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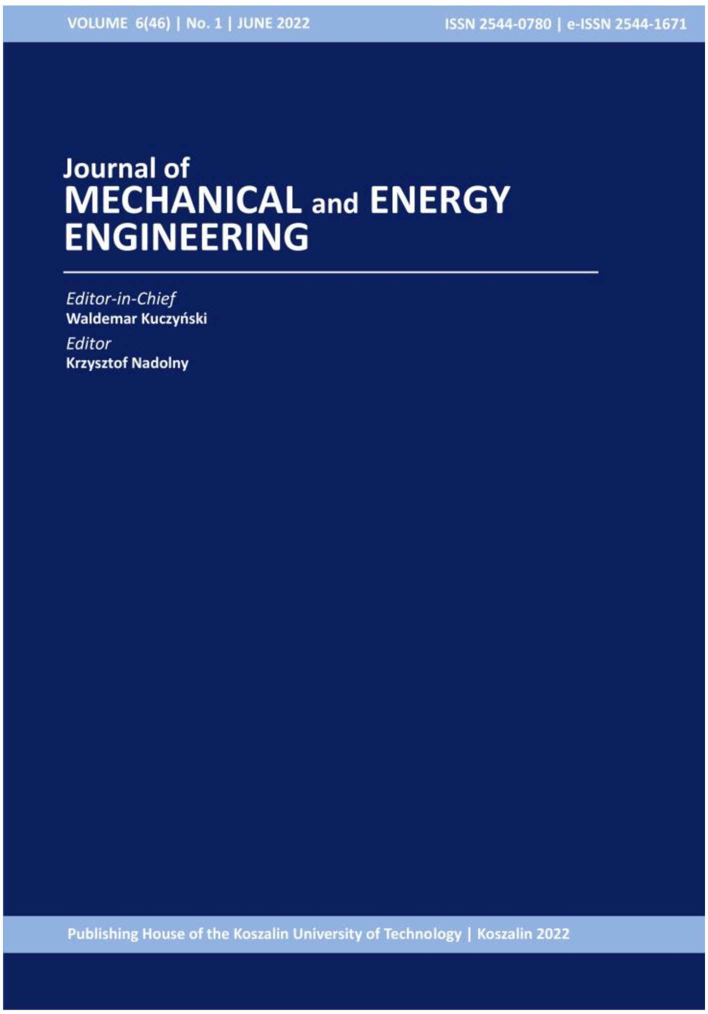

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DRYING KINETICS OF A SOLAR DRYER FOR DRYING OF POTATO CHIPS IN WESTERN MAHARASHTRA, INDIA

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Abstract: The current study focuses on the performance of a solar greenhouse dryer for drying of potato chips in Solar Dryer and Open sun conditions in Western Maharashtra. Potato chips is a value added product that can be effectively used during throughout the year as snacks, a side dish or an appetizer. It can be either deep dried or backed for consumption. The dried potato contains a high fiber content and it helps to lower the cholesterol level in blood reducing the risk of blood pressure if consumed backed. Potato chips can effectively be stored for one year to six months and consumed as snacks. The experiment was conducted for drying of potato chips in Solar Greenhouse Dryer and open sun conditions on 1st of April 2021 for 6 hours. The initial weight of the potato chips to be dried was 500 grams both for the solar greenhouse dryer and open sun drying conditions. The experiment was conducted at Bahe, Borgaon, Tal-Walwa, Dist-Sangli, Maharashtra, India located at 17.115°N and 74.33°E. The experimental observations collected during the tests were set as input data for the Design of the Experiments (DoE) i.e., for Response Surface Modelling (RSM). The main aim of using DoE i.e., Response Surface Modelling, is to obtain an optimum region for drying of potato chips in the Solar Greenhouse Dryer, from the surface plot; the region of maxima and minima was obtained. The contour plot obtained during modeling resembles the optimum region of drying; the optimum region for drying of potato chips is 47 to 50°C respectively. The Moisture Removal Rate (MRR) for drying of potato chips in the Solar Greenhouse Dryer and Open sun drying is 83% and 78% respectively. The drying rate observed during the experiment has a better resemblance with simulated Response Surface Modelling.

Keywords: solar greenhouse dryer, drying, potato chips, solar thermal energy, response surface methodology, design of experiments

1. INTRODUCTION

The solar drying technique is one of the oldest and traditional techniques used for the post-harvesting of crops, vegetables, and fruits. The main aim of the drying process is to decrease or release the moisture of the crop harvested so that excess growth of microbes prevents any further losses. Open drying was implemented in many countries as the drying process is easily accessible for crops, but open sun drying affects the flavour of the dried product, its texture and the colour because the temperature exceeds some limits [1]. Therefore, controlled drying is one of the advanced techniques that is used for drying crops under adequate temperature conditions to avoid flavor, texture, and color losses during the drying process. The loss during open sun drying is sometimes unrecoverable. The texture of dried products affects the taste of the product. The weather conditions also affect the open sun drying phenomenon. Uneven changes in the climate, uneven rainfall, uneven winds affect dried products to a greater extent. The quality and quantity of the final drier products are affected due to such uneven climatic conditions. The actual working of open sun drying is that the dried product is laid under solar radiation for drying [2]. The solar energy incident onto the dried product heats the product and it finally releases the moisture content into the adjacent dry air, thereby reducing the moisture of the dried product. The drying process is very useful in the agricultural context as it reduces post-harvest crop losses. It has been estimated that nearly 10% to 40% of crops harvested every year face the problem of post-harvest losses. [3]

In India, the climatic zones are divided into five types, namely hot and dry, warm and humid, composite, temperate and cold respectively. According to climatic zones and crops grown in those particular areas, there is a need for proper post-harvest technology that needs to be implemented considering the climatic zones [13-15]. Farmers in India rely most on open sun drying for agricultural yields, but in some parts of the nation like cold zones, probably the northern states of India, receive much smaller amounts of solar radiation. Therefore, there is a need for implementing a proper post-harvest technology that can suit the various climatic zones of India [4]. The Solar Greenhouse Dryer (SGHD) is an active device that utilizes the incident solar radiation on to the surface of the dryer to allow heat gained by solar insolation to be trapped into the dryer; and it utilizes that heat energy to dry agricultural yield by using natural convection. The rural areas of India lack electricity due to excess load shedding of these, which leads to major losses in agricultural yield in rural areas. The system designed for drying of agricultural yield should be independent from grid electricity, thus natural convection is to be considered for drying. The objective of the present study is to determine the parameters of the Solar Greenhouse dryer that matches the local conditions i.e., the local environmental conditions of Western Maharashtra and to evaluate the performance parameters like the temperature and moisture content of the dried product [5].

The term: the greenhouse dryer is used for a building that is highly glazed with thermal conditioning for a desired range, and it is used for cultivating crops, plants, vegetables, etc. The actual working of a greenhouse is that short-wave radiation falling on the greenhouse is absorbed by the outer glazing material thereby heating the interior area of the greenhouse and providing ambient heat for plants and vegetable growth respectively[6]. The heated space is retained within the enclosure of the greenhouse. This phenomenon is known as the greenhouse effect [7]. The important role in connection with the greenhouse effect phenomenon is played by the atmosphere, insulating roofs, walls, etc. [8]

When solar radiation strikes the surface of the Earth, some of it is absorbed by the Earth's surface, while the rest is reflected as infrared radiation. Infrared radiation emitted by the surface of the Earth is then absorbed by various gases like CO_2, methane, NO_x and water vapor. This absorption of infrared radiation by the atmosphere and various gases like CO_2, methane, NO_x, and vaporised water is known as the greenhouse effect. The greenhouse effect helps in maintaining the temperature of the Earth at ambient temperatures; without the greenhouse effect, the Earth's temperature would amount to -18°C respectively [8].

The various parameters considered during the designing of the solar greenhouse dryer are as follows:

1. Glazing Materials. Proper glazing materials allow maximum solar radiation to enter the greenhouse dryer. The heat loss from the glazing material should be as minimum as possible. The glazing material should possess maximum absorptivity and minimum reflexivity. Thin plastic foil absorbs direct and diffuse solar radiation [10].
2. Ventilation methods can be divided into free and forced ventilation. Free ventilation can be effectively used for solar drying as there is lack of electricity in rural areas.
3. Solar Orientation. The Solar Greenhouse Dryer should be south-oriented to gain the maximum solar radiation. The roof inclination should have a 23° to 25° roof angle to gain 90% of solar radiation. The north wall of the Solar Greenhouse Dryer is well insulated to avoid heat loss.[12]

The availability of electricity in the rural areas of Sangli, Satara and Kolhapur vary with time and climatic conditions. These areas have to face excess load shedding; thus, it is not possible to use air-conditioned atmosphere to prevent post-harvest loss by every farmer as the cost incurred by the storage unit is higher. Thus, there should be provision of proper drying technology that can be used by local farmers that is cost-effective and time-efficient [10].

2. METHODS

The proposed Solar Greenhouse Dryer has a triangular roof with a vent on the roof side to allow air passage for ventilation. The Solar Greenhouse Dryer is manufactured initially with a mild steel square pipe and it is covered with a thin plastic foil of 2 mm thickness to allow maximum solar gain during sunshine hours. The bottom surface of the Solar Greenhouse dryer was covered with a sandbar or course sediment for the heat gained from the sun to trap into the Solar Greenhouse Dryer. The roof of the Solar Greenhouse Dryer was provided with an inclination of 17° i.e., the latitude of Bahe Borgaon, Tal-Walwa, Dist-Sangli, Maharashtra, India, where the experiment was conducted [12]. The overall dimensions of the Solar Greenhouse Dryer are as given below:

Tab. 1. Dimensions of Solar greenhouse dryer

Sr. no.	Specifications	Details, mm
1	Length	1000
2	Height	400
4	Width	600

The drying tray provided for SGHD was inclined in relation to the base surface to maximize the inclined solar radiations onto the dryer. The two-air inlet was provided along with the upper duct section for free passage of air into the Solar Greenhouse Dryer. The drying tray is provided with a fine wire mesh for drying agricultural yield. The North wall of the Solar Greenhouse Dryer was insulated to avoid heat loss during the drying process. The drying process was performed using free convection, as in many rural areas there is load-shedding due to which electricity cannot be effectively used for the drying phenomenon [12]. The actual experimental setup with north wall insulation is as shown in the figure below:

Fig. 1. Experimental Setup of Solar greenhouse dryer

3. EXPERIMENTAL METHODOLOGY

Potato chips were to be dried in the Solar Greenhouse Dryer (SGHD). The whole potato was soaked overnight in an alum and water solution. The overnight soaked potatoes were sliced into chips, the initial weight of potato chips to be dried was 500 grams with the thickness of 1.30 mm for both SGHD and open sun drying respectively. The initial moisture of the sliced potato chips was considered to be 100% as a benchmark, and they were allowed to dry. The drying mechanism of the potato chips is as elaborated in block diagram below:

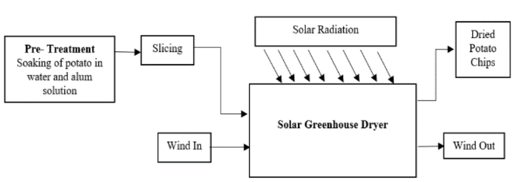

Fig. 2. Block diagram for drying of potato chips

4. MECHANISM OF DRYING

The major heat transfer associated with the drying process of potato chips is convection and radiation type of heat transfer. Initially, when the solar radiations strikes the roof and walls of the Solar Greenhouse dryer, the radiation type of heat transfer is observed i.e., the heat energy from solar radiation is transferred to the walls, roof and area enclosed by dryer. The second mode of heat transfer observed is a convection type of heat transfer, when the wind starts to flow inside the enclosed greenhouse dryer, the heat energy gained by the walls and the roof area during radiation is transferred throughout the dryer equally [10]. The combination of radiation and convection type of heat transfer continues after each and every cycle of the radiation and convection heat transfer. The dried product left on the drying net receives this combination of radiation and convection heat transfer, and water vapour inside the product is evaporated due to heat gained by the radiation and convection currents.

5. RESULTS

The details of drying of potato chips is as elaborated below in Table 2.

Tab. 2. Details of drying of potato chips

Sr. no	Time	Wind Speed, m/s	Solar Radn, W/m^2	Temp Atm, °C	Temp (SGHD), °C
1.	10:00 am	0.45	786	27	41
2.	11:00 am	0.75	938	23	48
3.	12:00 pm	0.50	980	40	52
4.	1:00 pm	0.40	1002	43	53
5.	2:00 pm	1.50	910	47	58
6.	3:00 pm	1.65	742	45	53
7.	4:00 pm	0.80	468	40	40

6. RESULTS OF RESPONSE SURFACE METHODOLOGY

The Response Surface Methodology is a set of mathematical and statistical tools for modelling and analysing problems in which the response of interest is influenced by a number of variables, with the main goal of optimising the response. For example, the temperature of the drying tray in the dryer depends upon two main factors, i.e. solar radiation and wind speed respectively. The Mini Tab a Statistical Simulation Software for the design of trials. Statistical Software was used to simulate the outcomes for the Response Surface Methodology (RSM). The main aim of using the Response Surface Methodology in drying of potato chips is to understand and evaluate the topography of the response of experimental observations and, based on the topography, finding the region of an optimum response. The steps involved in the simulation of RSM are as follows:

1. Initially, the Central Composite Design was selected as the number of variables available were a continuous factor.
2. In designs, the total number of runs selected during the simulation was 13, the number of centre points and the value of alpha was set on default, the default value for alpha was set to 1.414 respectively.
3. Next, in order to define the cube points, the dependent variables i.e., solar radiation and wind speed were selected, and the low and high values of each set were entered.

The coefficients coded used during Response Surface Regression are given below in the table 3.

Tab. 3. Coded Coefficients in Response Surface Regression for drying of potato chips

Sr. no	Terms	Coef.	SE Coef.	T-Value	P-Value	VIF
1.	Const	44.00	3.99	11.02	0.000	
2.	Wind Speed	-4.45	3.16	-1.41	0.201	1.00
3.	Solar Radn	0.29	3.16	0.09	0.930	1.00
4.	Wind Speed×Wind Speed	-0.69	3.39	-0.20	0.845	1.02
5.	Solar Radn×Solar Radn	0.31	3.39	0.09	0.929	1.02
6.	Wind Speed×Solar Radn	1.25	4.47	0.28	0.788	1.00

The observed Pareto Chart, the contour plot and the surface plot for drying of potato chips in the Solar Greenhouse Dryer is as shown below in Figures 3, 4 and 5 respectively.

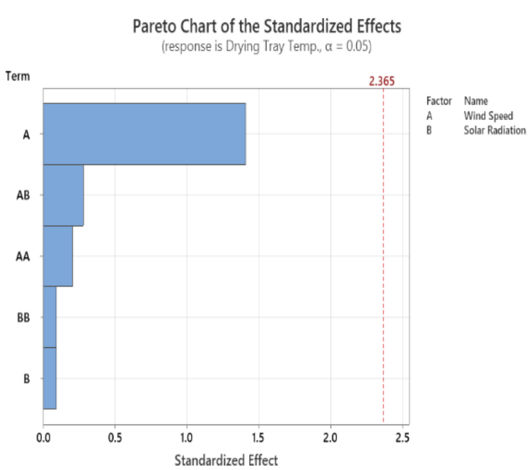

Fig. 3. Pareto chart for drying of potato chips

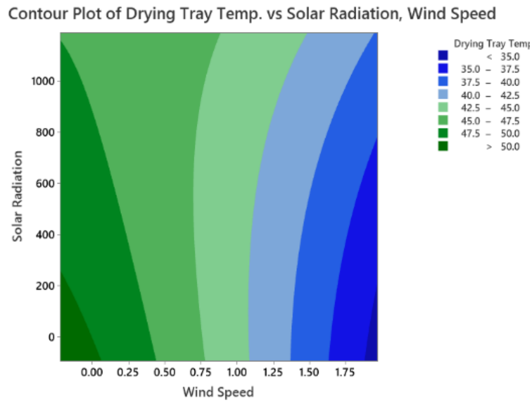

Fig. 4. Contour plot for drying of potato chips

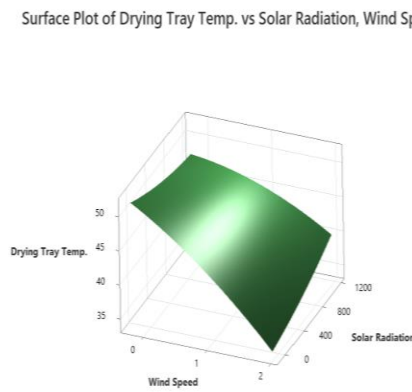

Fig. 5. Surface plot for drying of potato chips

The Analysis of Variance (ANOVA) for drying of potato chips in the Solar Greenhouse Dryer is as shown in table 4.

The contour plots enable to set such variable parameters as solar radiation or the wind speed to an optimum range for proper drying of potato chips. From the graph above, as elaborated in Figure 4, the blue region indicates the region where the drying process is not adequate, whereas the light green color indicates that the drying parameters are adequate; and the dark green region indicates the drying parameters are optimum for drying of potato chips. The upper right corner of the contour plot, cf. Figure 4, resembles the range of the drying tray temperature. Hence, as per the experimental observations, the proper optimum region should be decided accordingly. The contour plots obtained from the Response Surface Modelling indicate that the optimum drying temperature required for drying of potato chips is 47.5 to 50°C. Solar radiation ranging from 200 to 1000 W/m^2 and the wind speed ranging 0.10 to 0.45 m/s are adequate for drying of potato chips.

Tab. 4. ANOVA for drying of potato chips in the Solar Greenhouse Dryer

Sr. no	Source	DF	Adj SS	Adj MS	F-Val.	P-Val.
1.	Mdl	5	170.016	34.003	0.43	0.817
2.	Linear	2	159.333	79.667	1.00	0.415
3.	Wind Speed	1	158.664	158.664	1.99	0.201
4.	Solar Radn	1	0.669	0.669	0.01	0.930
5.	Square	2	4.433	2.216	0.03	0.973
6.	Wind Speed×Wind Speed	1	3.288	3.288	0.04	0.845
7.	Solar Radn×Solar Radn	1	0.679	0.679	0.01	0.929
8.	2-Way Interaction	1	6.250	6.250	0.08	0.788
9.	Wind Speed×Solar Radn	1	6.250	6.250	0.08	0.788
10.	Error	7	558.292	79.756		
11.	Lack-of-Fit	3	78.292	26.097	0.22	0.880
12.	Pure Error	4	480.000	120.000		
13.	Total	12	728.308			

The weight reduction of potato chips after drying is as given below in the table 6.

Tab. 5. Weight reduction in potato chips after drying

	SGHD		Open Sun	
Day	Initial Wt, gm	Final Wt, gm	Initial Wt, gm	Final Wt, gm
1.	500	85	500	110

The moisture removal rate (%) for SGHD and open sun drying for potato chips is as given below in the table 6.

Tab. 6. Moisture removal rate (%) of potato chips

Sr. No	Product	Moisture Removal (%) in SGHD	Moisture Removal (%) in open sun
1.	Potato chips	+83%	+73%

The details of the potato chips after drying for 6 hours in Solar Greenhouse Dryer and open sun are as shown in Fig. 6 and 7.

Fig. 6. Dried potato chips in Solar Dryer

Fig. 7. Dried potato chips in open sun condition

7. CONCLUSIONS

The Solar Greenhouse Dryer is an effective way to prevent the agricultural yield from deterioration due to an excess growth of moisture. The Solar Greenhouse Dryer provides the optimum temperature that is required for drying agricultural yields with high moisture content. The initial weight of potato chips to be dried was 500 grams both for the Solar Greenhouse Dryer and the Open Sun drying conditions.

The drying time for potato chips was 6 hours. The experimental observations were made on 1st of April 2021 at Bahe Borgaon, Tal-Walwa, Dist-Sangli, Maharashtra, India located at 17.115°N and 74.33°E. Potato chips were to be dried in the Solar Greenhouse Dryer (SGHD), the whole potato was soaked overnight in an alum and water solution. The potatoes soaked overnight were sliced into chips, the initial weight of the potato chips to be dried was 500 grams both for the SGHD and Open Sun drying respectively. The weight reduction of the potato chips after drying was 85 grams and 110 grams for the SGHD and Open Sun drying condition respectively. The Moisture Removal Rate (MRR) in percent after drying is 83% for the SGHD and 78% for Open Sun drying.

The experimental observations recorded during the drying process both for the SGHD and Open Sun drying was used as an input data for the Design of Experiments in the Response Surface Modelling (RSM). The main goal of the Response Surface Modelling (RSM) method is to understand the various topographies of the experimental observations; another major goal of the topography obtained is to find a region of an optimum response from the set of observations and move effectively along a path to obtain a maximum or minimum response. The results obtained from Response Surface Modelling coincide with those of the experimental observations. It is very clear from the results obtained from Response Surface Modelling that the optimum drying temperature for drying of potato chips ranges from 47.5°C to 50°C. Solar radiation required for optimum drying is in range of 200 W/m^2 to 1,000 W/m^2 and the wind speed of 0.10 m/s to 0.45 m/s is required.

Nomenclature

Acronyms

DoE – Design of Experiments
MRR – Moisture Removal Rate
RSM – Response Surface Modelling
SGHD – Solar Greenhouse Dryer

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