Analysis of Solar Tunnel Dryer Performance with Red Chili drying in two intervals

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Abstract
Chili is one of the most valuable as well as commercial crops of India. It is commonly drying under open sun; this practice is having lot of drawbacks which leads to poor quality. Solar tunnel dryer technology is an alternative to open sun drying. A large-scale natural convection solar greenhouse dryer was developed and tested at field levels. An experimental investigation was carried out in the dryer for drying 250 kg of red chilli in two intervals. The solar dryer reduced the moisture content of red chilli from 79% (w.b.) to about 10% (w.b.) in 55 h compared to 124 h taken by open-sun drying by saving 56% of drying time. The thermal efficiency of the dryer was found to be 16.25% for chilli drying with a specific energy consumption of 6.06 kWh/kg. The dried chilli produced in the solar greenhouse dryer showed high quality. It is found that solar tunnel drying process is a better alternate for open sun drying and also ensures the quality of product evidently.

Keywords: Solar Tunnel Dryer, moisture content, thermal efficiency, drying time.

Introduction
Chilli (*Capsicum annum L*) is an important spice produced in India, grown in an area of 7.44 lakh hectares with an annual production of 14.53 lakh MT[1]. It is an important ingredient in daily cuisine and consumed as fresh and in dried form. It is a rich source of vitamin A, C and E and is also believed to prevent heart diseases. Most of the chilliest produced in India are consumed within the country and only 5 to 7 per cent are exported. Drying is defined as the process of moisture removal due to simultaneous heat and mass transfer. It is also one of the oldest methods known for the preservation of fruits and vegetables. Drying provides longer shelf-life, lighter weight for transportation and requires less space for storage.

Open-sun drying is the most common method used to preserve agricultural products including coconuts, chilli, turmeric etc. in the world and also in India. However, it is labor intensive, takes long time and produces low quality products. Solar-drying technology offers an alternative which can process the vegetables, fruits, spices, herbs etc. in clean, hygienic and sanitary conditions to national and international standards with zero energy costs. It saves energy, time, occupies less area, improves product quality, and protects the environment. The most affecting factors related to the drying are the air temperature, air relative humidity and the air velocity in addition to the product initial moisture content. The solar dryers developed in the last 30 years have a loading capacity of 10-50 kg only, which could not meet the demand of medium and large scale drying requirements of farmers/traders and industries. Solar greenhouse type dryers are best suited for meeting these requirements. Many researchers around the world conducted experiments in this type of dryers for drying various agricultural products[2-9].

Very few studies were conducted for the drying of coconuts in large-scale solar greenhouse dryer[10-12]. Several studies specifically investigated solar drying systems for red chilli. A Special study reported that, the use of a solar greenhouse dryer to dry 300 kg of red chilli in Champasak, Lao People's Democratic Republic[13]. In this dryer, the moisture content was reduced from 75% to 15% in 3 days.

A similar study was conducted with technical and economic performance analysis of solar drying of red chilli in Bhutan by modeling an existing solar crop dryer at Khao-kor, Thailand using TRNSYS for possible replication in Bhutan[14] .From the evaluation, the average collector, pick-up and system efficiencies were determined as 44%, 24% and 16% respectively. A study on the mixed-mode forced convection solar tunnel dryer for drying 80 kg of red and green chilli in Bangladesh was referred[15]. They found that the moisture content of red chilli was reduced from 2.85 to 0.05 kg kg^{-1} (db) in 20 h in solar tunnel dryer and it took 32 h to reduce the moisture content to 0.09 and 0.40 kg kg^{-1} (db) in improved and conventional sun drying methods respectively.

In case of green chilli, about 0.06 kg kg^{-1}(db) moisture content was obtained from an initial moisture content of 7.6 kg kg^{-1} (db) in 22 h in solar tunnel dryer and 35 h to reach the moisture content to 0.10 and 0.70 kg kg^{-1}(db) in improved and conventional sun drying methods, respectively. As similar a study was conducted a performance analysis of solar drying system for red chilli[16].It was dried to a final moisture content of 10% (w.b.) from 80% (w.b.) in 33 h with 49% saving in drying time compared to open-sun drying. The specific energy consumption (SEC) was found to be 5.26 kWh/kg.

Malaysian red chilli was dried in solar tunnel dryer under similar conditions[17]. It was dried from approximately 80% (w.b.) to 10% (w.b.) moisture content within 33h compared with 65 h of open-sun drying with a specific moisture extraction rate (SMER) of 0.19 kg/kWh. In Thailand the performance of large-scale greenhouse type solar dryer for drying chilli was investigated[18]. It was found that five hundred kilograms of chilli with the initial moisture content of 74% (w.b.) was dried within 3 days while the natural sun dried needed 5 days. Like that a double-pass solar dryer for drying chilli in Central Vietnam was investigated[19]. The dryer reduced the moisture content of 40 kg chilli from 90% (w.b.) to 10% (w.b.) in 32 hrs used a forced convection solar dryer integrated with gravel as heat storage material for drying 40 kg of chilli[20].The dryer reduced the moisture content from 73% (w.b.) to 9% (w.b.) in 24 h with a drying efficiency of 21%.From the literature survey, it was found that many studies were conducted for chilli drying in large-scale solar greenhouses. This paper presents the energy and performance analysis in a large-scale solar greenhouse dryer for drying red chilli.

Material and Methods

Experimental set up: A pictorial view of solar greenhouse dryer used for the experiment is depicted in Fig 1. The dryer has the dimension of length 10 m, width 4 m and height 3 m. It consists of a hemispherical roof structure built on a black painted concrete floor constructed at Kondegoundanpalayam village of Pollachi Taluk. All sides of the dryer are covered with UV treated poly-ethylene sheet of 200 micron thickness in order to create the greenhouse effect inside the dryer. No post is used inside the greenhouse, allowing a better use of inside space. Two-tier metallic racks are used inside for keeping the products in layers for drying. Two turbo-vent fans are used for maintaining the air circulation inside the dryer.

A chimney with adjustable butterfly valve is used for removing the humid air from the dryer. The solar radiation passing through the transparent polyethylene film heats the air, the products inside the dryer and the concrete floor. The ambient air enters into the dryer from the air vents at the bottom is heated due to the greenhouse effect and it flows over the products to be dried.

Fig. 1: Solar greenhouse drier

Experimental procedure: Experiments were conducted during the period of April 2015 under the meteorological conditions of Pollachi (latitude 10.39ºN; longitude 77.03ºE), India. About 250 kg of red chilli was used for this experiment. Two trial runs were conducted for the products. The experiments were started at 9.00 a.m. and continued until 5.00 p.m. The drying was continued on subsequent days until the desired moisture content was reached. The initial moisture content of the products was determined by the oven method (103°C for 24 h). About 50 g of the products were taken from the dryer and weighed every 1 h interval using the digital weighing balance.

Also, 50 g of the products were placed outside the dryer as control samples for natural sun drying. The moisture content of the products inside the dryer was compared with that of the control samples. The solar intensity, ambient and dryer temperatures, air relative humidity, air velocity were measured at every one hour interval till the end of drying. An experimental uncertainty analysis was also performed.

Uncertainty analysis: No experimental measurement is perfect and the measurement of any variable contains inaccuracies to some degree. Therefore, it is very important to understand the potential sources and magnitudes of errors that could influence the measurements and represent it in the form of an uncertainty along with the measurements. Thus, the uncertainty analysis is needed to prove the accuracy of the experiments. The independent parameters measured in the drying experiments are, air temperature, air humidity, air velocity, solar radiation and mass of samples.

Let w_R be the total uncertainty in the result and w_1, w_2, w_3,…..w_n are the uncertainties in the independent variables, then

$$w_R = [w_1^2+w_2^2+.....+w_n^2]$$

To carry out the temperature measurement of air, four calibrated temperature sensors with an accuracy of ± 0.5°C are used at four different locations inside the dryer. Four humidity sensors with uncertainty ± 0.2% are placed at four different locations inside the dryer for measuring the humidity of air. A Pyranometer (Equinox, model TM-207, accuracy ± 0.1%) is used to measure the instantaneous solar radiation. All the measuring instruments are connected to a computer through a data logger (Simex, model SRD-99).

Air velocity at dryer exit is measured by using a vane type thermo-anemometer (Equinox, model EQ-618B, accuracy ± 0.5%). A digital electronic balance (Shimadzu Corporation, model AY-220, accuracy ± 0.1mg) is used to weigh the samples. The table 1 shows the total uncertainties of various measurements taken during the experiments.

Performance Analyses:
Determination of moisture content: The moisture content on wet basis (M_{wb}) is calculated using the eq. (1):

$$Mwb = \frac{\mathrm{mi-mf}}{\mathrm{mi}} \quad (1)$$

Determination of dryer thermal efficiency: Thermal efficiency of the solar greenhouse dryer is estimated using the eq. (2):

$$\eta = \frac{\mathrm{WL}}{\mathrm{A*l}} \times 100 \quad (2)$$

The mass of water evaporated from the products is calculated using equation:

$$W = \frac{mi(mi-mf)}{(100-mf)} \quad (3)$$

Table 1
Uncertainty analysis

S.N.	Description	Units	Total uncertainty
1.	Temperature of air (ambient and dryer)	°C	0.346
2.	Relative humidity of air (ambient and dryer)	%	0.223
3.	Solar radiation	W/m^2	0.14
4.	Air velocity	m/s	0.173
5.	Mass loss	g	0.5

Saving in drying time: Drying time is an important performance parameter of the dryer which represents the time taken by the dryer for removing the moisture content from initial level to the final level. The solar greenhouse dryer considerably reduces the drying time compared to open-sun drying. The percentage of time saved for drying the products in the solar greenhouse dryer in comparison with open-sun drying method was calculated using the following equation as reported by Fudholi et al.(2013a):

$$s = \frac{\mathrm{tos} - \mathrm{tsp}}{\mathrm{tos}} \quad (4)$$

Specific Energy Consumption (SEC): Specific Energy Consumption (SEC) is the amount of energy required by the dryer to extract one kg of moisture from the product. It is one of the performance parameters of the dryer. The specific energy consumption (SEC), was calculated using the following equation.

$$SEC = \frac{\mathrm{Pt}}{\mathrm{W}} \mathrm{k\,Wh/kg} \quad (5)$$

Specific Moisture Extraction Rate (SMER): Specific Moisture Extraction Rate (SMER) is another performance index, which is used to describe the effectiveness of drying. It is in effect, the inverse of specific energy consumption and is given by the ratio between the total moisture removed to the total energy input. The specific moisture extraction rate (SMER) was calculated by the below formulae:

$$SMER = \frac{W}{Pt} kg/kWh \quad (6)$$

Results and Discussion

Drying of Red chilli: Two experimental studies were carried out in this solar greenhouse dryer using 250 kg of red chilli during Apr. 2015 is shown in fig.2. The chillies were loaded onto the trays in a thin layer as shown in fig.5. The experiments were started at 9.00 am and continued till 5.00 pm. After 5.00 pm, the chillies were collected and put it in an air-tight plastic bag to prevent re-absorption of moisture during night and again placed in the dryer in the next morning for further drying.

Fig. 2: Drying of red chilli in the dryer

The variation of solar radiation and air temperature during the drying of red chilli is shown in fig.3. During the experiments, the solar radiation increased in the forenoon and decreased in the afternoon. It varied between 111-892 W/m^2 during the drying period. The temperature inside the dryer during the drying period varied between 28-64°C whereas the ambient temperature varied between 25-37°C. The maximum temperature attained inside the dryer was 61, 63 and 64°C respectively during 1st, 2nd and 3rd day of drying respectively. The temperature inside the solar dryer was 10-28°C higher than the ambient temperature during the experimental period due to greenhouse effect. The relative humidity of air inside the dryer was always lower than that of the ambient air during the daytime. The low air humidity and high air temperature inside the dryer provides a favorable atmosphere for drying.

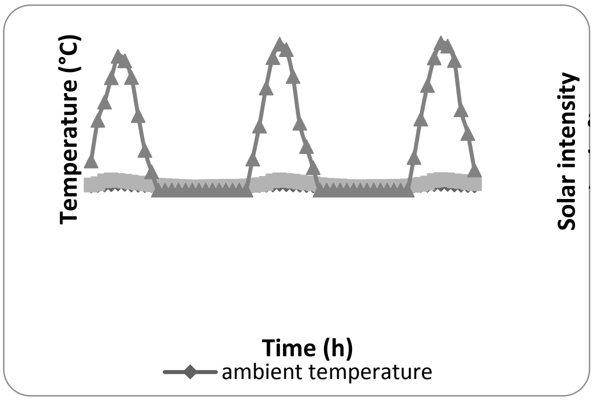

Fig. 3: Variation of air temperature and solar intensity

Fig. 4 shows the variation in moisture content of red chilli dried in the solar greenhouse dryer and in open-sun drying. It was observed that the moisture content of chilli was reduced from an initial value of 79% to a final value of 10% in 55 h whereas the open-sun dried samples took 124 h for reducing the moisture content to the same level. Therefore, the solar greenhouse dryer saves 56% of drying time. The average thermal efficiency of the dryer was found to be 16.25%. The specific moisture extraction rate (SMER) of the dryer was 165, 33 and 10 g/kWh during the 1st, 2nd and 3rd day of the drying. The specific energy consumption (SEC) of the dryer was found to be 6.06 kWh/kg.

The drying rate was found to be higher during the initial stages of drying when the product surface has enough moisture to evaporate (constant rate period). It decreased towards the end of drying once its surface is depleted with moisture (falling rate period). The quality of the red chilli produced was superior compared to open-sun drying. The color of the chilli produced from the solar dryer was comparable to that of good quality dried chilli available in local markets. In addition, the chilli dried in this dryer was completely protected from insects, animals and rain.

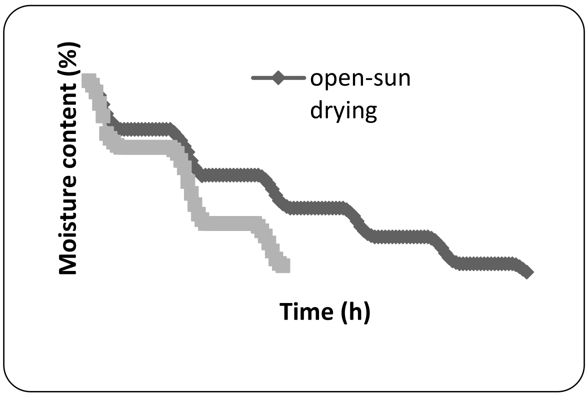

Fig. 4: Variation of moisture content for chilli

Conclusion

Most of the agricultural products require a drying temperature of 50-60°C for producing good quality dried products, solar greenhouse type dryers are best suited for such applications. This type of dryers is suitable for medium and large-scale drying of agricultural/industrial products. In order to demonstrate the drying potential of this type of dryer, a performance analysis was conducted for red chilli and the following conclusions are made from the experiments:

The red chilli was dried in the solar greenhouse dryer from an initial moisture content of 79% to a final moisture content of 10% in 55 h compared to 124 h required in open-sun drying. The solar greenhouse dryer saves 56% drying time compared to open-sun drying. The average thermal efficiency of the dryer for chilli drying was found to be 16.25%. The specific energy consumption (SEC) of the dryer was found to be 6.06 kWh/kg.The quality of the red chilli produced was superior compared to open-sun drying.

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