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Design of Solar Dryer for Drying Characteristics Study

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Abstract—*Drying is an excellent way to preserve food, and solar food dryers are appropriate food preservation technology for sustainable development. In the present work, the solar agricultural dryer was designed and constructed. The solar dryer consisted of solar air collector and drying chamber. Heated air in the dryer passes through the potatoes slices of 3.58 mm thickness by natural convection process. White or Irish type of Potato was used for drying experiments. The dehydration of untreated potato slices was optimized by response surface methodology (RSM). During the drying period, temperature and the loss of weight were measured continuously after 30 minutes. The overall optimum conditions resulted in desirable dried potato slices were achieved when the drying time was 510 minutes, with a maximum inside temperature of 66.0°C and the minimum inside temperature of 33.1°C. The response surface analysis showed a significant (0.05) relationship between the independent variables and response variables.*

Introduction

Drying has always been of great importance for conserving agricultural products in agricultural countries like India. The drying process is the most common form of food preservation and extends the food shelf life. It is a simultaneous heat and mass transfer operation in which moisture is removed from food material and carried away by hot air [1]. Open sun drying is a well-known food preservation technique that is still the most common method used to preserve agricultural products in tropical and subtropical countries.

In India, drying is achieved natural method by spreading out the material on the ground. This method has many disadvantages, like low quality and hygienic problems. Being unprotected from windborne dirt and dust, rain, infestation by insects, rodents and other animals, the quality of food is seriously degraded. The process also requires a large area of land, takes time, and highly is labour intensive [2]. The resulting loss of food quality in the dried products may affect trade potential and economic worth. For preventing the deterioration of the materials, different types of drying methods have been developed. The conventional dryers are not economical due to the high energy cost [2]. For that reason, direct or indirect sun dryers have a good opportunity for quality and efficiency improvement.

In this purpose, there have been many studies on the drying behaviour of vegetables and fruits such as pineapple [2], sweet pepper and garlic [3], tomato seed [4], grape [5] & [6], tomato [7], figs and onion [8], red pepper [5] & [9]. This study was undertaken to investigate the drying characteristics of Potato in the solar agricultural dryer in Awantipora.

Materials and Methods

In this study, the solar agricultural dryer was constructed having 55.6x 43.5x46.5 cm from the front and 55.6x43.5x55.5 cm from the back. The dryer was supported by four legs, 10cm each. Transparent glass of 8mm thick was used. The size of the glass used to cover the dryer was 53.5x43 cm. The dryer consists of a solar collector cum drying chamber which has a tray (21x16 cm) made up of wire mesh on which the potato slices are placed for drying. The wire mesh was used to permit the free flow of air within the dryer. The interior of the simple solar dryer was painted black to promote absorption of heat energy while as the exterior was painted with black and white to minimize the adverse effects of weather and insect attack on the plywood and also for aesthetic appeal and dryer was tilted at the angle of 43° east. There is an air vent on one side of the solar collector and drying chamber where air enters and is heated up. This air passes through the tray around the food, removing the moisture content and exists through the air vent (or outlet) on the other side of the dryer.

The angle of tilt (β) of the solar collector was equal to 33.9°+ lat Φ (43), where lat Φ is the latitude of the solar collector cum drying chamber [7]. The latitude of Awantipora where the dryer was designed and used is 33.9 N.

The hot air acts as a drying medium. It extracts and conveys the moisture from the potato slices to the atmosphere under natural convection. Thus the system is a simple solar dryer, and no mechanical device is required to control the intake of air into the dryer.

Experimental Procedure

Drying experiments were conducted during the periods of August in Awantipora (J&K). The potato was used in this study as an experimental product. Experimental solar drying run was conducted on White or Irish Potato. Potatoes (Kufri Badshah) were purchased from the local market. They were thoroughly cleaned to remove any dirt and dust particles attached to the surface. They were peeled and cut into slices of the required thickness of 3.58mm. The untreated samples were weighed and the spread in a single layer on the wire mesh tray inside the dryer. The potatoes were dried without any chemical treatment. The drying started when loading was completed, normally at 9.30 am IST.

The important parameters, like drying air temperature and loss of mass affecting the performance of the dryer, were measured. The temperature inside and outside the dryer was measured with the help of Laboratory thermometer.

To determine the mass loss of the product during the experiment, potato samples were taken out of the dryer after every 30 minutes and weighed with an electronic balance. The temperature both inside and outside the dryer was also recorded. During the drying experiment, the weather was mostly sunny. The moisture loss was calculated using the following formula:

Total Percent moisture loss = {(initial weight-new weight)/ (Initial weight-final weight)}*100

Results and discussions

In this study, the potato sample was dried, and drying variables such as temperature and weight loss were determined. The dryer temperature, ambient temperature, and moisture loss at different time intervals are given in table 1. During the drying experiments, the lowest and highest temperatures recorded outside and inside the dryer was 24.0°C and 31.1°C respectively while as the lowest and highest temperatures recorded inside the dryer was 33.1°C and 66.0°C respectively. The potato slices in 240 minutes showed 90 percent moisture loss and in 270 minutes for 95 percent moisture loss. After about 300 minutes, 100 percent moisture reduction took place. The percentage of moisture loss was plotted in fig. 1. As can be seen from the graph, the is the slope of the curve is sharp for time interval 0 to 120 minutes, showing the region where unbound moisture is removed from the potato slice. As the slope of this region is uniform, this shows a constant rate region of the curve. The drying curve first showed a rapid decrease in weight, and the very little reduction was observed with the increase in drying time, which was due to a decrease in moisture content. From time interval 120 to 300 minutes, the slope is less than that of the first region but uniform showing the removal of unbound moisture.

Table 1. Temerture and moisture loss at different time intervals

Time (min)	Temperature of dryer	Ambient Temperature	%age moisture loss
0	33.1	24	0
30	37.1	25	13.95
60	39.3	25.8	36.83
90	50.2	29	62.5
120	51.1	29.6	82.18
150	52	29.8	87.2
180	58.2	31	87.89
210	60	31	89.91
240	62.4	31	91.58
270	60.4	31	95.19
300	66	31.1	99.41
330	61	30.4	99.42
360	61.3	30	99.43
390	62	31	99.95
420	59.2	30	99.99
450	57.1	30	100
480	55.2	30	100
510	48.5	28.5	100

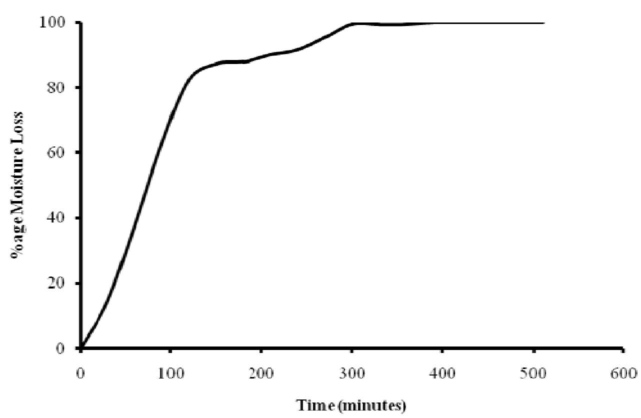

Fig. 1: Moisture loss vs. time for drying of potato slice.

A Model equation for drying was formulated which described the drying rates a function of inside and outside temperature. The model equation is given as:

$$M = -285.90 + 0.083 * t - 0.86 * Ti + 13.35 * To$$

Where m is the percentage moisture, t is a time in minutes, Ti is inside temperature, and To is outside temperature. The P value is given in table 2 and R square values in table 3. The Model F-value of 153.89 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, C are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. The "Pred R-Squared" of 0.9465 is in reasonable agreement with the "Adj R-Squared" of 0.9643. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. The ratio of 36.251 indicates an adequate signal.

Table 2: P-value for the model equation

Source	Sum of square	DF	Mean square value	F square value	P value Prob>5
Model significant	16115.8	3	5371.92	153.89	< 0.0001
A- Time	1863.34	1	1863.34	53.38	< 0.0001
B- Inside Temperature	78.98	1	78.98	2.26	0.1548
C- Outside Temperature	1076.2	1	1076.2	30.83	< 0.0001
Residual	488.7	14	34.91		
Cor Total	16604.47	17			

Table 3: Statistical analysis of data

Std. Dev.	5.91	R-Squared	0.9706
Mean	80.25	Adj R-Squared	0.9643
C.V. %	7.36	Pred R-Squared	0.9465
Press	888.81	Adeq R-Precision	36.251

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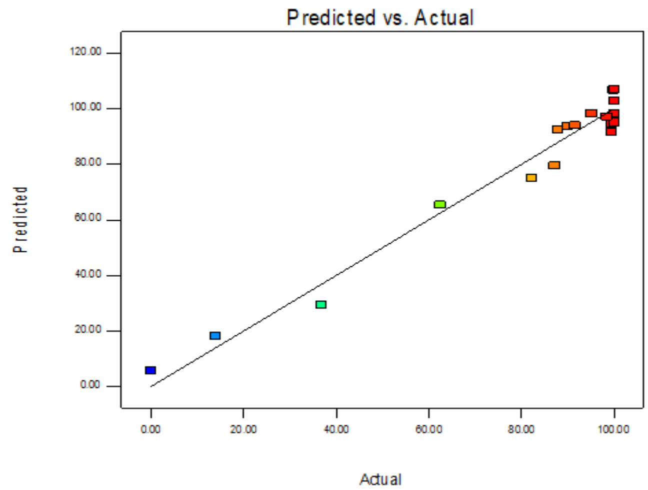

Fig. 2: Predicted vs. actual values.

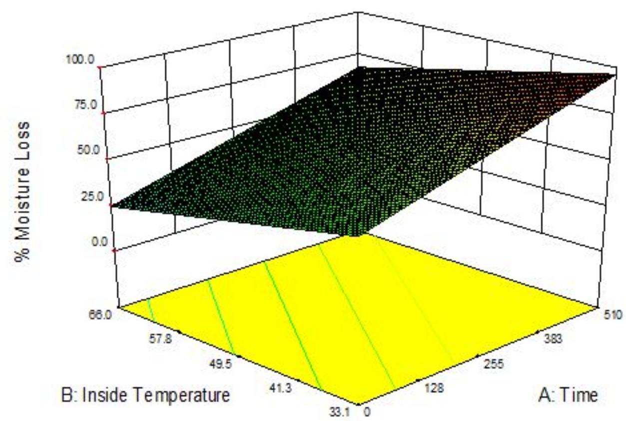

Fig. 3: Moisture loss as a function of time and temperature

The experimental values and model predicted values were plotted in fig. 2. The experimental response values were shown in good agreement with the predicted values. The closeness between the experiment and predicated confirmed the adequacy of the corresponding response surface models employed for describing the differences obtained in the dried potato as a function of drying conditions.

Fig. 3 is a graphical representation of the experimental data obtained during the drying process. It was plotted to understand the interaction of the three variables viz a viz time, inside temperature and percent moisture loss, and locate the optimal value of each variable for maximal response. During the experiment, it was observed from the curves that average total percept moisture loss after 30 minutes incurred during initial minutes of drying reported progressive dehydration phase which was due to high moisture percentage present in potato slices and high temperature inside the dryer followed by slow in the later phase of drying. It was found further drying of potatoes during later phase did not bring any considerable decrease in weight. This consolidated prediction based on data generated confirmed the lowest safe moisture content of potatoes. The results show that these variables had a significant effect on the drying process. Similar results were observed by Lesekan and Abbas [8] and Doymaz and Pala [4].

Conclusion

The present study was designed to optimize the characteristics of dried potato slices using response surface methodology (RSM). The response surface analysis showed a significant (0.05) relationship between the independent variables and response variables. The coefficient of determination (R^2) was one of the important criteria to select the best equation in the solar drying curves of the dried samples of potato the value of R^2 was 0.9706. In addition to R^2, the various statistical parameters, such as the standard deviation, Mean, C.V%, and Press were also determined. During the drying period, temperature and the loss of weight the moisture content was expressed as total percent moisture loss after every 30 minutes. The potato slices in 240 minutes showed 90 percent moisture loss and in 270 minutes for 95 percent moisture loss. After about 300 minutes, 100 percent moisture reduction took place.

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