American Journal of Renewable and Sustainable Energy
Vol. 4, No. 1, 2018, pp. 1-7
http://www.aiscience.org/journal/ajrse
ISSN: 2381-7437 (Print); ISSN: 2381-7445 (Online)

Performance and Evaluation of Pop Can Solar Dryer for Batch Products

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Abstract

The objective of this work was to evaluate performance of pop can solar dryer which works as indirect type passive mode without thermal energy storage for the drying of product. Drying is one of the oldest methods using solar energy where the product such as vegetables, fruits, fish, and meat to be dried exposed directly to the sun. This method has many disadvantages such as spoilt products due to rain, wind, dust, insect infestation, animal attack and fungi. Foods should be dried rapidly, but the speed of drying will cause the outside becomes hard before the moisture inside has a chance to evaporate and it will affect the quality of dried product due to over drying. Food products, especially fruits and vegetables require hot air in the temperature range of 45–75°C for safe drying. This design was employed and has compared with the performance testing through parameters such as temperature, moisture content. All experimentation was carried at Amravati Maharashtra India (Latitude: 20.95 Longitude: 77.75 with 5.44 kWh/m^2/day solar irradiance in normal sunny days. The effect of temperature and moisture contents against time and its effect on rate of drying for chilli are studied in this research. It was clear that the use of pop can solar dryer reduced the drying time significantly and essentially provides better product quality compared with conventional drying method.

Keywords

Air-Heating, Pop Can Collector, Flat Plate Collector, Pop Can Solar Panel

Received: May 14, 2017 / Accepted: March 1, 2018 / Published online: March 24, 2018

1. Introduction

This type of solar dryer was inspired by commercial solar air heater which uses recycled aluminium soda cans stacked end to end to create long tubes for the air flow through it with help of fins, so that where two cans meet causes turbulence in the air flow and make more air flow in contact with inner surface of cans and therefore take more heat from the cans resulting in increased efficiency [1]. Solar energy is the one most abundant renewable energy source and emits energy at a rate of 3.8×10^{23} kW, of which, approximately 1.8×10^{14} kW is intercepted by the earth [2]. On just about all solar thermal collectors, the sun shines through the glazing, and hits the collector absorber heating it One of the most potential applications of solar energy is the supply of hot air for the drying of agricultural, textile, marine products, heating of buildings to maintain a comfortable environment especially in the winter season [3] and re-generating dehumidify agent. Unlike other sources of energy, solar energy can play a significant role for air heating system because the warm air is also the final receiver of energy. This energy possesses a thermal conversion mode which necessitates a simple technology which is adapted to the site and to the particular region for many applications. All these systems are based on the solar air collectors [4]. The air flows through the inlet and over or inside or through the absorber picking up heat as it goes. This heated air then flows out the collector outlet and

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into the room being heated [5]. The main differences between air heating collector designs have to do with how the air flows over the absorber [6-8]. In full sun, the incoming solar energy is about 1000 watts per square meter (m^2) of collector area of this 1000 watts/m^2, about 10% is absorbed or reflected by the glazing and never gets to the absorber, of the remaining solar energy, and about 90% is absorbed by the absorber. So for the 1000 watts/m^2 that arrive at the collector face, about 850 watts/m^2 end up actually heating up the absorber [9-10]. In this sense, proper utilization of solar energy for crop drying can easily be possible by choosing a proper solar dryer.

Figure 1. Working mechanism and schematic view of pop can collector.

Pop Solar dryer can raise the ambient temperature to a higher value for effective drying. Several studies have been reported on drying crops and grains [11]. Figure 1 explains input air with blue colour which is supplied to pop can collector and output air is shown by red colour representing increased temperature which is supplied to drying unit.

2. Description of Pop Can Solar Dryer

The pop can solar dryer was designed, constructed and tested at PRM Institute of Technology and Research Badnera-Amravati (MS) India during the period of 2014–2015. The pop can solar dryer consisted with several parts: pop can solar collectors, drying chamber. A schematic view of the solar dryer is shown in Figure 1. The components and specifications of the pop can solar dryer are given in Table 1 [12].

Table 1. Components and specifications of the pop can solar dryer.

Sr no	Component	Specifications
Pop can Solar collector		
1.	Type	Indirect passive type pop can solar dryer.
2.	Area	1.4 m^2 (171×60 cm).
3.	Transparent surface	Acrylic glass 5 mm thick.
4.	Absorber	2 mm thick pop can.
5.	Collector tilt	15^0 true south.
6.	Insulation	Rock wool 50 mm thick.
Drying chamber		
1.	Type	Vertical Type
2.	Area	0.50 m^2 (76×60 cm).
3.	Height	120 cm.
4.	Insulation	50 mm thick rock wool.
5.	Tray	03 tray made of plywood and aluminium mesh (76 × 60 cm).

3. Material and Method

Basically it is indirect-type dryers with natural convection of air for drying. Especially pop cans are used in solar collector in place of flat plate. In order to increase the capacity of a dryer i.e. operate with more than one layer of trays with crops within the available area, the trays are generally placed in vertical racks with some space in between consecutive trays. Dryer was tested and compared with flat plate collector having same area for both clear and cloudy weather conditions with necessary formulation required for testing, like heat energy balance equation for absorber, heat gained by the air required for drying products, total energy required for drying, mass of water evaporated from drying cabinet and release moisture to the atmosphere [15]. Table 2 shows different parameters and reason for modification of pop can solar collector. Figure 2 shows actual pop can solar dryer with pop can solar collector coloured in matt finish black colour for maximum solar absorption and wooden drying cabinet.

Table 2. Parameters for comparing dryers and reasons for modification.

Sr.No	Parameters	Reasons for modification
1	Maintenance and purchase cost of dryers	Extend useful life and effective for small/large scale farmer.
2	Drying capacity	How much temperature exceeds from existing temperature and quantity of product used at same time.
3	Quality of final product	Final moisture content after drying
4	Adaptability to local conditions	Fits to available condition and material resources.
5	Efficiency	Solar energy used effectively.

The energy balance of the absorber is obtained by equating the total heat gained to the total heat loosed by the heat absorber of the pop can solar collector. Therefore,

$$IA_c = Q_u + Q_{cond} + Q_{conv} + Q_R + Q_\rho, \quad (1)$$

Where: I = rate of total radiation incident on the absorber‘s Surface (Wm^{-2});

Ac = collector area (m^2); Qu= rate of useful energy collected by the air (W);

Q_{cond}= rate of conduction losses from the absorber (W); Q_{conv}= rate of convective losses from the absorber (W);

Q_R = rate of long wave re-radiation from the absorber (W); Q_ρ = rate of reflection losses from the absorber (W).

The three heat loss terms Q_{cond}, Q_{conv} and, Q_R are usually combined into one-term (Q_L), i.e.,

Figure 2. Photograph of experimental setup (Actual Indirect-Type Passive pop can solar dryer).

$$Q_L = Q_{cond} + Q_{conv} + Q_R. \quad (2)$$

If τ is the transmittance of the transparent cover and I_T is the total solar radiation incident on the top surface, therefore,

$$I A_c = \tau I_T A_c. \quad (3)$$

The reflected energy from the absorber is given by the expression:

$$Q_\rho = \rho \tau I_T A_c, \quad (4)$$

Where ρ is the reflection coefficient of the pop can absorber.

Substitution of Eqs. (2), (3) and (4) in Eq. (1) becomes:

$\tau I_T A_c = Q_u + Q_L + \rho \tau I_T A_c$, or

$$Q_u = \tau I_T A_c (1 - \rho) - Q_L. \quad (5)$$

For an absorber $(1 - \rho) = \alpha$ and hence,

$$Q_u = (\alpha\tau) I_T A_c - Q_L, \quad (6)$$

Where α is solar absorbance.

Q_L composed of different convection and radiation parts. It is presented in the following form [13]:

$$Q_L = U_L A_c (T_c - T_a), \quad (7)$$

Where: U_L = overall heat transfer coefficient of the absorber ($Wm^{-2} K^{-1}$);

T_c= temperature of the collector‘s absorber (K);

T_a = ambient air temperature (K). From Equations (6) and (7) the useful energy gained by the collector is expressed as:

$$Q_u = (\alpha \tau) I_T A_c - U_L A_c (T_c - T_a). \quad (8)$$

Therefore, the energy per unit area (q_u) of the collector is

$$q_u = (\alpha \tau) I_T - U_L (T_c - T_a). \quad (9)$$

If the heated air leaving the collector temperature, the heat gained by the air Q_g is:

$$Q_g = .C_{pa} (T_c - T_a), \quad (10)$$

Where:

m_a= mass of air leaving the dryer per unit time (kgs^{-1});

C_{pa}= specific heat capacity of air ($kJkg^{-1} K^{-1}$).

The total energy required for drying a given quantity of chilli can be estimated using the basic energy balance equation for the evaporation of water from chilli as moisture removal [14]

$$m_w l_v = m_a c_p (T_1 - T_2) \quad (11)$$

Where: lv = latent heat ($kJ\ kg^{-1}$); m_w= mass of water evaporated from the food item (kg); m_a= mass of drying air (kg);

T_1 and T_2 = initial and final temperatures of the drying air respectively (K); C_p = Specific heat at constant pressure ($kJ\ kg^{-1} K^{-1}$).

The mass of water evaporated is calculated from Eq. 12:

$$m_w = \frac{m_i (M_i - M_e)}{100 - M_e}, \quad (12)$$

Where:

m_i= initial mass of the food item (kg);

M_e = equilibrium moisture content (% dry basis);

M_i = initial moisture content (% dry basis).

All the readings regarding temperature are measured in Degree Centrigrade (°C) and then converted to Kelvin (K) for calculation purpose.

4. Result and Dryer Performance

Chilli ripe is a popular ingredient in Indian food, and chilli is most common spices cultivated in India. It is grown in all parts of country, hills and plain region. Experimental investigation on drying chilli has been compared with different design and shapes of solar dryers [11]. The moisture content of raw chilli is usually in the range of 75-90%, while dried chilli contains about 4-9% of moisture. Chilli required 5-13 days for open sun drying while by solar dryers drying time varied from 12hrs to 9 days depending on weather conditions and dryer design. The results obtained during the test period revealed that the temperatures inside the dryer and solar collector were much higher than the ambient temperature during most hours of the day-light, as presented in Table 3. The temperature rise inside the drying cabinet was up to 81% for about three hours immediately after 12.00 (noon). The Average temperature values are indicated in the table 3 for comparison point of view.

Table 3. Comparative study of pop can and flat plate solar dryers for chilli.

Type of dryer	Moisture %		Drying time Days	Temperature in °C (degree centigrade)		Load capacity Kg	Efficiency %
	initial	final		Ambient Average	Dryer Average		
Pop can dryer	80	8	01	33.55	60.40	5-10	60.51
Flat plate dryer	80	22	03	33.55	52.45	5-10	29.56

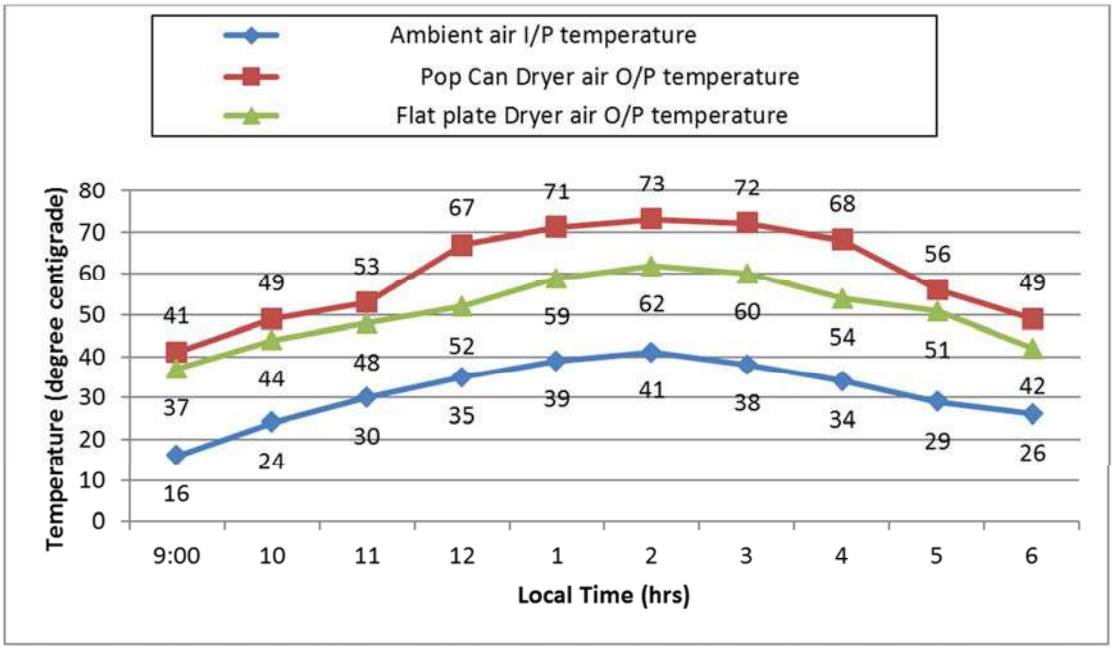

Figure 3. Comparing pop can dryer versus flat plate dryer for same ambient temperature in cloudy weather condition.

From figure 3. it is clear that pop can dryer has attained maximum temperature reading, which indirectly shows pop can dryer is working and given some of the promising results with 73°C maximum output temperature for 41°C minimum input temperature at 2:00 pm in cloudy weather condition.

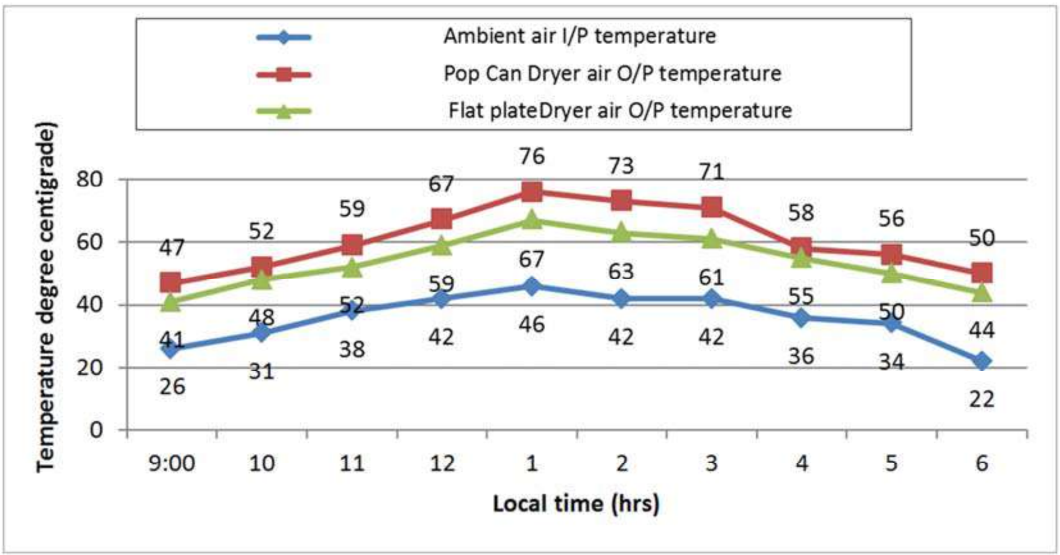

Figure 4. Comparing pop can dryer versus flat plate dryer for same ambient temperature in clear weather conditions.

From figure 4. it is clear that pop can dryer has attained 76°C maximum output temperature for 46°C minimum input temperature at 1:00 pm in clear weather conditions.

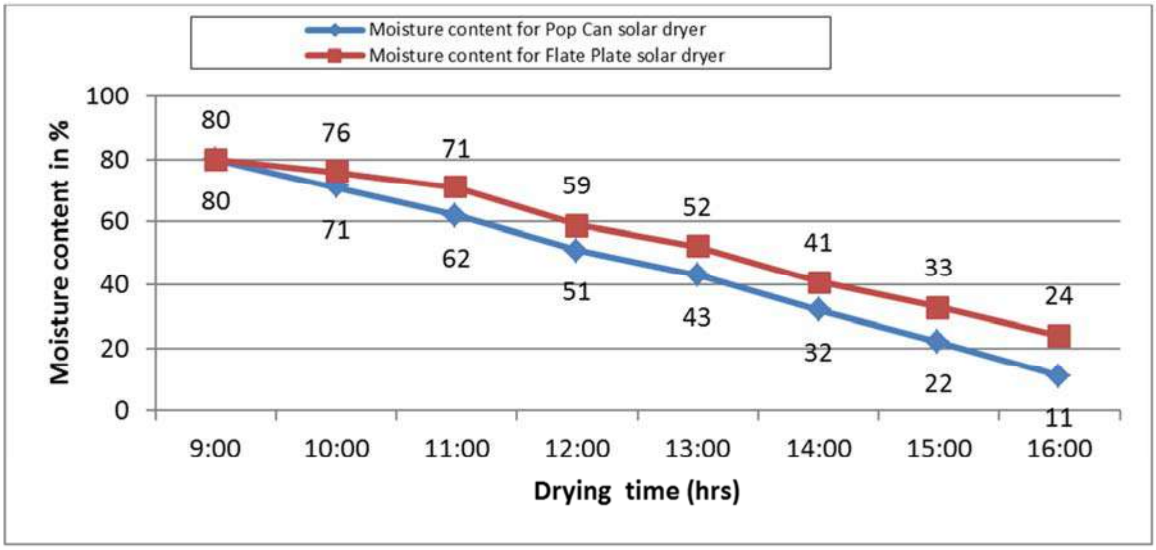

Figure 5. Comparing Drying time versus product moisture content for batch product (potato) with cloudy weather conditions.

Figure 5. explains that there is surprisingly tremendous change or fall in product moisture content in pop can dryer which satisfies basis aim of drying research by reducing 80% moisture content to 11%, and flat plate collector reduces it to 24%.

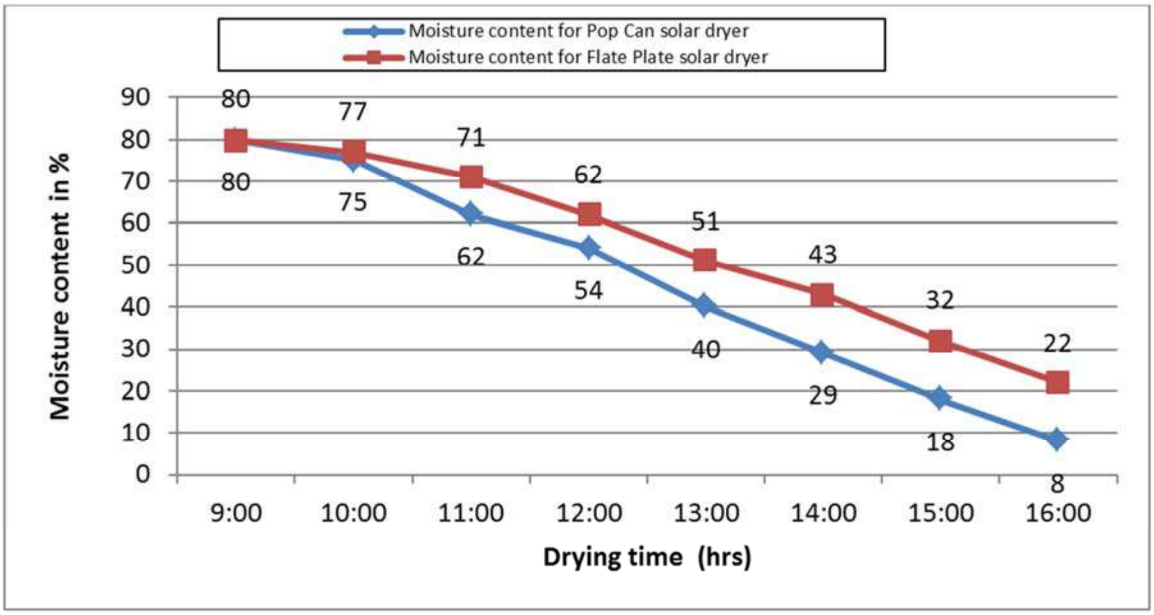

Figure 6. Comparing Drying time versus product moisture content for batch product (potato) with clear weather conditions.

Figure 6. explains that there was surprisingly tremendous change or fall in product moisture content in pop can dryer which satisfies basis aim of drying research by reducing 80% moisture content to 08%, and flat plate collector reduces it to 22%.

5. Conclusion

The simple and inexpensive pop can solar dryer was designed and constructed using locally sourced materials which is the modification as far. The hourly variation of the temperatures inside the cabinet and air-heater are much higher than the ambient temperature during the most hours of the day-light. The maximum temperature rise inside the drying cabinet by using pop can dryer was up to 30°C and minimum temperature rise 28°C in clean weather conditions, and for cloudy weather condition it was 28°C maximum temperature rise and 25°C minimum temperature rise for about three hours immediately after 12.00h (noon). The pop can solar dryer was tested for drying chilli. The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product. Capacity of the dryer was to dry about 5 kg chilli in both sunny and cloudy days from an initial moisture content of 80% to final moisture content of 8% and 11%. Pop can dryer can also be used as room heater in cold weather conditions in Vidharbha region of Maharashtra. It was shown that the use of pop can solar dryer reduced the drying time significantly and essentially provides better product quality compared with conventional drying method in both clear and cloudy weather conditions.

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