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# Thermal Performance of Natural Convection Solar Dryer for Drying Chilli

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**ABSTRACT: The study assesses the performance of a natural convection solar dryer to dry chilli to overcome the shortcomings of traditional open sun drying. The dryer was consisting of two main components collector and drying chamber. A flat plate collector was used for generating hot air. A diffuser type chimney was used for exhausting moisture from the drying chamber. One kilogram of fresh ripe Chilli with moisture content 80% (wb) wastaken in the trays of the drying chamber. The final drying level of red chilli was obtained in the solar dryer after 20 h, but it took about 30 h for the same weather condition in the open sun drying system.**

**Keywords:** Natural convectiondryer, dryer performance, drying time, moisture content, red chillies

## I. INTRODUCTION

The uses of solar energy technologies in tropical countries have a wide range compared to other countries [1-5]. In India, Sun shines over an average of 3000-3200 h/yr, providing approximately 2000 kWh/m$^2$-yr of horizontal solar radiation [6-16]. Solar drying relies on, as does sun drying, on the sun as its source of energy. Putting the product in the sun on the mats is the simplest and cheapest way. There are, however, problems with this method. The crop is blown with dust and dirt, and unexpected rainstorms can wet the crop again [17-26].

Solar drying operation's essential function is to reduce the moisture content to the level required. The drying process is defined as the removal of moisture due to simultaneous transfer of heat and mass. The removal of moisture involves two procedures such as low temperature heating and moist hot air exhaust. The chilli (*Capsicum annum*) is a favourite spice and used widely in most regions of the world to flavour and add taste to everyday foods. It is used as an essential ingredient in everyday cuisine all over the world. Indian red chillies named mirch are very hot and tiny. It is 3-4 cm long, which is usually dried in the sun. Like many other fruits, red chilli peppers present high water contents.Major chilli growing countries are India, China, Indonesia, Korea, Pakistan, Egypt, Mexico, USA, Italy, and Hungary. Chilli is an Indian commercial crop. The biggest chilli producing states in India are Tamil Nadu, Andhra Pradesh, and Karnataka.

At harvest time, chilies mainly contain moisture content in the range of 75 to 80%. They will be prone to mould growth and spoilage if the chilies are not thoroughly dried. Moldy chilli's sales value can be less than 50% of the average value. The entire crop can be lost in extreme cases. It is preferable to use the cheapest method available for the home use of dried chilies, which is sun drying. Also, the traditional process is highly time-consuming. However, sun drying in dry climates with plenty of sunshine is only practical. The solar dryer has ample potential for drying products requiring less than 60°C hot air, and if the dried products have a guaranteed market.

The present study on the solar dryer is part of ongoing research under local conditions at the Department of Mechanical Engineering, University of PRIST, Puducherry campus. The study's primary principle is to assess the thermal performance of a natural convection solar dryer for drying chilli.

## II. MATERIALS AND METHODS

*A. Raw materials*

Fresh red chillies used in this study were acquired from the local market at Cuddalore district, Tamilnadu, Indi**a.** With 1000 g of fresh chilli sample, each batch was prepared. Before the experiments, chilies were not treated with any chemicals or sliced.

*B. Study location*

Puducherry, is located in the tropical region of South Asia, India (Latitude 15° 11′ and 12° 35′; Longitude 78° 38′ and 80° 0′) receives abundant solar radiation [1]. However, the average sunshine duration is only eight hours per day (9.00am-6.00pm) based on solar radiation intensity. The experiments were carried out in the Energy Park, Department of Mechanical Engineering, PRIST University, Puducherry Campus - 605007, India [27].

*C. Solar dryer*

The drying system was classified as the natural convection dryer of the indirect type. Figure 1 shows a schematic diagram of the solar dryer. Solar drying consists of a solar collector, a chamber for drying and a chimney [28-29]. The dryer is designed with the help of a chimney to ventilate the air by natural convection. The design parameters of the fabricated solar dryer are shown in Table 1.

*D. Experimental procedure*

Experiments on the natural convection solar dryer are carried out to study the drying rate of the chilli.

**Table 1: Design parameters of the Solar dryer.**

| Component | Specifications |
|---|---|
| **Solar collector** | |
| Type<br>Area<br>Glass cover<br>Number of Glazing<br>Absorber plate<br><br>Tilt angle<br>Insulation | Flat plate<br>2.2m²<br>4mm<br>2<br>Aluminum sheet,<br>2 mm thick<br>15º<br>Glass wool |
| **Drying chamber** | |
| Size/No of Trays | 0.64 × 0.6 × 0.73 m / 10 |
| Tray area | 0.54 × 0.51 m |
| Chimney | Bottom 0.16 × 0.16,Top 0.2 × 0.2 & Height 0.6 m |
| Tray thickness | 0.003 m |

By spreading the chilli inside in a single layer, the dryer is laden with 1 kg of chilli at 9:00 am. With the required moisture content, the process is continued.

The temperature, solar radiation, relative humidity, and weight losses were calculated using appropriate instruments during the drying experiment of red chilli. The ambient temperature has been recorded using a 0.5℃ accuracy thermometer [30]. The temperatures of air at the top, bottom and middle of the solar drying chamber were recorded by using K-type thermocouples with sensors at an accuracy of ± 0.5℃. The reduction in weight due to the drying process was measured using an electronic balance of accuracy 0.01g. By spreading the chilli inside in a single layer, the dryer is loaded with 1 kg of chilli at 9:00 am. With the required moisture content, the process is continued.

Table 2 presents the uncertainties that occurred at the time of measurements. The errors and uncertainties in the experiments are tabulated based on instrument selection, condition, calibration, observation, test planning, and environment. It was determined the total drying time needed to reach the desired moisture content value.

**Table 2: Uncertainties of the Parameters during drying [31].**

| Parameters | Expression | Unit | Value |
|---|---|---|---|
| Ambient air temperature | T | ℃ | ±0.2 |
| Collector outlet temperature | T | ℃ | ±0.4 |
| Drying chamber temperaturetemperature | T | ℃ | ±0.35 |
| Solar radiation | I | $W/m^2$ | ±1 |
| Weight loss of the sample | m | g | ±0.002 |
| Air velocity | V | m/sec | ±0.1 |

**Fig. 1.** Photograph of the solar dryer.

**Fig. 2.** Photograph of the chilli before and after drying.

*E. Performance indices [32-35]*

**Average drying rate.** The average drying rate, $M_{dr}$, is estimated by the moisture mass removed by the dryer and the drying time as shown by the equation below, where;

$$M_{dr} = \frac{m_w}{t_d} \quad \ldots(1)$$

Where: $M_{dr}$ = average drying rate, kg/hour and $t_d$ = overall drying time.

**The thermal efficiency of the solar collector.** Thesteady state thermal efficiency of the solar air collector is given as:

$$\eta_c = \frac{Q_g}{I_T A_c} \quad \ldots(2)$$

Where; $Q_g$= mass flow rate × specific heat capacity of dry air × Average change in temperature;

$A_c$ = Collector area;

$I_T$ = Average solar irradiation (W/m$^2$).

**Thermal Efficiency of the Solar dryer (solar collector as the only source of heat).** The thermal efficiency of the solar dryer can be defined as the ratio of the thermal equivalent of the evaporated water plus the quantity of heat used to raise the temperature of the product to the useful heat gained by drying air from the solar collector.

The dryer system efficiency can be defined as the ratio of the evaporated water thermal equivalent plus the amount of heat used to raise the temperature of the product to the useful heat produced by the drying air of the solar collector.

Where $Q_a$ is the useful heat gained by the dry air. Hence,

$$\eta_{syst} = \frac{(M_W \times L_v) + (M_g \times Cp_g \times \Delta T)}{Q_a} \quad \ldots(3)$$

Where $Q_a = M_a C_{pa}$ ($T_{\text{into drying chamber}} - T_{\text{ambient temperature}}$),; $M_w$ = mass of evaporated water, $L_V$ = latent heat of vaporization (2270 KJ/Kg), Mg = mass of the chillidried, $C_{pg}$ = specific heat capacity of the chilli, and ∆T = change in temperature.

**Dehydration ratio.** The ratio of dehydration was calculated as the weight ratio of the product to that of the dried product prior to drying.

$$DR = \frac{weight\ of\ the\ material\ before\ drying}{weight\ of\ the\ dried\ material} \quad \ldots(4)$$

## III. RESULTS AND DISCUSSIONS

During the drying period, the ambient temperature ranged from a minimum of 30°C to a maximum of 42°C. The corresponding average temperature ranged from 42°C to 61°C inside the solar dryer. It is observed that on an experimental day the average drying tray temperature within the solar dryer is 55°C. This is because more solar energy is absorbed inside the solar dryer and the solar dryer prevents heat loss.

*A. Drying characteristics of chilli*

Due to the rapid heat and mass transfer across the skin (i.e., pericarp) of the fruit, the drop rate drying period was pragmatic. The thickness of the fruit's pericarp and thermophysical properties can affect heat and mass transfer directly during drying. The fruits show a constant drying period of the rate may include specific thermophysical properties that decrease the rate of heat and mass transfer during drying. A constant drying period for hygroscopic products is generally observed. Figure 3 and 4 show the variation of moisture content and drying rate for the two me modes of drying. On average, solar dryer requires a total drying time of 20 hours (3 days) to reduce the moisture content of chilly from 80% to a final moisture content of 10%, while open sun drying requires an average of 30 hours (4 days) to achieve the same moisture content. Drying time for drying chilli from the initial moisture content of 80 percent (wb) to 10 percent (wb) was found to be 20 hours and 30 hours in the natural convection mode of solar drying and sun drying. In all cases, with the decrease in moisture content, the drying rate decreases. During the drying period, the drying rate continuously decreased.

*B. Dryer performance*

On the basis of the experimental data, the drying efficiency of the solar dryers was calculated by taking into account the total moisture evaporated during the drying process associated with the total heat input and heat from the product. The average collector efficiency and dryer efficiency of the natural convection solar dryer were found to be 44% and 6% respectively. The performance index of the of the fabricated solar dryer are shown in Table 3. The performance of natural convection solar dryer was found to be better than drying open sun. The dryer's low efficiency can be attributed to the increase of the convective heat loss associated with the system. The dryer efficiencies and drying rates of chilli are summarized in the table below using Solar drying and open sun drying method. The experimentally determined dryer efficiency has an average standard error estimate of 5%.

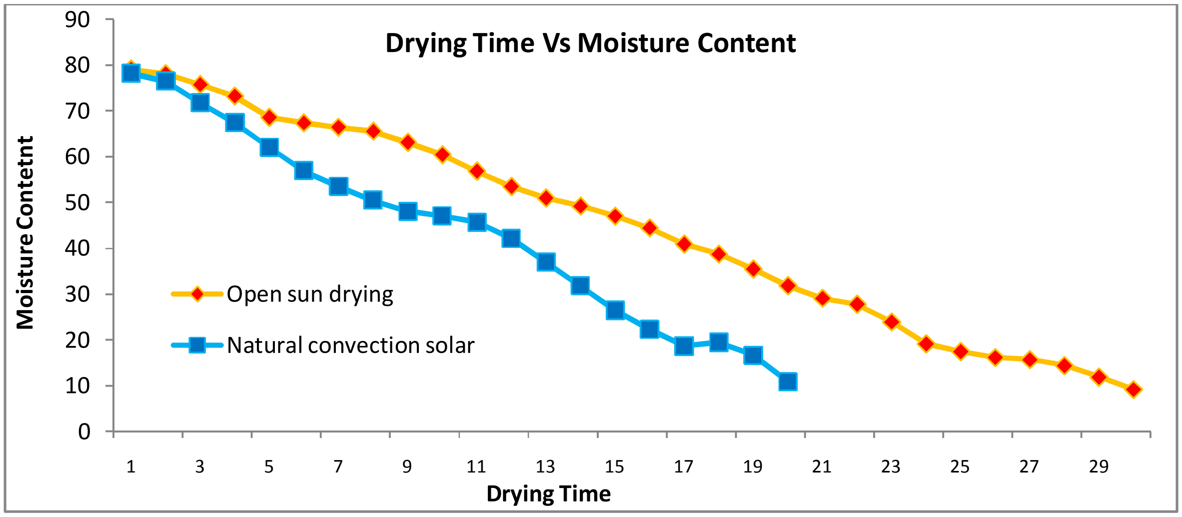


**Fig. 3.** Variation of moisture content with drying time.

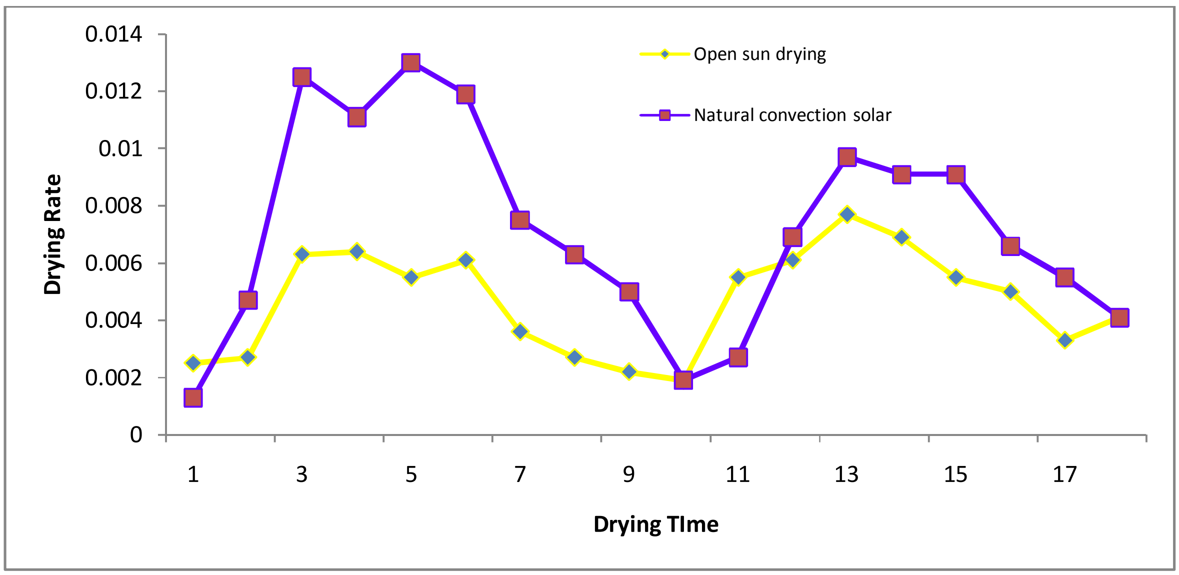


**Fig. 4.** Comparison of drying rate.

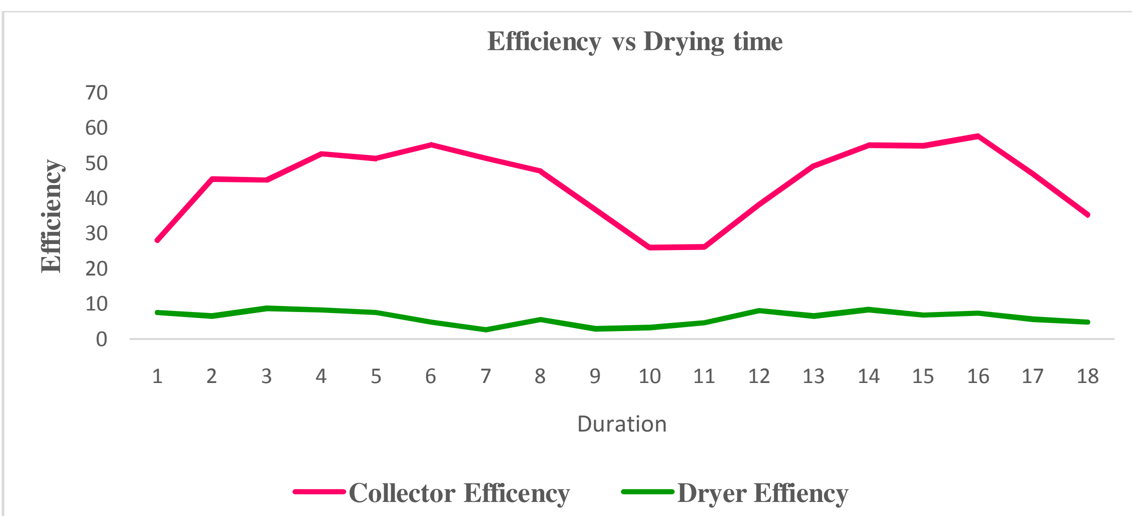


**Fig. 5.** Variation of collector and dryer efficiency with drying time.

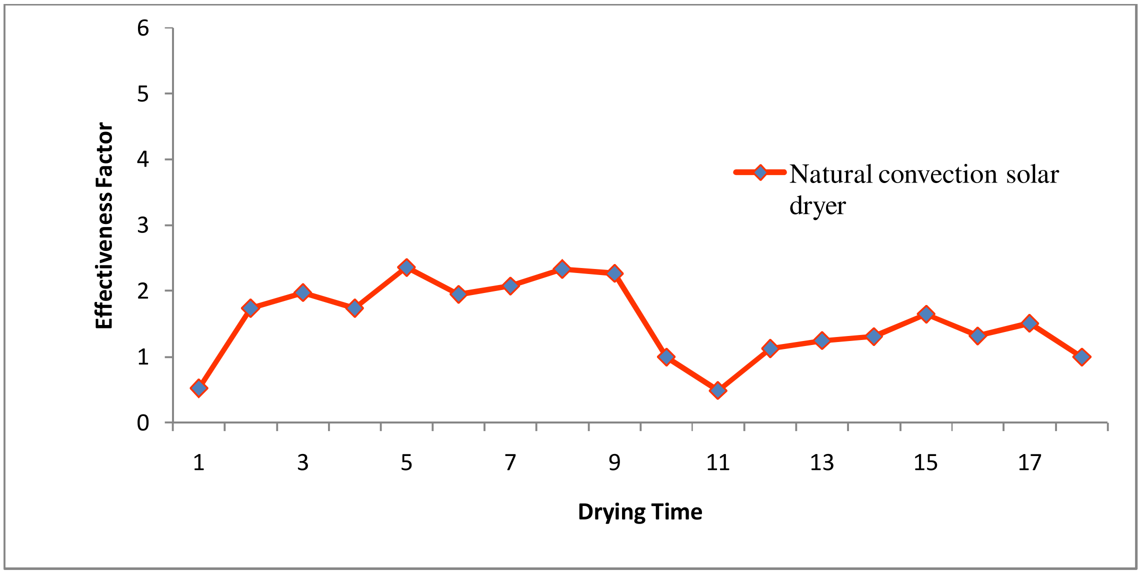


**Fig. 6.** Variation of effectiveness factor with drying time.

**Table 3: Performance of the dryer.**

| Drying method | Drying rate (moisture removal rate), kg/hr | Dryer efficiency (%) |
|---|---|---|
| Open sun drying | 0.0004 | N/A |
| Natural convection solar drying | 0.0008 | 6 |

## IV. CONCLUSION

Based on the experimental results of the solar dryer, the following conclusions can be drawn.

(i) For solar cabinet dryers, an average total drying time of 20 hours (3 days) is required to reduce the moisture content of chilli from 80% to a final moisture content of 10%, while open sun drying requires an average of 30 hours (4 days) to achieve the same moisture content.

(ii) Natural convection solar dryer achieved a considerable reduction of 34% in drying time when compared to that of open sun drying.

(iii) The natural convection solar dryer, the optimum temperature of 50-55°C was achieved, which helped to maintain the product quality rather than open sun drying.

(iv) Further, it is to be noted that, this solar dryer is essential for Indian farmers as they have small land holdings and a combination of agriculture based entrepreneurship is the key to sustainable livelihood.

(v) The product dehydration ratio of 9:1 indicates that nine parts of the original product have been reduced to one part of the final product.

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