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Performance Evaluation of Solar Tunnel Dryer for Drying Red Chilli using Taguchi L_{27} Orthogonal Array

Y. M. Jibhakate[1], Dr. A. C. Waghmare[2], Dr. S. K. Choudhary[3]

[1]Department of Mechanical Engineering, KITS, Ramtek, India
[2]Department of Mechanical Engineering, Umrer College of Engineering, Umrer, India
[3]Department of Mechanical Engineering, KDK College of Engineering, Nagpur, India

ABSTRACT

The Solar Tunnel Dryer can provide the best alternative method to dry red chillies in less time. The performance of the solar tunnel dryer depends on various parameters such as ambient temperature, solar radiation intensity, wind velocity, relative humidity, temperature of air inside the solar tunnel dryer etc. The experimentations are carried out at Umrer in Vidarbha region of Maharashtra. In this work Solar Tunnel Dryer (STD) performance is investigated by varying different process parameters, which includes absorber material (ABM), polyethene cover thickness (CT), air flow velocity over drying bed (AFV) and drying layer thickness (DLT). Three different levels of each parameter are chosen to form different combinations of experiments using Taguchi L_{27} orthogonal array with three interactions in between ABM×CT, ABM×AFV, and ABM×DLT. Total 27 experiments are designed and fabricated for drying 5 kg of red chilli. The initial moisture content of red chilli is 80% which is reduced to 5%. The efficiency, total moisture removed and drying time of individual STD are investigated. Considerable reduction in drying time and better quality of dried products are observed as compared to open sun drying.

Keywords: Solar Tunnel Dryer, Moisture Content, Dryer Efficiency, Taguchi Orthogonal Array.

I. INTRODUCTION

Chilli (Capsicum annuum / Capsicum frutescens) is the most important cash crop of India. It is grown almost throughout the country. India is the largest chilli producing country which contributes 36% of global production. Chilli is the largest spice item exported from India. In India, Andhra Pradesh is the largest producer of chilli followed by Maharashtra, Karnataka, Orissa and Madhya Pradesh. Bhiwapur, Umrer, and Kuhi Tahasils of Vidarbha region produce red chilli on a large scale in Maharashtra. To dry the red chilli, the traditional open sun method is used in which farmers spread the chilli on fields and turn twice or thrice in a day for uniform drying. The slow drying rate is one of the causes of contamination, infestation, microbial attacks, discoloration, etc., which leads to the post-harvest losses and a low quality of dried products, and ultimately, farmers do not get the proper return for their harvest. Open sun drying is one of the oldest technique employed for processing agricultural and food products. Open sun drying has been traditionally practiced in India for drying agricultural products. However, this method of drying is extremely weather dependent and has the problems of contamination, infestation, microbial attacks, discoloration etc., thus affecting the quality of dried product. Additionally, the drying time required for a given commodity can be quite long and results in post-harvest losses.

Solar drying of agricultural products in enclosed structures is an alternative way of reducing post-harvest losses and low quality of dried products associated with traditional open sun drying methods [1]. In the open sun drying, the rate of drying depends on intensity of solar radiation, ambient temperature, wind velocity, relative humidity, initial moisture content, types of crops, crop absorptivity and mass of product exposed per unit area [2]. The experiments were performed on forced convection solar tunnel dryer for drying black pepper and found that the dried samples were qualified for ASTA and Agmark standards. Quality improvement such as colour, appearance, aroma and pungency were achieved [3]. The performance study of STD for drying handmade paper was done. 1500 sheets of handmade paper were dried in 4-5 hours from initial moisture content of 53.85 % to final moisture content of 9.96% with superior quality than dried in open [4]. Optimization of physical components of the STD was reported for drying red chilli efficiently and economically without its colour loss [5]. Experimental investigation of STD for year round performance was investigated with natural and forced circulation mode and seen the effects of collector length, cover radius, collector inclination with the horizontal for rising inlet air temperature [6]. Experimental and Neural Network prediction of a STD performance for drying jackfruit bulbs and leather was done. A NN approach with seven inputs, one output and two hidden layers were used to predict the performance of STD. The prediction of the model is found to be excellent and can be used to predict the potential of the dryer for different locations [7].

The solar tunnel drying system leads to faster drying and protect it from rain, dust, storm, birds, rodents, insects and pests. This ensures better quality of dried products, which would fetch a higher price for the dried products. This method has several advantages such as less spoilage and less microbiological infestation, thus leads to improved and more consistent product quality. Moreover, many rural areas in India suffer from unreliable and poor supply of electricity. Fortunately, it is blessed with abundant solar energy potential that can be used for different applications.

In this work, four physical parameters of STD with three levels of each are used and experiments are planned according to Taguchi orthogonal array. The efficiency, total moisture removed and drying time of the chilli are estimated.

II. METHODS AND MATERIAL

1. Solar Tunnel Dryer

As shown in Fig.1, solar tunnel dryer has a tunnel like structure. It is designed and constructed for drying 5 kg of fresh red chilli with initial moisture content of 80% which reduced to 5%. A semicircular portion of the dryer is covered with UV polyethene sheet. The absorber dimensions of the STD are along length 1.98 m, width 0.762 m and height at centre 0.381 m. Absorber sheet is fixed on plywood and coated with black paint to improve its performance. A battery operated DC fan at the bottom of the absorber with adjustable butterfly valve and exhaust vent at the rear end are fixed. STD is provided with trays for keeping red chilli in different layer thickness for drying.

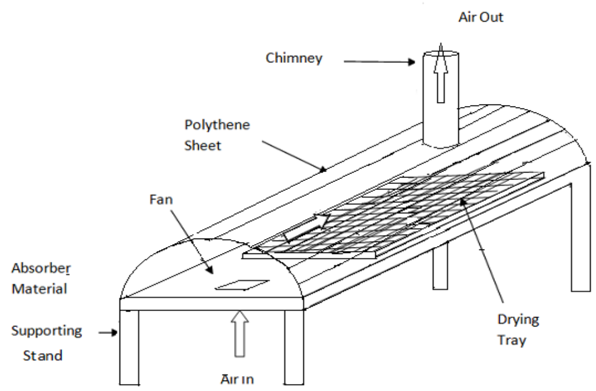

Figure 1. Schematic of Solar Tunnel Dryer

2. Experimental Methodology Using Taguchi Orthogonal Array

The Taguchi method is being extensively used in industry and engineering analysis due to its wide range of applications. The classical experiment design method is too complex, time consuming and not easy to use. A large number of experiments are to be carried out when number of process parameters are more. To overcome this, Taguchi method uses a special design of orthogonal array to study the entire parameter space with minimum number of experiments [8]. In this study four parameters namely absorber material (aluminum, tin and concrete), polyethene cover thickness (130, 200 and 240 microns), air flow velocity (0.4, 0.7 and1.0 m/s) over drying bed and drying bed thickness (20, 30 and 50 mm) are taken for experimentation. Each parameter is investigated at three levels to study the non-linearity effect of process parameters. To check the process parameter effects on performance around 81 (3^4) experiments are required to conduct, but by using Taguchi orthogonal array 27 experiments are sufficient. Table1 represents the number of process parameters and their levels.

Table 1. Parameters and their corresponding levels

Parameters	Levels		
	1	2	3
A. Absorbing material	Aluminum	Tin	Concrete
B. cover thickness(micron)	130	200	240
C. Air flow velocity(m/s)	0.4	0.7	1.0
D. Drying bed thickness(mm)	20	30	50

Taguchi orthogonal array gives twenty seven sets of possible combinations for four parameters and three levels of each parameter. Three interactions between the parameters are considered for the Orthogonal Array (plan of experiment) using MINITAB-17 software, shown in Table 2.

Table 2. Plan of Experiments

Experiment No.	Absorber Material (ABM)	Cover Thickness(CT) microns	Air Flow Velocity(AFV) m/s	Drying Layer Thickness(DLT) mm
E1	Concrete	130	0.4	20
E2	Concrete	130	0.7	30
E3	Concrete	130	1.0	50
E4	Concrete	200	0.4	30
E5	Concrete	200	0.7	50
E6	Concrete	200	1.0	20
E7	Concrete	240	0.4	50
E8	Concrete	240	0.7	20
E9	Concrete	240	1.0	30
E10	Tin	130	0.4	20
E11	Tin	130	0.7	30
E12	Tin	130	1.0	50
E13	Tin	200	0.4	30
E14	Tin	200	0.7	50
E15	Tin	200	1.0	20
E16	Tin	240	0.4	50
E17	Tin	240	0.7	20
E18	Tin	240	1.0	30
E19	Aluminum	130	0.4	20
E20	Aluminum	130	0.7	30
E21	Aluminum	130	1.0	50
E22	Aluminum	200	0.4	30
E23	Aluminum	200	0.7	50
E24	Aluminum	200	1.0	20
E25	Aluminum	240	0.4	50
E26	Aluminum	240	0.7	20
E27	Aluminum	240	1.0	30

3. Experimentation

The 27 solar tunnel dryers are fabricated as per the Taguchi orthogonal array. All sets of experiments are kept in N-S direction under meteorological conditions of Umrer (latitude, 20.85^{0}N: longitude, 79.33^{0}E) in India during the month of February and potential sunshine duration based on higher solar intensity.

Jayanti grade red chillies are taken for experimentation. Solar tunnel dryers are loaded with 5 kg of Chilli and dried until the required final moisture is attained. The fresh chillies are spread on the trays in 20 mm, 30 mm and 50 mm layer thickness inside the dryer. Solar tunnel dryers are kept on stand. A thermocol is provided as an insulator at the bottom of absorber to avoid heat losses. The Battery operated D.C. fans are used to vary the air flow velocity over the drying bed, which are fixed at the bottom of absorber. The anemometer is used to measure the velocity of air flow over the drying bed. The tests are conducted on nine sets from 09.00 to 16.00 h. The ambient temperature, solar tunnel dryer inside temperatures is measured using a digital thermometer and solar radiation intensity is measured by using solar meter at an interval of an hour. At the end of the day chillies are taken out from individual setup and moisture loss is measured using an electronic digital weighing machine. Next day morning all setups are reloaded with the chillies. The same procedure is repeated until the chillies are dried. For the first day, the drying is carried out for five hours and readings are taken, but for subsequent days the drying is carried out for seven hours or up to the required moisture content is reached.

To evaluate the performance of the solar tunnel dryer, efficiency and total moisture removed are calculated on per day basis. Experimentations are continued until 5 % moisture is achieved in each dryer and total drying time is recorded. 5 kg of chillies are also kept in the open sun for drying and drying time is recorded.

Figure 2. Solar Tunnel Dryer Set Up

4. Data Analysis

Determination of Dryer Efficiency (η)

Efficiency of Solar Tunnel Dryer is calculated as

$$\eta = \frac{Mw \times hfg}{A \times I \times Time} \times 100 \qquad (1)$$

Where, η, dryer efficiency; Mw , mass of water evaporated per day (kg); hfg, latent heat of vaporization of water (KJ/kg); A, area of STD (m^2); and I, solar intensity (W/m^2).

III. RESULTS AND DISCUSSION

It is observed that the ambient temperature, dryer temperature and solar radiation intensity are varying according to the time from morning to evening, but the maximum values are observed during 13.00 to 14.00 h for all experimental setups.

i. Efficiency of Dryers

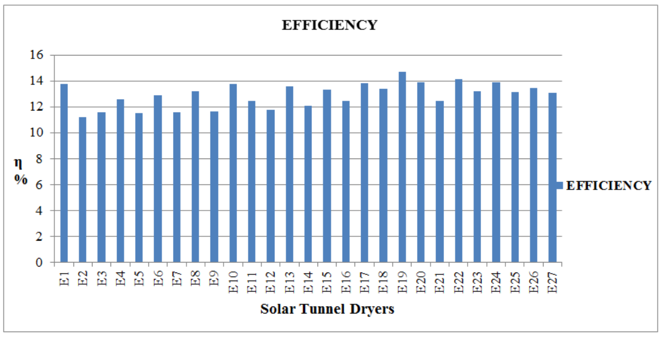

Figure 3. Efficiency of Solar Tunnel Dryers

As shown in Fig 3, the maximum efficiency is for experimental setup E19, 14.69%, followed by experimental setups E22, E20, E24, E17 etc. For maximum efficiency the combination of experimental setup is aluminum absorber, cover thickness 130 microns, air flow velocity over drying bed 0.4 m/s and drying bed thickness 20 mm. For E22 experiment, the combination is aluminum absorber, cover thickness 200 micron, air flow velocity over drying bed is 0.4m/s and drying bed thickness 30 mm, whereas experiment E20 has a combination of aluminum absorber, 130 micron cover thickness, air flow velocity over drying layer 0.7 m/s and 30 mm drying layer thickness. This indicates that the efficiency of dryer is influenced by parameters absorber material (Al), cover thickness (130 micron), air flow velocity over drying bed (0.4 m/s) and drying bed thickness (20 mm)

ii. Total Moisture Removed from Chillies

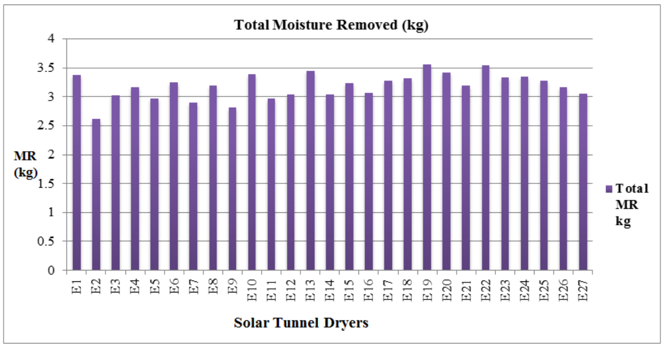

Figure 4. Total Moisture removed from chillies

As shown in Fig 4, the moisture removal rate is higher during initial drying hours and later it decreases. The maximum total moisture removed 3.96 kg is observed for first experimental setup E19 followed by experimental setup E22, 3.54 kg and later E13, E20, E10 etc. For maximum total moisture removed the combination of experimental setup is aluminum absorber, cover thickness 130 microns, air flow velocity over drying layer 0.4 m/s and drying layer thickness 20 mm. For E22 experiment, the combination is aluminum absorber, cover thickness 200 micron, air flow velocity over drying bed is 0.4m/s and drying layer thickness 30 mm, whereas experiment E13 has a combination of Tin absorber, 200 micron cover thickness, air flow velocity over drying bed 0.4 m/s and 30 mm drying layer thickness. This indicates that the total moisture removed is depending on the parameters absorber material (Al), cover thickness (130 micron), air flow velocity over drying bed (0.4 m/s) and drying bed thickness (20 mm)

iii. Drying time

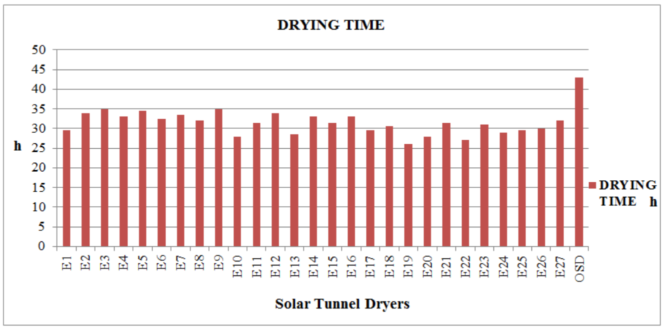

Figure 5. Variation in drying time for dryers

As per Fig 5, all dryers reduce the drying time for chilli as compared to open sun drying. Dryer E19 takes less time as compared to other dryers. The dryer E19 takes 26 h followed by dryers E22, E20, E10 etc. E22 takes 27 and E20 28 h. Again the same experimental combinations we are getting, as it is observed for efficiency and total moisture removed. The open sun drying takes around 43 h for drying. The reduction in drying time is 39.53% for E19 compared with open sun drying.

IV. CONCLUSION

- Solar tunnel dryers are fabricated as per design parameters and experimentations are performed on twenty seven dryers. A Maximum temperature of 54.2^oC is recorded inside the dryer which is 20^oC higher as compared to ambient temperature. The efficiency, moisture removed and total drying time for each setup are obtained.
- In comparison with all twenty seven sets, it is observed that dryer E19 performs well as compared to other dryers. Dryer E19 has achieved maximum efficiency, total moisture removed and minimum time for drying chilli.
- Dryer E19 is having aluminum absorber, 130 microns (polyethylene) sheet is used for covering. The absorber is black painted to absorb more radiation. Air flow velocity over drying bed is maintained to 0.4 m/s .Chillies are arranged on drying tray for 20 mm layer thickness. The 130 micron polythene sheet transmits more solar radiation in the dryer. The collector and drying product absorb radiation and gets heated. Collector transfer heat to the flowing air and due to this air dry bulb temperature is increased. This decrease air relative humidity and increase the rate of moisture absorption from the chilli.
- From the experimental study it is clear that the thin layer of 20 mm allows more space to chilli to expose. With 0.4 m/s velocity air gets more time to increase its temperature, interact with drying products and absorbs the more amount of moisture. Higher the temperature inside dryer minimizes the drying time of product. Drying time considerably reduced by using the solar tunnel dryer as compared to open sun drying and good quality dried products is obtained.
- The interactions are not affecting the performance of the dryers.
- Also conclude that the Taguchi orthogonal array gives optimum parameter setting with less number of experimental trials.

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