temperature accuracy, it was measured thought "K" type thermocouple and immersed in cooking pot with securely 10 mm above from bottom of pot.

First figure of merit test

During the test quasi steady state temperature, final steady cooker tray temperature is achieved when the stagnation temperature was attained. The cooker was placed in open sun without load and reflector was covered with black cloth. The "K" type thermocouple was placed fixed on different temperature measuring points. Thermocouples are connected with data logger for automatic recording of measured data. Solar irradiance at the slop of aperture of cooker and wind velocity at the level of aperture of cooker was measured through digital solar power meter and digital anemometer, respectively. The test was started at 10.00 AM to till the maximum temperature achieved. The measured data of the test is given in Table.1. The variation of measured parameters of the experiment is shown in Fig.22.

The test was performed in order to determine the first figure of merit and compare it with the standard methods. Recorded values are shown in Table.1. The F_1 was observed 0.1084 by using **Error! Reference source not found.** which was lower than 0.12 A-grade cooker. Therefore, developed cooker marked as a B-Grade solar cooker. The lower value of first figure of merit due to higher convection and radiation losses from the side walls and maybe the side insulator was not thick enough.

Second figure of merit test

During this test solar cooker was loaded with 4 kg of water at 28°C in an aluminium cooking pot and that was painted black. The water has slightly high temperature then ambient temperature. The measuring parameters were recorded at a regular interval of 30 minutes till the water temperature exceeded 95°C. The measured data of the test is given in Table 2. The variation of measured parameters of the experiment is shown in Fig.2 Variation of stagnation test parameters

Fig.3.

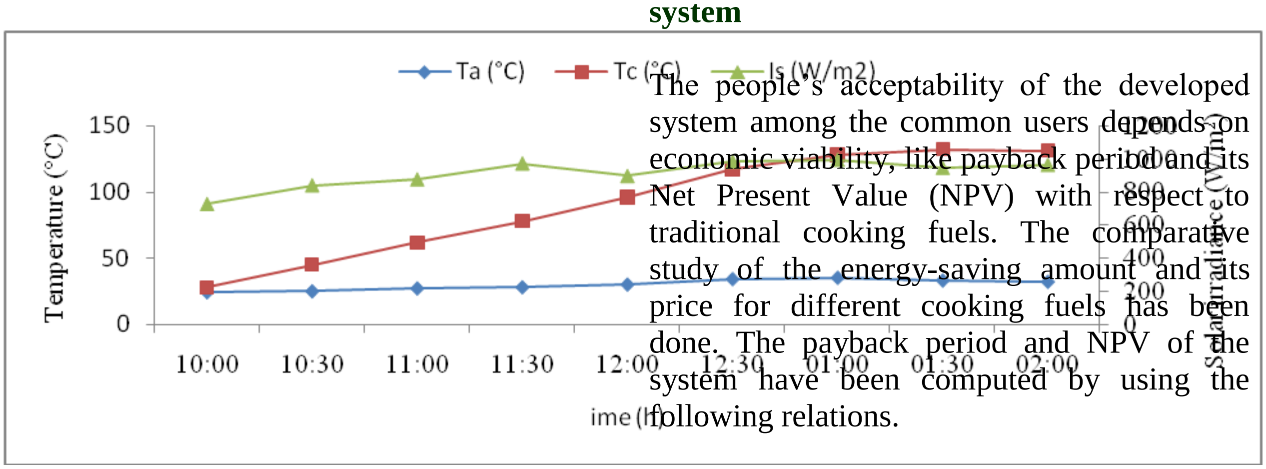
This test was conducted in order to determine the second figure of merit of solar cooker by standard method. The mass of distilled water in the four cooking pots was 4.00 kg and time required for achieving the highest water temperature was 210 minutes. After the interval of 210 minutes, the temperature was increased by 66.30°C. For the test water temperatures for T_{w1} was 29.56 °C and T_{w2} is 95.86 °C were chosen. The following values were recorded at a regular interval during the experiment: ambient temperature, water temperature, insolation, wind speed, and time for the water temperature to increase from 29.56 °C to 95.87 °C as shown in **Error! Reference source not found.** and Figure 3. The second figure of merit F_2 was observed as 0.40 using **Error! Reference source not found.** which is equal to the recommended standard value.

Cooking power estimation and efficiency

The standard cooking power (P_s) of the cooker was calculated 58.41 watt by using **Error! Reference source not found.**. The thermal efficiency of the solar cooker was found 37.76% which was higher than Chaudhari *et al.*, 2018

Cost economics of designed solar cooking system

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 price for different cooking fuels has been done. The payback period and NPV of the system have been computed by using the following relations.



Energy produced by the cooker

The heat energy required for cooking for a single person is 900 kJ (Singh, 2009). The solar cooker was designed to cook for a five head family but it can cook only 80% of the meal while another part of the meal is considered as frying based food. Two meals can be cook per day. The energy produce by solar cooker per day is 7200 kJ.

Energy content of an LPG cylinder

The calorific value of LPG is considered 49371.20 kJ per kg. For the domestic purpose, the weight of an LPG cylinder is typically 14.2 kg of gas. So the total energy content of a full cylinder is 701071.04 kJ per cylinder.

Table.1 Stagnation test

Time	Ta (°C)	Tc (°C)	Is (W/m2)
10:00	24	28	729
10:30	25	45	842
11:00	27	62	878
11:30	28	78	974
12:00	30	96	898
12:30	34	117	985
01:00	35	128	996
01:30	33	132	948
02:00	32	131	965

(Where, T_a ambient temperature, T_c cooker temperature, and I_s Solar intensity)

Table.2 Thermal load test

Time	**T_a (°C)**	**T_w (°C)**	**I_s (W/m^2)**	**Wind Speed(m/s)**
10:00	24.21	29.56	712	0.1
10:30	26.01	33.48	802	0.3
11:00	27.13	39.58	788	0.1
11:30	27.72	48.58	872	0.1
12:00	30.01	61.74	896	0.4
12:30	32.96	73.69	941	0.5
01:00	34.25	88.54	984	0.8
01:30	33.47	95.87	982	0.5
02:00	34.31	96.18	859	0.7

(Where, T_a ambient temperature, T_w water temperature, and I_s Solar intensity)

Fig.1 Developed solar box type cooker during testing

Fig.2 Variation of stagnation test parameters

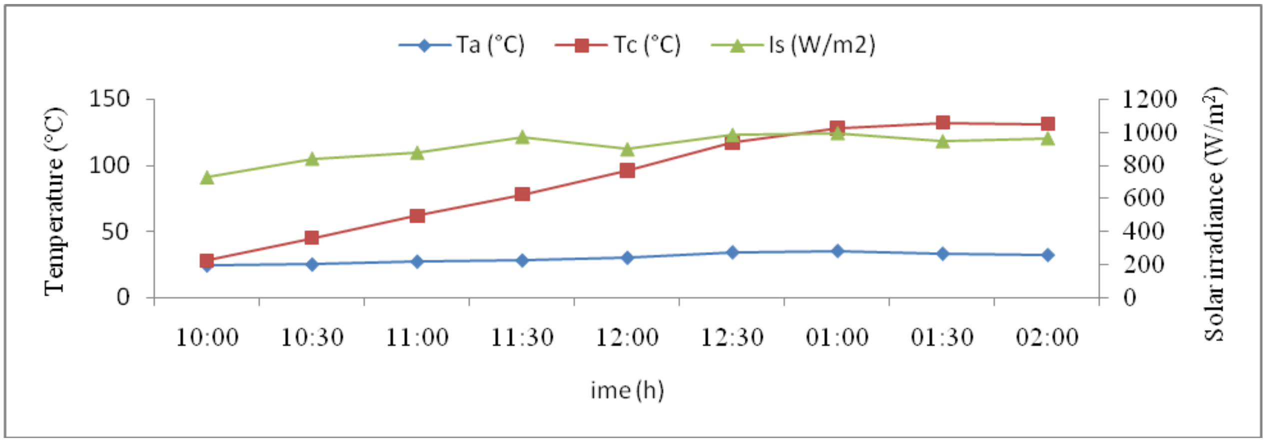
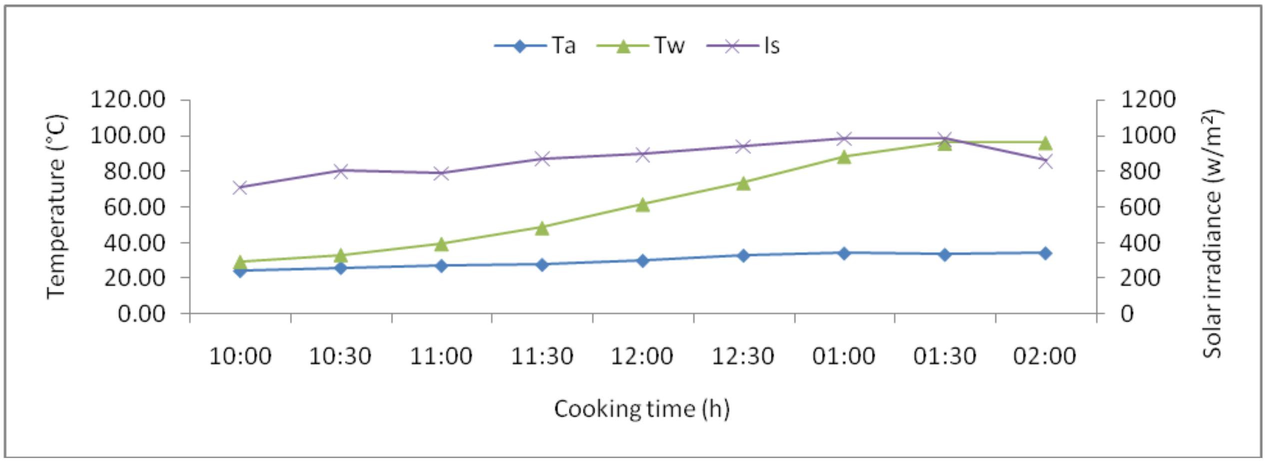


Fig.3 The variation of measured parameters of the full load experiment



The burner efficiency considered only 60% therefore useful energy is 420642.62 kJ per cylinder (Singh, 2009).

When, LPG replace by solar cooker, 58.42 days can be run single cylinder for a family. A family of five members needs 5.13 LPG cylinders in a year. The cost of an LPG cylinder considered 568 (Non-subsidized in Gujarat). The cost of new connection of an LPG with double bottle cylinder (two cylinders and one regulator) along with the cost of LPG is 3550.

So, after subtracting cost of new connection of LPG cylinder from total investment cost of the developed solar cooker, the total cost of solar cooker is 3140.

The payback period is 1.08 years and this cooker can save 51.3 LPG cylinders during its ten years of lifetime.

Energy content of a fuel-wood

When fuel-wood replace by the solar cooker, considering the average daily fuel-wood requirement in developing countries 1.3 kg per person which is mainly used for cooking and heating purpose. Considered 300 sunny days therefore 390 kg fuel-wood require per year for single person and for family needs

1950 kg of wood in a year. Considering cost of fuel-wood is 7.0 per kg. The payback periods is 0.49 years and assume 20% efficiency of wood stoves. So it can save 19500 kg of fuel-wood during its ten years of lifetime.

After conducting performance analysis on the data obtained from the cooker, it is concluded that box-type solar cooker could provide improved heat collection and efficient cooking. This cooker developed 88.41 watt cooking power and 37.76% thermal efficiency which offers faster cooking and reducing the cooking time considerably. It can also be used in India for fast and effective cooking of various types of foods.

References

Adegoke, C.O., Fasheun, T.A. Performance Evaluation of a Solar Cooker under a Tropical Humid Climate. Nigerian Journal of Revenue Energy, (1998): 6(1 & 2): 71–74.

Annual Report, Ministry of Non-conventional Energy Sources, Government of India, New Delhi 11003, 2002-2003.

Arunachala U. C., Anuj Jhalaria, Sheikh Mashhood, 2014, Design, Fabrication and Performance Analysis of Solar Cooker for Night Cooking, Applied Sciences, Engineering & Technology: Pp. 406-412.

ASAE S580.1 NOV 2013 Testing and Reporting Solar Cooker Performance.

Bello, A.M.A., Makinde, V., and Sulu, H.T, (2010), Performance Tests and Thermal Efficiency Evaluation of a Constructed Solar Box Cooker at a Guinea Savannah Station (Ilorin, Nigeria), Journal of American Science, 6(2): 32-38.

Folaranmi, J., 2013, Performance evaluation of a double-glazed box-type solar oven with reflector, Hindawi publishing corporation journal of renewable energy, Volume 2013, Article ID 184352, 8 Pp.

Garba, M.M., and Danmallam, I.M., 2014, Techno-economic and environmental impact analysis of a passive solar cooker for application in Nigeria, The International Journal Of Engineering And Science, 3, 06-10.

IS 13429 (Parts 1, 2 & 3), 'Indian Standard: Solar Cooker', Bureau of Indian Standards, New Delhi (1992).

Purohit, I., and Negi, B. S. (2014). Design and testing of a box type solar cooker employing non-tracking reflectors.

Ramesh Harajibhai Chaudhari and Shubham Bhavsar (2017), Hybrid Solar Box Type Dryer cum Cooker of Chilly Drying For Domestic Usage, International Journal of Science and Research, 6(6): 1614-1618.

Ramesh Harajibhai Chaudhari, Alok Gora, V.M. Modi and Hitesh Chaudhari. 2018. Economic Analysis of Hybrid Solar Dryer for Ginger Drying. Int.J.Curr. Microbiol.App.Sci. 7(11): 2725- 2731.

Singh, C.S, 2009, Renewable Energy Technologies-A practical guide to beginners. PHI Learning Private Limited, New Delhi, Pp. 60-68.

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