

Hybrid Solar Box Type Dryer cum Cooker of Chilly Drying For Domestic Usage

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Abstract: *The energy has become a basic need in today's life with drastic increase in power consumption; there is a need to search for an alternate energy source. Solar energy is one such established reliable source. Solar dryer and cooker are used to make use of solar heat energy for domestic use in rural areas but, it is working on ambient temperature and high initial cost is one of the major problems for poor rural people. The present research was conducted on design and development of a low cost hybrid solution for minimise the problems. The function is to developed hybrid dryer cum cooker was work on both electric and solar energy and those where enable to use it in early morning hours and on cloudy days, or when solar radiation decreases or disappears either as a dryer or as a cooker. A thermal performance test of developed solar cooker cum dryer was conducted for solar and for hybrid solutions. The data were evaluated by automatic sensor system for hourly period. The experimental results were thermal efficiency of solar dryer 23.42%, hybrid dryer 38.56% and solar cooker was 29.39%.*

Keywords: Hybrid, Solar dryer, solar cooker, electric heating element, thermal performance, chilly drying

1. Introduction

Agriculture plays an important role in Indian economy as 65-70% of the population depends on agriculture for employment. But yet the national food production could not meet the needs of the populations. Because of post harvest loss of fruits and vegetables are high, And improper preservation of seasonal agricultural products and depleting energy reserves causes considerable loss, thereby reducing the food supply significantly (Sundari et al, 2013).

At the time of harvesting, almost all agricultural products are harvested at high moisture content of 30-35%. Drying is required for improving shelf life of agricultural products mainly vegetables, spices and fruits. Sun drying is the traditional method for drying but it has several drawbacks, solar drying is the very important method for improves the sun drying method. Several research and performance studies on solar dryer with flat plate collectors and heat storage material have been reported aiming at the improvement of the drying system (Ahmad Fudholi et al, 2013).

There are many designs of solar, electrical and mechanical dryers and 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. Developed hybrid dryer cum cooker will become a good alternative for the drying and cooking applications. It can operate around the full day and during any season and it has required less area for operate.

2. Materials and Methods

This study was carried out at CTAE campus in Udaipur. The study area falls at 24°38'N - latitude, 73°42'E – longitude and at an altitude of 582.5m above mean sea level.

The dryer cum cooker consist of chamber box, heating element, air flow facility and mirror type reflector (Fig. 1(a) and (b)). The electrical heating system was fitted to the bottom of existing system to continue drying or cooking operation a few hours after sun set or cloudy period to till the required value and increase the efficiency of system.

When system working as a dryer, air flow entering inside a chamber through an inlet pipe. These are fitted in front of chamber wall with control valves. Humid air going outside through the outlet pipes. These are fitted with back side wall of chamber with closing caps. But when device used as a cooker, air flowing facility can control or close through valves and closing caps.

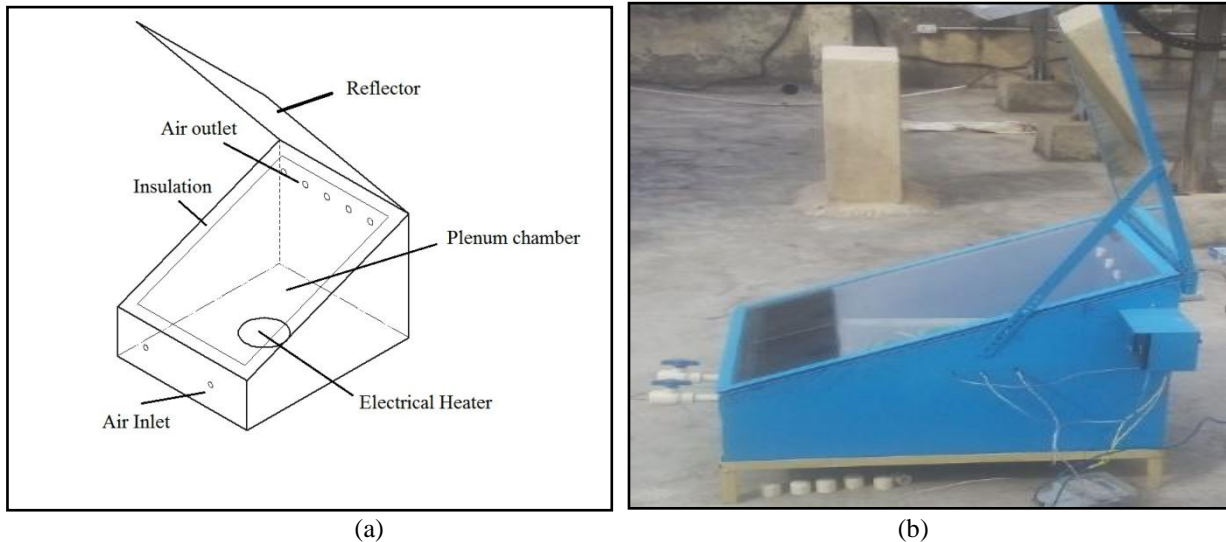


Figure 1: Schematic view and photograph of a hybrid solar dryer cum cooker

Table 1: Specifications of the hybrid solar dryer cum cooker integrated with heating element.

Sr. No.	Particulars	Specifications
1.	Drying capacity of developed system	3 kg of green chili
2.	Cooking capacity of developed system	4 -5 people
3.	Outer size of the developed dryer cum cooker	700 × 600 mm
4.	Inner size of the developed dryer cum cooker	640 × 540 mm
5.	Thickness of insulation to chamber box	25 mm glass wool
6.	Aperture area of collector	0.382 m ²
7.	Transparent glass cover	5 mm thick,
8.	Inlet pipe diameter	10 mm (2 nos.)
9.	Outlet pipe diameter	25 mm (5 nos.)

3. Experimental Procedure

This study was performed in the form of no load and full load condition with and without hybrid system by as a dryer for chili drying and as a cooker for water boiling test. For drying test, 3 kg of fresh green chili was spread on drying tray uniformly and loaded in the dryer in the month of February. One kg of green chili was also spread on floor of around 0.20 m² area for comparing the study with open sun drying. The quantity of the loaded product, drying time, and drying temperature in the dryer, solar intensity, moisture content of the product, ambient temperature and wind velocity were measured through pre-calibrated instruments during experiment.

4. Instrumentations and Devices

(A) A 10 g of fresh and good quality chili sample prepared for determine the initial moisture content, and kept inside to digital moisture analyzer for 10 minutes and temperature maintained at 130°C. (B) Temperature at various locations is measured and recorded with the help of RTD (Resistance Temperature Detector) sensor and digital data Taker (Enviro data logger DT82E). (C) A humidity meter is used to measure the humidity at the entry and exit of the dryer (± 1% accuracy). (D) Solar intensity is measured using a digital solar power meter (TENMARS 207). (E) A digital electronic weighing balance is used for weighing the

samples (D-Sonic Digital scale: ± 0.1g accuracy). (F) A moisture analyzer used for analyze the moisture content of product (Sartorius MA 35). (G) Digital controller (THITHA TDC-96) was used for control the electric heating supply when reach on required temperature range inside the chamber.

Thermal Performance of box type solar cooker: The thermal performance of box type solar cooker is evaluated in the form of F₁ and F₂ respectively.

The first figure of merit (F₁) is the stagnation test (no load) for box type solar cooker and is giving as; the ratio of optical efficiency F_{η_o} to overall heat loss coefficient F_{u_l} of the collector. It is represented by mathematically as (Folaranmi, 2013);

$$F_1 = \frac{\eta_o}{U_L} = \frac{T_{pz} - T_{az}}{I_s} \quad (1)$$

Where, τ is the transmittance of glass, T_{pz} is the final steady cooker tray temperature, °C, T_{az} is ambient air temperature, °C, α is Absorptance of the cooking tray, U_L is heat loss coefficient of the cooker, I_s is solar radiation during steady state, W/m².

The second figure of merit (F₂) is determined by full load test in which known amount of water is sensibly heated in a solar cooker. The second figure of merit is given as (Folaranmi, 2013);

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

Where, M_w is mass of water kg, C_{pw} is specific heat of water kJ/kg°C, A_c is aperture area of cooker in m², (t₂ - t₁) is time taken for heating from T_{w1} to T_{w2}, sec., T_a is average air temperature over time period (t₂ - t₁), °C, I_s is average radiation over time period (t₂ - t₁), W/m².

Thermal efficiency of solar cooker: Thermal efficiency of box type solar cooker was calculated by using following equation (Akoy, 2015);

$$\eta_c = \frac{M_f \times C_f \times \Delta T_f}{A_c \times I_{av} \times \Delta T} \times 100 \quad (3)$$

Where, η_c is thermal efficiency of solar cooker (%), M_f is mass of cooking fluid (kg), C_f is specific heat of cooking fluid, (kJ/kg°C), ΔT_f is difference between the max and

ambient air temperature ($^{\circ}\text{C}$), I_{av} is average solar intensity during the time interval (W/m^2), ΔT is time required to achieve the max temperature of fluid (s).

The average cooking power (P) is defined as the rate of useful energy available during heating period:

$$P = \frac{M_w C_w (T_2 - T_1)}{600} \quad (4)$$

Where, M_w is mass of water (kg), C_w is specific heat of water ($\text{kJ}/\text{kg}^{\circ}\text{C}$), T_1 is initial water temperature ($^{\circ}\text{C}$), T_2 is final water temperature ($^{\circ}\text{C}$).

To determine the standardizing cooking power (P_s) from the cooking power (P) each interval is corrected to a standard insolation of $700\text{W}/\text{m}^2$:

$$P_s = \frac{P \times 700}{I_s} \quad (5)$$

Where, P is cooking power (W), $700\text{W}/\text{m}^2$ is standard insolation.

During the experiment data recorded on hourly basis from 10.00am to 5.00pm. All the drying samples are weighed on hourly basis until the product acquires constant weight that is equilibrium moisture content.

Drying efficiency of solar dryer: The effective total area surface of the dryer for collecting incident radiation is related to the system drying efficiency (η_d), which is given by (Forson, et al, 2007):

$$\eta_d = \frac{M_w \times \lambda_w}{A_c \times I_s \times t} \times 100 \quad (6)$$

Where, M_w is mass of water to be removed during drying (kg), λ_w is the latent heat of vaporization of water (kJ/kg), t is total time required (s), I_s is solar insolation (W/m^2), A_c is total collector area (m^2).

Drying efficiency of hybrid dryer: This is defined as the ratio of the useful output of a device to the input of the device. (η_d), which is given by (Hossain, et al, 2008):

$$\eta_d = \frac{M_w \times \lambda_w}{(A_c \times I_s \times t) + Q_h} \times 100 \quad (7)$$

Where, Q_h is heat produced by electric heater (kW).

5. Results

The thermal performance of developed cooker was conducted in the form of F_1 and F_2 : the value of stagnation temperature tests (F_1) was found 0.11, and as per standards this cooker marked as B- grade cooker. The value of water boiling test (F_2) was found 0.41. The thermal efficiency of solar cooker was 28.93%. The average cooking power was found 84.18 W and standardized cooking power was 63.76 W.

The drying of green chili from initial moisture content 80.58% (wb) to final moisture content was 6.89% (wb), required time for removing moisture are 23 hrs whereas in hybrid condition was 18 hrs.

The drying efficiency of solar dryer was found 19.12% and in hybrid condition was 19.50%.

6. Discussion

The hybrid function was added for improving the overall efficiency of solar cooker and also they have used electricity only for starting; accelerate the temperature, and during the period of insufficient sunshine for cooking. The functions of current study support the previous research in this field (Ali, 2010 and Ebierto 2012).

The thermal evaluation performance test to determine the stagnation temperature test box type cooker was carried out on suitable clear sky. The stagnation temperature test, which is no load test, was started at 10.00 am to till the maximum plate temperature (128°C). This achieved in three hours. The following measurements were taken: solar radiation power ($867\text{W}/\text{m}^2$), ambient air temperature (30°C). This test was performed in order to determine the first figure of merit of the cooker and compare it with the standard. Recorded values for this test was recorded at a regular interval during the experiment are shown in figure 1. Equation (5) was used to compute F_1 . However, the obtained value of F_1 is (0.11) where the allowed standard F_1 test states that 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 cooker is marked as a B-Grade solar cooker. The obtained results of current study support the previous research in this field (Nollens, 2012).

Water heat up test experiment of the solar cooker was conducted in order to determine the second figure of merit (F_2). The test was conducted in a clear sky conditions following the International Standard Procedure. For the full load test water temperatures for $T_{w1} = 25^{\circ}\text{C}$ and $T_{w2} = 95^{\circ}\text{C}$ were chosen. The following values were recorded at a regular interval during the experiment: ambient temperature, water temperature, insolation and time for the water temperature to increase from T_{w1} to T_{w2} as shown in figure 2. The obtained results of current study support the previous research in this field (Folaramni, 2013).

Normally thermal efficiency of box type solar cooker is in range between 20 to 30%. The thermal efficiency of solar cooker was found 29.39%. The obtained results of current study support the previous research in this field 27.6% (Mazen, 2010).

Cooking power experiment was conducted based on international standard procedure. Experiment was conducted for the load of 4.0kg of water. Solar cooker was exposed to the sun at 10.00 am (local time) to 14.00 pm (local time), and the following values were recorded at 10-minute interval: initial temperature of water, final temperature of water, ambient temperature, average wind speed, and solar insolation. From the data recorded (4) and (5) were used, respectively, to calculate P and P_s for each interval. Cooking power and Standard cooking power (P_s) is plotted against the solar radiation as shown in figure 3. The average value of cooking power is 84.18 W and average value of standardized cooking power is 63.76 W. The values of power calculation of current study are not supporting to previous study (Mazen, 2008).

The no load test for developed solar dryer was carried out and found the average temperature attained inside the drying chamber was 68°C. The obtained average ambient temperature was 28°C. The recorded parameters are record on 30 minutes intervals are shown in figure 4. The results of current study are support the previous study which found average drying chamber was 67°C (Ezekoye 2006).

The full load test of developed dryer was carried out with 3 kg of green chili. The initial moisture content of chili was 81.65% (wb) and final moisture content was 5.45% (wb). When dryer running on only solar energy, the time required for removing moisture content was 18 hrs but when use electricity with solar energy for accelerate the drying speed, time required for drying is 10 hrs. The variations of moisture content were shown in figure 5. The results of current study are greater than the previous study. (Bhanu Prakash, 2014). The drying efficiency of developed solar dryer when it running on solar energy only was 19.12% and time required for chili drying was 18 hrs. The results of current study are not support the previous study which found the drying efficiency for drying of sliced tomato, okra and carrot during drying in solar dryer was found to be 21.8%, 21.2% and 24.9% (Eke *et al.* 2013).

The drying efficiency of developed hybrid solar dryer when it running on hybrid mode (electricity was used in morning and evening time) was 19.50% and time required for chili drying was 9 hrs. The working process and results of current study are support the previous study, they developed hybrid solar-electrical dryer and performance of dryer was tested for drying of banana slices (Ferreira, 2007)

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FIGURES:

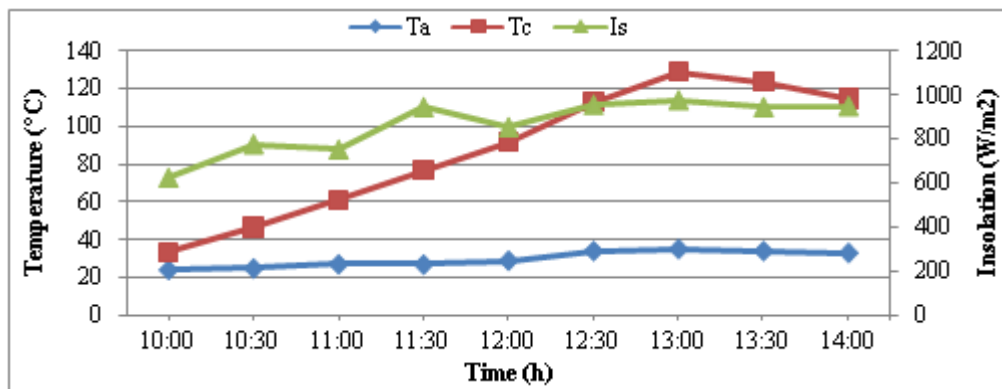


Figure 1: Stagnation temperature test of a solar cooker for the first figure of merit

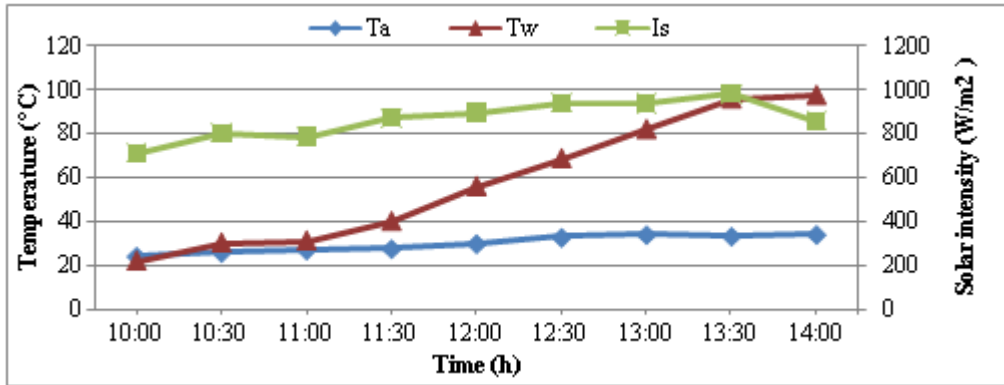


Figure 2: Water boiling test of a solar cooker for the second figure of merit

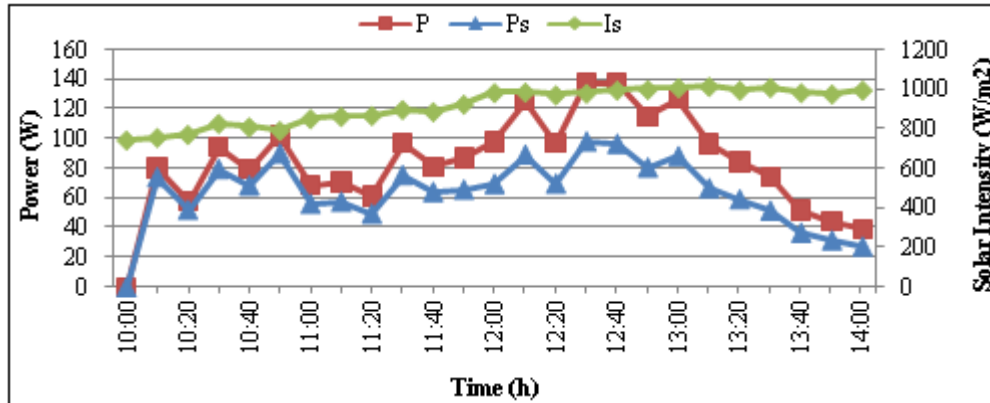


Figure 3: Variation of cooking power (P) and standardized cooking power (Ps)

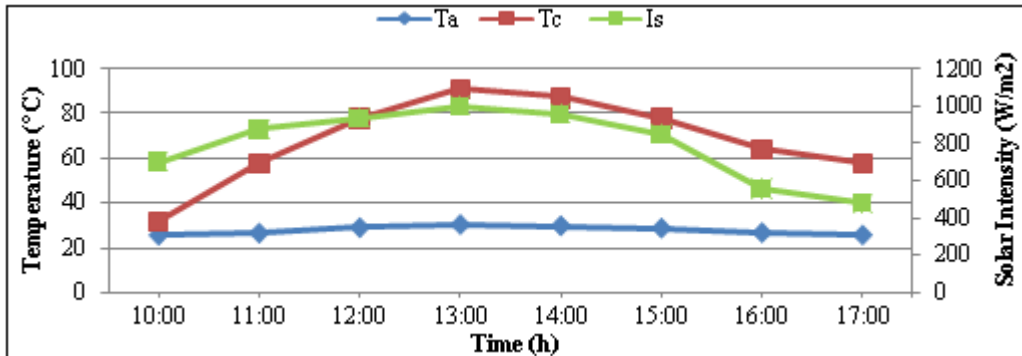


Figure 4: No load curve for solar dryer test

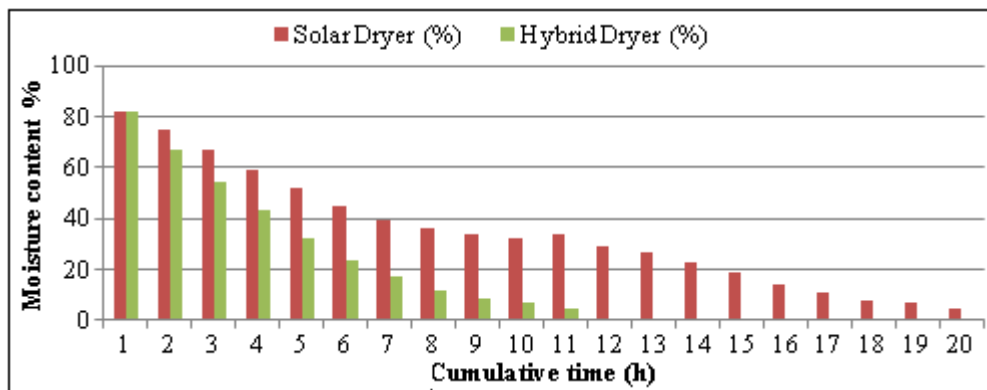


Figure 5: Variation in moisture content of chili drying with respect to time