



Solar Hybrid System: Innovations in Cooking, Drying, and Power Generation

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2024/v30i31863

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here:

<https://www.sdiarticle5.com/review-history/112784>

Original Research Article

Received: 28/11/2023

Accepted: 02/02/2024

Published: 05/02/2024

ABSTRACT

A hybrid system has been designed and developed which comprises the principle of solar thermal and photovoltaic. Flat plate collector and concentrating trough collector were incorporated under solar thermal technology. Solar thermal device which makes the most using infrared radiation out of solar spectrum. Black copper sheet at focal point of the solar trough served as a stand for cooking pan was able to gain direct as well as high intensity reflected solar radiation to expedite the cooking

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process. The electric unit of the system worked on the principle of photovoltaic effect. Main components of the hybrid system were collector housing, solar trough reflector, triangular shaped glazing surfaces, copper sheet to place cooking pots and dedicated insulation to prevent heat loss. The dual concept hybrid system was found exceptionally speedier as compared to traditional box type cooker. Results revealed that cooking pot attained maximum temperature of 104.50 C at 12.30 pm, which was sufficient for cooking nutritious food. The experiment was conducted in winter season on 18th January, 2018. Average thermal efficiency (η_{therm}) was estimated as 35.1%, cooking power (P) was estimated 47.68 W and the overall heat loss coefficient was calculated 3.03 W/m²°C. Average cooking time found to be just 130 minutes which was otherwise more than 3 hrs in case of traditional box type cooker. Electric power which was stored in the battery can operate 5W dc bulb for 9 hours in single charging. It also could operate smart phone charger and a dc fan (12V, 4Ah) for 60 minutes each.

Keywords: Solar thermal; photovoltaic; hybrid system; cooking; drying; and power generation.

1. INTRODUCTION

Solar cooking presents an alternative energy source for cooking, which is simple, safe and convenient without consuming fuels, and polluting the environment. It is appropriate for hundreds of millions of people around the world with scarce fuel and financial resource to pay for cooking fuel. Drying is basically a simple process for removal of moisture by evaporation from a product in order to reach the desired moisture content and is an energy intensive operation. Drying of fruits, vegetables, and food are essential for keeping them for a long time without further deterioration in the quality of the product. Besides, it is seen that some novel approaches in drying, such as solar-based hybrid drying system are amongst the most promising sustainable technologies [1]. Solar Photovoltaic System has potential to illuminate millions of homes without access to electricity. Looking to the need of a device which can be used for

cooking, drying as well as for power generation for lighting and small fan, a hybrid system has been developed comprising principle of solar thermal and photovoltaic.

2. MATERIALS AND METHODS

The present study was carried out on design, development and performance evaluation of low cost solar thermal and photovoltaic (PV) hybrid system for cooking of pulse, amla drying, lighting and cooling for household usage.

2.1 Thermal Performance Evaluation of Hybrid Solar System

The test for thermal performance of cooking system was conducted as per IS 13429 (Part 3):2000. The thermal performance tests were carried out in the form of first and second Figure of merit [4].

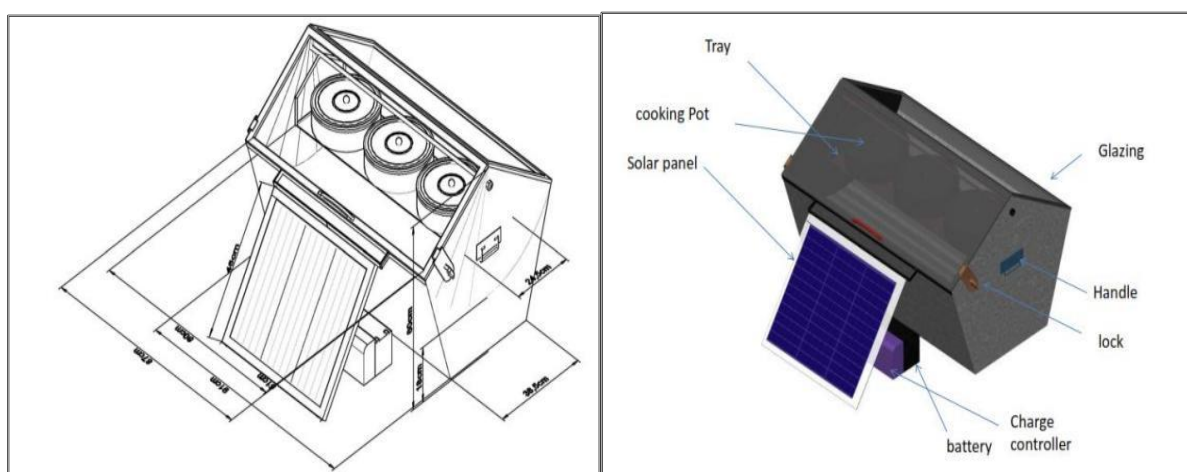


Fig. 1. Schematic diagram and actual image of the system

2.1.1 Stagnation temperature test

The stagnation test (no load) for solar cooker and is giving as; the ratio of optical efficiency F_{no} to overall heat loss coefficient F_{ul} of the collector. It is represented by mathematically as [2];

$$F_1 = \frac{\eta}{1} = \frac{T_{ps} - T_a}{G} \quad (1)$$

Where,

F_1 = Stagnation value
 T_{ps} = Maximum plate surface temperature, °C
 T_a = Average ambient temperature, °C
 G = Average solar radiation, W/m²

2.1.2 Sensible heating of water test

The sensible heat test in which known amount of water is sensibly heated in a solar cooker. The second Figure of merit is given as [2-3].

$$F_2 = F' \eta_0 C_R = \frac{F_1 (MC)_w}{A \tau} \ln \left[\frac{1 - \left(\frac{1}{F_1}\right) \left(\frac{T_{w1} - T_a}{G}\right)}{1 - \left(\frac{1}{F_1}\right) \left(\frac{T_{w2} - T_a}{G}\right)} \right] \quad (2)$$

Where,

F_2 = sensible heat value
 F' = Heat exchange efficiency factor
 η_0 = Optical efficiency
 C_R = Heat capacity ratio
 F_1 = First Figure of merit
 $(MC)_w$ = Product of the mass of water and its specific heat capacity
 A = Absorber area, m²
 τ = Time interval, hr
 T_{w1} = Initial temperature of water, °C
 T_{w2} = Final temperature of water, °C
 T_a = Average ambient temperature, °C
 G = Average solar radiation.

2.2 Cooking Power Estimation

The cooking power was calculated in the form of average cooking power and standardized cooking power [4-5]. According to ASAE S580.

$$P = \frac{(T_1 - T_2) M C_p}{600} \quad (3)$$

Where,

p = cooking power (W)
 T_1 = initial temperature, °C
 T_2 = final temperature, °C
 M = mass of water (kg)
 C_p = Specific Heat Capacity of Water (4168 kJ/[kg-K])

2.2.1 Standardized cooking power

To determine the standardizing cooking power (P_s) from the cooking power (P) and each interval is corrected to a standard insolation of 700 W/m²

$$P = \frac{P_s \times 700}{I_s} \quad (4)$$

Where,
 700 = Standard Insolation, W/m²
 I_s = Average insolation, W/m²

2.3 Overall Thermal Efficiency of Solar Cooker

Thermal efficiency was calculated by following equation [6-8]

$$\eta = \frac{M_f C_f \Delta T_f}{I_{av} A_c \Delta t} \quad (5)$$

Where,

η = Thermal efficiency (%)
 M_f = Mass of cooking fluid (kg)
 C_f = Specific heat of cooking fluid (j/kg.K)
 ΔT_f = Difference between the maximum and ambient air temperature.
 I_{av} = Average solar intensity (W/m²) during the time interval.
 A_c = Aperture area (m²) of the cooker.
 Δt = Time required to achieve the maximum temperature of the cooking fluid (s).

2.4 Performance Evaluation of Drying System

The performance evaluation of drying system was conducted to know the performance of developed dryer at college of Renewable Energy and Environmental Engineering for anola drying. The tests were conducted from 10.00 to 17.00 hrs duration and the hourly data recorded [9].

2.4.1 Moisture content of product

The moisture content of product during an experiment at hourly time interval was determined by calculating the mass of dry matter of product. Moisture content (g water per 100g of sample) at various times, were calculated by the following formula;

$$MC_{(wb)} = \frac{(W_1 - W_2) * 100}{W_1} \quad (6)$$

Where,
 W_1 = weight of sample before drying, (g)
 W_2 = weight of dried sample, (g)

2.4.2 Dry matter

It is the matter left after complete removal of moisture from the product. The dry matter and mass of dry matter in sample was calculated by the following formula;

$$DM (\%) = 100.0 - IMC (wb)$$

$$\text{Weight of DM} = \text{Initial mass of sample} \times \frac{DM\%}{100} \quad (7)$$

2.5 Drying Rate

Drying rate is gram of moisture removed per hour per 100 g of dry matter was calculated by using the following formula,

$$DR = \frac{M_M}{D_M \times t} \quad (8)$$

Where,

M_m = mass of moisture remove kg

D_m = dry mss in kg

T = time

2.6 Dry Matter Recovery

Dry matter recovery is defined as the ratio of final weight of dried product to the initial weight of product and was calculated by using following formula;

$$\text{Dry matter recovery (\%)} = \frac{D_s \times 100}{F_s} \quad (9)$$

Where,

D_s = dry sample weight, gm

F_s = fresh sample weight , gm

2.7 Electrical Performance of Photovoltaic System

$$\text{Total hour} = \frac{\text{batttery power rating}}{\text{sum of applinces power rating}} \quad (10)$$

Table 1. Electrical performance was evaluated based on following load requirements.

Appliances	Power rating
Bulb	5 W
Fan	12 V 4 Ah (48 W)
Mobile charger	5 V 2 Ah

3. RESULTS AND DISCUSSION

3.1 Stagnation Test

It is observed that Fig. 2 shows the ambient temperature, inside cooker tray temperature and solar insolation versus time on winter day of 1st December, 2018 the experiment conducted for the stagnation temperature without load condition. Test of the hybrid solar cooker at 10:00 am, at this time, T_{amb} noticed was around 30.25°C, and solar insolation was 660 W/m². A significant effect of the ambient conditions was observed over plate temperature. Results revealed that inside temperature of cooking box was found to be maximum at 13:35 hrs., which was 102.5°C and humidity varies inside chamber 22 to 11% .

However ambient temperature at that time was 34°C and insolation 690 W/m². Stagnation value F1 under no load of hybrid solar cooker was found to be 0.11 m²°C /W.

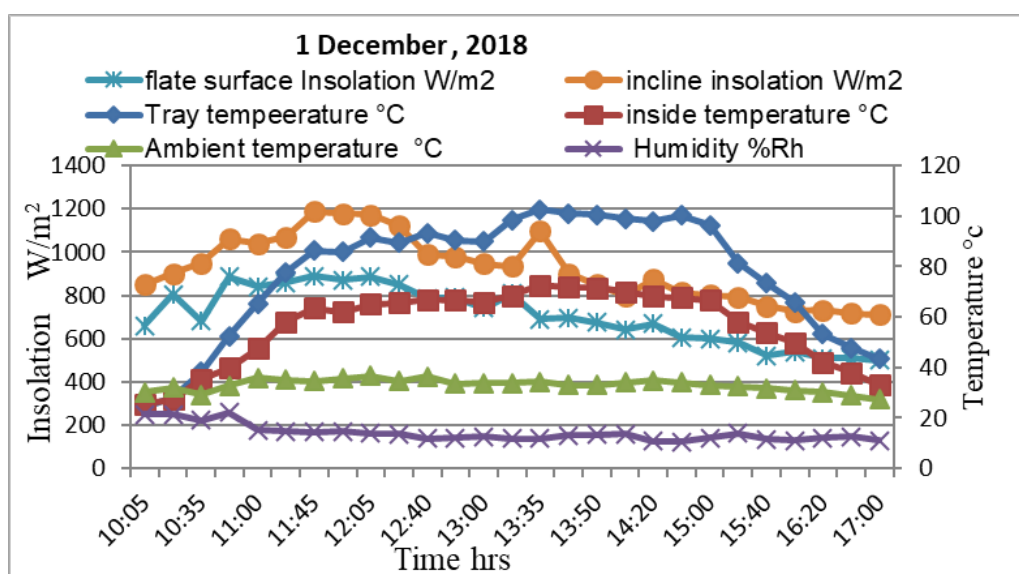


Fig. 2. Stagnation test

3.2 Sensible Heat Test

It is observed that Fig. 3. shows the ambient temperature, inside pan temperature and solar insolation versus time on winter day of 3rd December, 2018. In the experiment 1.5 kg water was considered as a cooking stuff and placed into three cooking pan for an equal quantity (500 grams in each vessel). Test of the Hybrid system was commenced at 10.00 am, where, T_{amb} recorded was around 30°C, T_P (plate temperature) was around 19°C and solar insolation was 660 W/m².

A significant effect of the ambient conditions was observed over plate temperature. Results revealed that inside temperature of cooking pan was found to be maximum at 13:20 hrs., which was 101°C. However cooking temperature of

98.5°C was attained in just 100 minutes of test commenced at 12.30 pm [3]. The temperature showed increasing trend thereafter till 15.20 hrs. Sensible heat (F2) determined by conducting sensible heating test of known mass of water were found to be 0.42 m²°C /W. Average thermal efficiency (η_{therm}) was estimated as 22%, cooking power (P) was estimated 47.68 W and the overall heat loss coefficient was calculated 3.03 W/m²°C. Actual cooking time for cooking of pulse was found to be about 130 minutes which was 180 minutes in case of traditional box type cooker. The experiment was conducted in winter season on 3rd December, 2018 where initial, maximum and final data of horizontal insolation were observed as 879, 786 and 513 W/m² at 11:20, 12.40 and 17.00 hrs respectively.

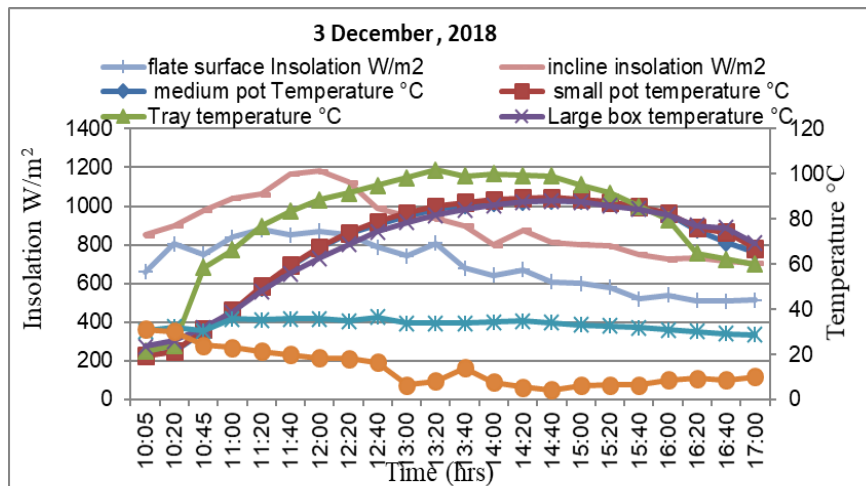


Fig. 3. Sensible heat test

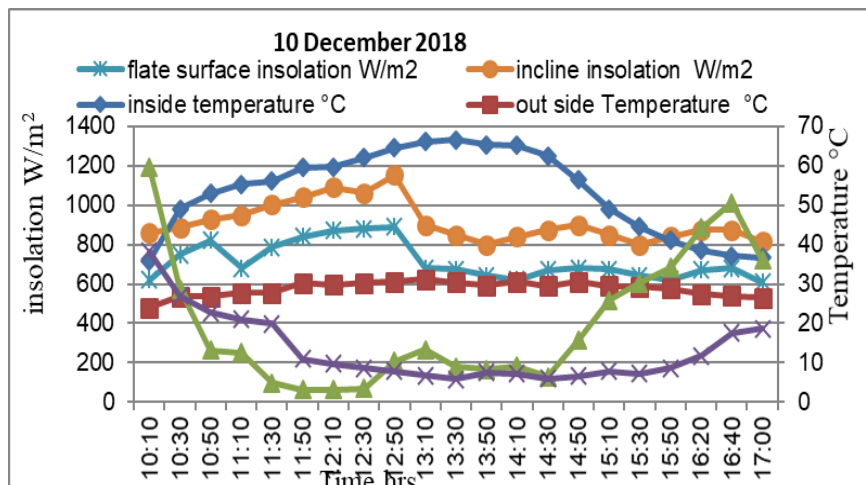


Fig. 4. Drying test

3.3 Drying Test

It is observed in the Fig. 4 shows the humidity, temperature inside and outside of the dryer during the process for the drying of Amla continuously for 14 hrs starting from 10:10 am from 10th to 11th December 2018. The experiment revealed that initial moisture content of Amla as 90.24%, after 14 hrs drying moisture content was 3.14%, drying rate of the hybrid solar cooker was found to be 4.99 kg /h. The quality of product better in term of appearance similar result obtain for solar drying [10,11].

3.4 Electricity Generation

30 W panel which mounted on the hybrid solar cooker generated 150W power per day, which stored in the battery of 12 V, 7Ah. The Figure shows the system can operate 5W dc bulb for 9 hours in single charging, it was sufficient to operate smart phone charger , bulb and a dc fan (12V , 4Ah) for 55 min . Battery charging and discharging performance shown below in the Fig. 5. The battery took 4 hours for full charging.

3.5 Energy Produced by the Cooker

The heat energy required for cooking for a single person is 900 kJ [12]. 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. Considering cooking two meals per day. The heat energy produced by the solar cooker per day is,

$$= 5 \times 2 \times 0.8 \times 900$$

The energy produce by solar cooker per day is 7200 kJ [13].

3.6 Energy Content of an LPG Cylinder

The calorific value of LPG is 49371.20 kJ per kg. For the domestic purpose, the weight of an LPG cylinder is typically 14.2 kg of gas. The total energy of a full cylinder is $49371.2 \times 14.2 = 701071.04$ kJ per cylinder. But only 60% of this energy is used for heating other part goes to waste, therefore useful energy is $701071.04 \times 0.6 = 420642.62$ kJ per cylinder (Singh, 2009).

When LPG will be replaced by solar cooker, the number of days required by solar cooker to produce equivalent energy of LPG cylinder is

$$= \frac{420642.62 \text{ KJ}}{7200 \text{ KJ/Day}}$$

$$= 58.42 \text{ Days}$$

$$= \frac{365}{58.42}$$

=6.25 cylinders are required in a year.

A family of five members needs 6.25 LPG cylinders in a year. The cost of an LPG cylinder is ₹900 (Non-subsidized). New connection of an LPG with double bottle cylinder (two cylinders and one regulator) along with the cost of LPG is ₹4500.

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 ₹6120.

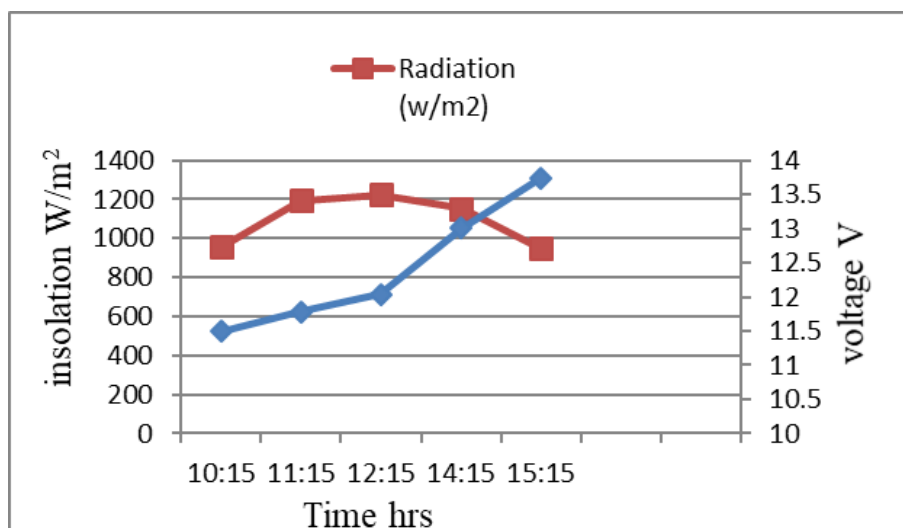


Fig. 5. Battery charging test

$$\begin{aligned} \text{Payback period} &= \frac{\text{Cost of developed hybrid system}}{\text{Cost of energy saved per year}} \\ &= \frac{6120}{5.13 \times 900} \\ &= 1.32 \text{ Years} \end{aligned}$$

The payback period was 1.32 years and this solar cooker can save 51.3 LPG cylinders in ten years of time, estimated to be the lifetime of the developed solar cooker.

4. SUMMARY AND CONCLUSION

It is observed that amla drying moisture content of reduced 90.24 percent to 3.14 per cent, after 14 hrs drying, drying rate of the hybrid solar cooker was found to be 4.99 kg /h. It is observed that actual cooking time was found to be about 130 minutes which was 27 percent lesser than traditional box type cooker. Average thermal efficiency (η_{therm}) of the hybrid system calculated as 22 per cent, cooking power (P) was estimated as 47.68 W and the overall heat loss coefficient was calculated to be 3.03 W/m²°C. The electric unit of the system was found able to operate 5W DC bulb for 9 hours, smart phone charger and a dc fan (12V, 4Ah) for one hour each in single charging. The cost of the system was worked out as Rs. 6120.00.

COMPETING INTERESTS

Authors have declared that no competing interests exist

REFERENCES

1. Canan A, Ibrahim D, Arun M A comprehensive review of recent advances in renewable-based drying technologies for a sustainable future. *Drying Technology*. 2022;40(6):1029-1050. DOI: 10.1080/07373937.2020.1848858.
2. Folaranmi J. Performance Evaluation of a Double-Glazed Box-Type Solar Oven with Reflector *Journal of Renewable Energy*. 2013(1). DOI: 10.1155/2013/184352
3. El-Sebaili AA, Ibrahim A. Experimental testing of a box-type solar cooker using the standard procedure of cooking power. *Renewable Energy* 2005;30:1861–71.
4. Funk P. A. Evaluating the international standard procedure for testing solar cookers and reporting performance. *Solar Energy*. 2000;68(1):1–7.
5. Lahkar PJ, Samdarshi SK. A review of the thermal performance parameters of box type solar cookers and identifications. of their correlations, journal homepage: www.elsevier.com/locate/rser, *Renewable and Sustainable Energy Reviews*. 2010; 14:1615–1621 DOI:10.1016/j.rser.2010.02.009.
6. Ekechukwu OV, Ugwuoke NT. Design and measured performance of a plane reflector augmented box-type solar energy cooker. *Renewable Energy*. 2003;28:1935–52.
7. Gaur A, Singh OP, Singh SK, Pandey GN. Performance study of solar cooker with modified utensil. *Renewable Energy*. 1999;18:121–9.
8. Hussain M, Das KC, Huda A. The performance of a box-type solar cooker with auxiliary heating. *Renewable Energy*. 1997;12(2):151–5.
9. Kumar S, Kandpal TC, Mullick SC. Heat losses from a paraboloid concentrator solar cooker: Experimental investigations on effect of reflector orientation. *Renewable Energy*. 1993;8:871–6.
10. Sanchavat H, Kothari S, Sharma D, Jain N K, Sharma G P, Patel S K. Design and Evaluation of Biomass Combustor and Solar Dryer for Turmeric Processing. *Agricultural Mechanization in Asia, Africa and Latin America*. 2016;47(4):16-20.
11. Pande PC, Thanvi KP. Design and development of a solar cooker cum drier. *International Journal of Energy Research*. 1988;12:539–45.
12. Singh, C.S, 2009, *Renewable Energy Technologies-A practical guide to beginners*. PHI Learning Private Limited, New Delhi, Pp. 60-68.
13. Sharma A, Chen CR, Murty VVS, Shukla A. Solar cooker with latent heat storage systems: A review. *Renewable and Sustainable Energy Reviews*. 2009;13: 1599–605.

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