DEVELOPMENT OF APPLIED SCALE MODEL FOR AIRFLOW AND HEAT TRANSFER THROUGH FORCED-AIR DRYING OF PLUM (*PRUNUS DOMESTICA*.L.) USING THIN LAYER APPROACHES

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Abstract
The main objective of solar drying in horticultural products is to reduce the moisture content to a required level that allows a safe and extended shelf-life duration. Solar drying is also considered as a significant technique for food security and quality. Drying of plums were carried out in a drying chamber attached with a flat plat solar collector at three different temperatures and three air velocities. The whole plum fruits, were subjected to the drying process. The research was carried out in completely randomized design (CRD) with temperature and air velocity as factors having three levels with three replications. During drying of plums, the maximum moisture loss (wet basis) recorded 2.629 % at 65 ^oC while minimum recorded 2.459 % at 45 ^oC, and 2.550 % at 0.5 m. s^{-1} air velocity followed by 2.549 % at 1.0 m. s^{-1}. Highest activation energy of 46.97 kJ.mol^{-1} recorded at 65 ^oC while minimum of 38.19 kJ.mol^{-1} recorded at 45 ^oC. Similarly, maximum activation energy of 45.07 kJ.mol^{-1} recorded at 0.1 m. s^{-1}air velocity followed by 43.95 kJmol^{-1} at 0.5 m. s^{-1}. The maximum moisture diffusivity of $1.76x10^{-9}$ recorded at 65 ^oC while minimum of $0.91x10^{-9}$ recorded at 45 ^oC. In all the six best published models for plums, the modified page model gave significant results with R^2 of 0.99, RMSE value of 0.08, and a X^2 value of 0.62. Temperature showed significant effect on increase of moisture loss $hour^{-1}$, activation energy and moisture diffusivity. Air velocity showed non-significant results on moisture loss.
Key words: Airflow, Heat transfer, Forced-air drying, Plum, Thin layer approaches

Introduction

A plum (*Prunus Domestica*.L.) fruit belongs to (family Rosaceae) an angiosperm tree and it is distributed throughout the northern climate regions of the globe. Plums belong to the same family as nectarines, peaches, cherries, apples, berries, apricots and almond. These are medium size stoned fruits with dark purple, red skin color. It contains a fair number of important vitamins and minerals but are relatively low in calories. Besides nutrients they have many more health benefits. They are rich in vitamins and were used for the treatment of gastrointestinal diseases in the past. These were considered to be the first fruit used domestically (Ahmadi *et al*., 2008). It is a temperate fruit and grown in climates with well-differentiated seasons. It requires a moderately high temperature in the spring and early summer and fairly cold winter (Kurmanov *et al.*, 2015). The plum is a high-cost fruit and consumed mostly in its fresh state with over 70% of the product delivered by the fresh produce

market. It is susceptible to mechanical damage, microbial decay and water loss. However, plum is one of the most perishable fruits and in some cases, these prevent the product from reaching the consumer at its optimal quality after transport and distribution (Manganaris *et al*., 2007).
According to FAO statistics (2016), the world's largest producers are Iran, Turkey and Czech Republic, accounting for world production of plums are 23.1, 21.6 and 14.7% respectively, followed by Pakistan, Spain, Italy, Uzbekistan, Algeria, Japan, Morocco, Egypt. It is used for preparation of jellies, jam, marmalades, pulp, juices, nectars and extruded products, and consumed in fresh, dried and frozen forms (Sevil *et al*., 2019). In Pakistan, there is a high demand of dried plums called Alobukhara. It has a good demand in market and also used in different dishes, juices and consumed as whole dried fruit. It is considered to be a good tonic for weight lost and removing toxic materials from the liver. For this purpose, it is mixed with tamarind (Imlli) and consumed as a syrup called Alobukhara syrup (Hussain., 2018). Plums are mainly dried in the open sun, but this technique causes more losses during drying as the fruit is attacked by pests and microbes. Also, the deposition of dust from the environment makes it a product contaminated by mycotoxin which further causes poor quality and reduce chances of export. The technique is also unhygienic and the product may affect from rancidity due to uncontrolled drying environment. Solar dried plums have a high demand and have very good market in Pakistan as well as in the world. Plums dried in the open sun cause rancidity, mycotoxin infestation and dust deposition. These cause losses during drying and reduction in the quality of the dried fruit. The process is also unhygienic and unstable. The aim of this study is to dry plums using flat plate solar collector under controlled temperature, humidity and air velocity on hygienic environment to achieve high quality solar dried plums. To study the effect of different dryer temperatures on the drying of plums and different air velocities on the drying of plums. The interaction effect of dryer temperature and air velocity on the drying of plums. And also, to test the applicability of thin layer drying models for air flow and heat transfer through forced-air drying of plums.

Materials and methods

The research study was performed in the Department of Agricultural Mechanization and Renewable Energy Technologies in the year 2020. The University of Agriculture, Peshawar, Pakistan. The research was carried out in completely randomized design (CRD) with temperature and air velocity as factors having three levels with three replications. The total number of treatments were 9 in the study.

Table 3.1. Experimental Factors and their Levels

Factor 1	**Temperature**
T1	45±1 °C
T2	55±1 °C
T3	65±1 °C
Factor 2	**Air Velocity**
V1	$m.s^{-1}$ (Natural)
V2	0.5 $m.\ s^{-1}$
V3	1.0 $m.\ s^{-1}$

Solar Irradiance

Solar irradiance was determined by using sun power meter during sunshine in the experimental time.

Sample Preparation

Approximately uniform size of plums were selected and used. The collected samples were stored at 3±0.5 ^oC for 1 hour before using in experiments. Moisture content of plums was determined with oven drying method at 100 ^oC in a vacuum oven (model EV 018, Nuve laboratory and sterilization Tech.) for 24 hours. The initial moisture content of plums samples were 87±1.0 % (Bano *et al*., 2015).

Drying Process

Drying experiments were performed in a flat plate solar collector (FPSC) with dryer. The dryer consists of centrifugal fan to supply the air flow and an electronic proportional controller (ENDA, EUC442). Prior to drying of plums samples were blanched by dipping in hot water at 80 ^oC for 5 minutes. These samples were immediately cooled down in tap water at room temperature to avoid excess heat, and placed on tissue paper to absorb the excess surface water prior to drying. The plums were immersed in 2 % potassium metabisulfite solution at 35 ^oC for 10 minutes (Lopez *et al*., 2018). The dryer was turned on about 1 hour before the drying process to reach steady-state or equilibrium conditions before each drying experiment. After the steady state conditions for the operation temperature, Plums were placed on the tray of the dryer and dried simultaneously. The drying experiments were performed at 45,55 and 65 ^oC air temperature. The air velocity was kept at 0.1,0.5 and 1.0 ms^{-1} in drying chamber. During drying the samples were taken after 2 hours intervals and weighed, before being returned to the dryer (Hanif *et al*., 2018).

At the end of each drying experiment, the final moisture content of the samples were determined. Samples were dried approximately 15% final moisture content. Moisture content was given in wet-basis. The amount of dry matter was calculated by using the mean final moisture content and weight of the dried plums (Khattak *et al*., 2019). The moisture contents were also expressed in dry basis. All the experiments were replicated three times at each air temperature and average value.

Mathematical Modeling of Drying Curves

Mathematical models that describe drying mechanisms of plums provide the required temperature and moisture information. The best model describing the drying behavior of plums is selected by testing the five commonly used thin layers drying models given in Table 1. However, the moisture ratio (MR) was simplified to M/Mo instead of the (M – Me) / (Mo – Me)

To developed and test the physical applied model for the moisture loss ratio.

The coefficient of determination (R^2), Root mean square error (RMSE) and reduced chi square (χ^2) obtained from these equations were used to compare the relative goodness of fit of experimental data. These parameters can be calculated as follows.

$$R^2 = 1-\left[\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right] \quad \text{.....................[3.1]}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2\right]^{1/2} \quad \text{..........[3.2]}$$

$$X^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2}{N - Z} \text{.....................[3.3]}$$

Table 3.2. Mathematical models applied to drying curves

Model name	Model Equation	References
Logarithmic	MR = α exp (-kt) + c	Onwude*et al.*, 2016
Lewis	MR = exp (-kt)	Agbossou*et al.*, 2016 Henderson
andPabis	MR = α exp (-kt)	Olabinjo*et al.*, 2017
Page	MR =exp (-ktn)	Hicham*et al* 2018
Modified Page	MR = exp[-(kt)n]	Hanif*et al.*, 2015

Variations of moisture content with drying time of blanched (B) and immersed in 2 % potassium metabisulfite solution (I) plums at different air temperatures. $MR_{exp.\ i}$ is the ith experimentally observed moisture ratio, $MR_{pre,}$ is the ith predicted moisture ratio. N is the number of observation and Z is the number of constant.

The best model describing the drying behavior of plums were chosen as the one with the highest coefficient of determination and the least mean relative percent error and the least root mean square error. In addition, reduced Chi square was used to determine the goodness of the fit. The lower values of reduce Chi square, the better goodness of the fit (Agbossou *et al.*, 2016).

Calculation of Effective Moisture Diffusivity

The experimental drying data for the determination of moisture diffusivity was interpreted by fick's Second law of diffusion. The solution of Fick's second law in spherical coordinates is given below (Eq. 4), with the assumption of moisture migration being by diffusion, negligible shrinkage, constant diffusion coefficients and temperature (Hicham *et al.*, 2018).

$$MR = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-\frac{n^2\pi^2 D_{eff}t}{R^2}\right) \text{..[3.4]}$$

$$\text{In (MR)} = \text{In}\left(\frac{6}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff}t}{R^2}\right) \text{..[3.5]}$$

The effective moisture diffusivity was calculated by using the method of slopes. Diffusion coefficients are typically determined by plotting experimental drying data in terms of in (MR) versus time as given in Eq. (5) From Eq. (5), (Hanif et., 2016) a plot of In (MR) versus time gives a straight line with a slope of

$$\text{Slope} = \frac{\pi 2 D eff}{R2} \text{..................................[3.6]}$$

Calculation of Activation Energy

Arrhenius type equation is using to calculated the activation energy (Ea) (Onwude et al., 2016)

$$D_{eff} = D_0 \exp\left(\frac{-Ea}{RT}\right) \text{.................................[3.7]}$$

Where D_o is the pre-exponential factor of the Arrhenius equation ($m^2\ s^{-1}$), E_a is the activation energy (kj $mo1^{-1}$), R is the universal gas constant ($kJmo1^{-1}\ K^{-1}$), and T is the absolute air temperature (K). The activation energy is determined from the slope of the Arrhenius plot, In (D_{eff}) versus T^{-1}.

Parameters studied

1. Solar Irradiance
2. Temperature and humidity of dryer and ambient air
3. Moisture lost
4. Drying rate
5. Moisture diffusivity
6. Activation energy.
7. Applicability of thin layer models on moisture loss ratio.

Statistical Analysis

The research was carried out in completely randomized design (CRD) with Temperature and air velocity as factors have three levels with three replications. The total number of treatments were 9 in the experiment. The significance of differences among the treatments were analyzed with the help of ANOVA. Statistical significances were set at P-value of <0.05 (Liu *et al.*, 2011).

Results

4.1 Solar Irradiance

The solar irradiance data of the site is given in figure (4.1). The results shows that solar irradiance was received by the solar collector from 6:00 am to 7:00 pm. There were 11 hours of sunshine duration at total. At 6 am the solar irradiance was 100 w.m^{-2} which increase with time and at noon 12:00 maximum solar irradiance of 890 w.m^{-2} was recorded. The flux then began to decreased and at 7:00 pm it was recorded that 120 w.m^{-2} of solar irradiance was available which became zero at 8:00 pm.

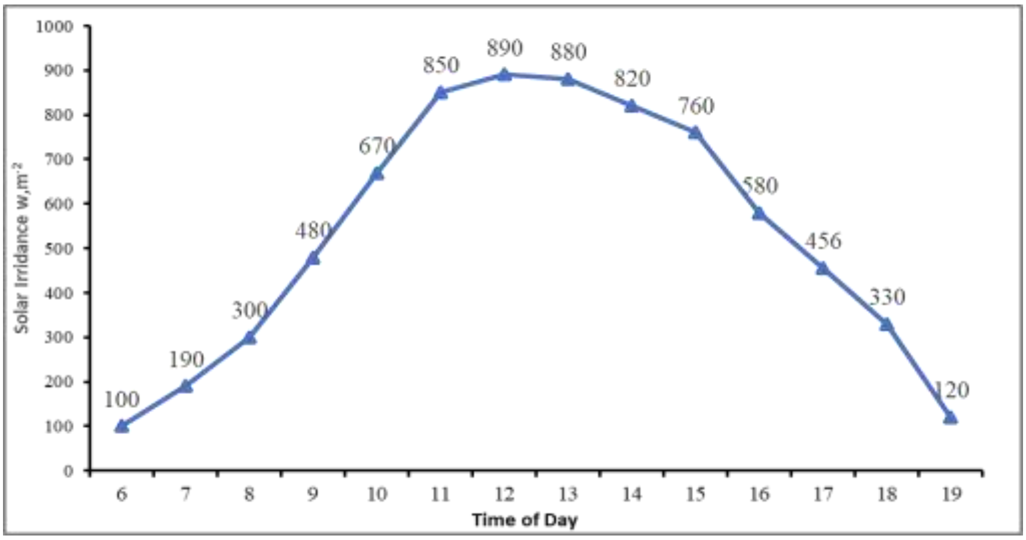

Figure 4.1. Solar Irriadance at different day timmings during the experimental period

4.2 Temperature and Humidity of dryer and ambient air

Temperature and humidity data of the dryer assembly of the solar collector is given in Figure 4.2. The ambient temperature data shows that at 6:00 am the recorded ambient temperature was 32 ^{o}C which gradually raised to 34 ^{o}C at 10:00 am and reached to maximum at 1:00 pm. It again decreased gradually and reached to 35 ^{o}C at 7:00 pm similarly the dryer temperature shows that it was 40 ^{o}C at 6:00 am which gradually increased to 44 ^{o}C at 10:00 am and reached to maximum of 52 ^{o}C at 1:00

pm. It again stated decreasing gradually and reached to 35 °C at 7:00 pm. The humidity data of the dryer showed that relative humidity of the dryer was 60 % at 6:00 am which gradually decreased to 26 % at 10:00 am and reached to maximum of 19 % at 2:00 pm. It again stated increasing and reached to 39 % at 7:00 pm.

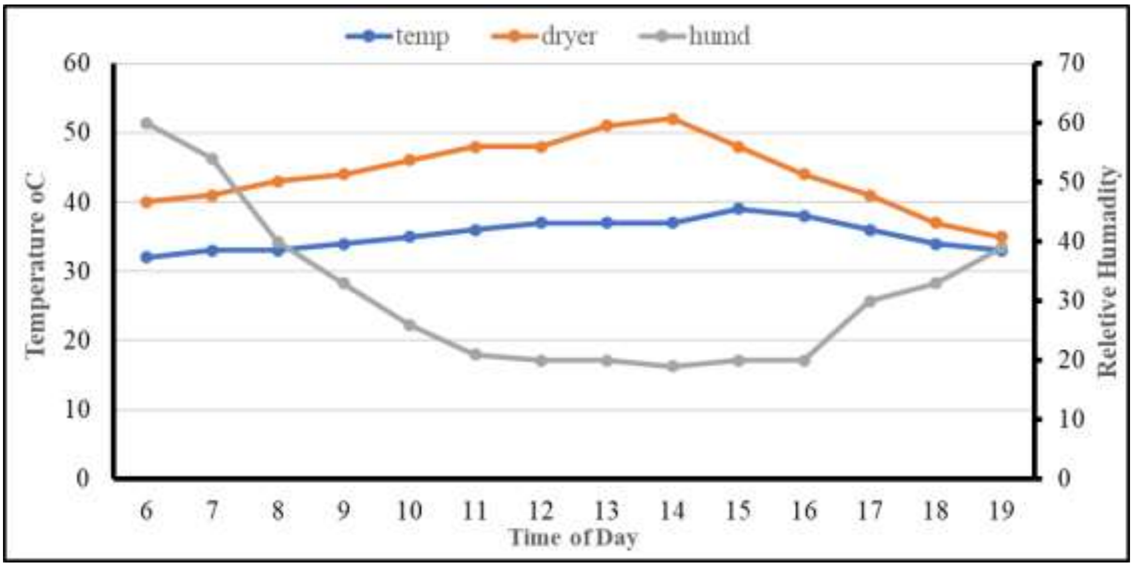

Figure 4.2 Temperature and Humdity of the dryer at different day timmings during the experimental period.

4.3 Moisture Loss per hour

The results of moisture loss per hour by plums under different velocities at 45 °C temperature are given in Figure 4.3. The initial moisture content was 85 % which was reduced to less than 10%. It took almost 26 hours during drying to achieve this moisture at air velocity of 0.1 ms^{-1}. Moisture content reduced to 81% after two hours of drying and reached to 51 % at 13 hours of drying interval. It reached to 28 % after 20 hours of drying and reached to 9 % after 26 hours of drying. The results of moisture loss per hour by plums under different velocities at temperature 55 °C is given in Figure 4.4. The initial moisture content was 85% which reduced to less than 10 %. It took almost 23 hours during drying to achieve this moisture at Air velocity 0.5 m. s^{-1}. Moisture content reduced to 81 % after two hours of drying and reached to 42 % at 13 hours of drying interval. It reached to 16 % after 20 hours of drying and reached to 9 % after 23 hours of drying.

The results of moisture loss per hour by plums under different velocities at temperature 65 °C is given in Figure 4.5. The initial moisture content was 85 % which reduced to less than 10 %. It took almost 19 hours during drying to achieve this moisture at air velocity 1 ms^{-1}. Moisture content reduced to 79 % after two hours of drying and reached to 31 % at 13 hours of drying interval. It reached to 21 % after 15 hours of drying and reached to 10 % after 19 hours of drying.

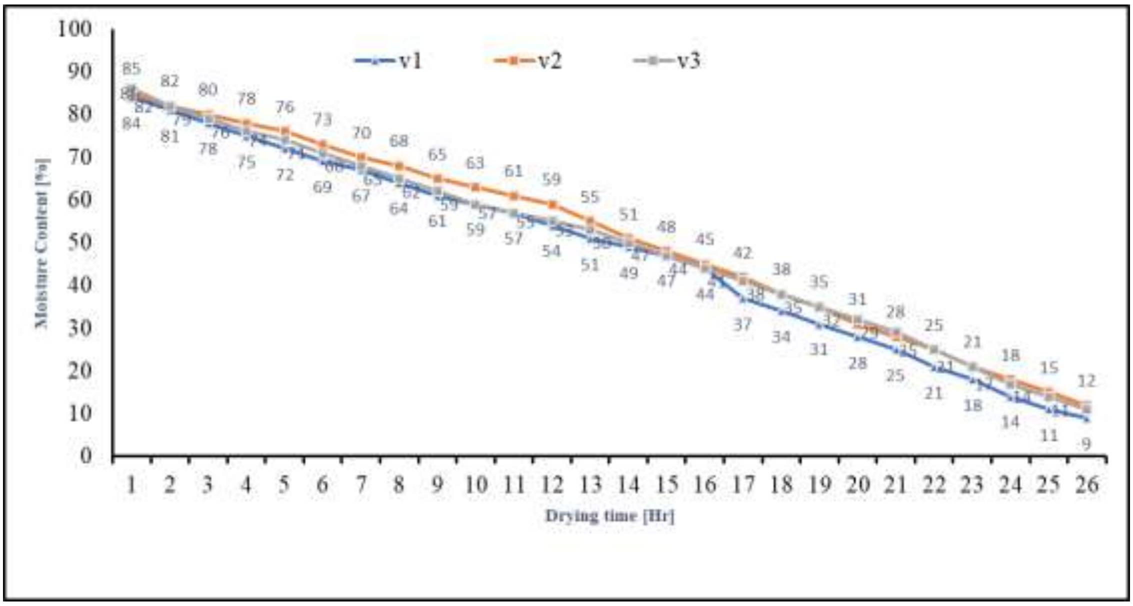

Figure 4.3 Moisture Loss per hour at 45 ^{o}C

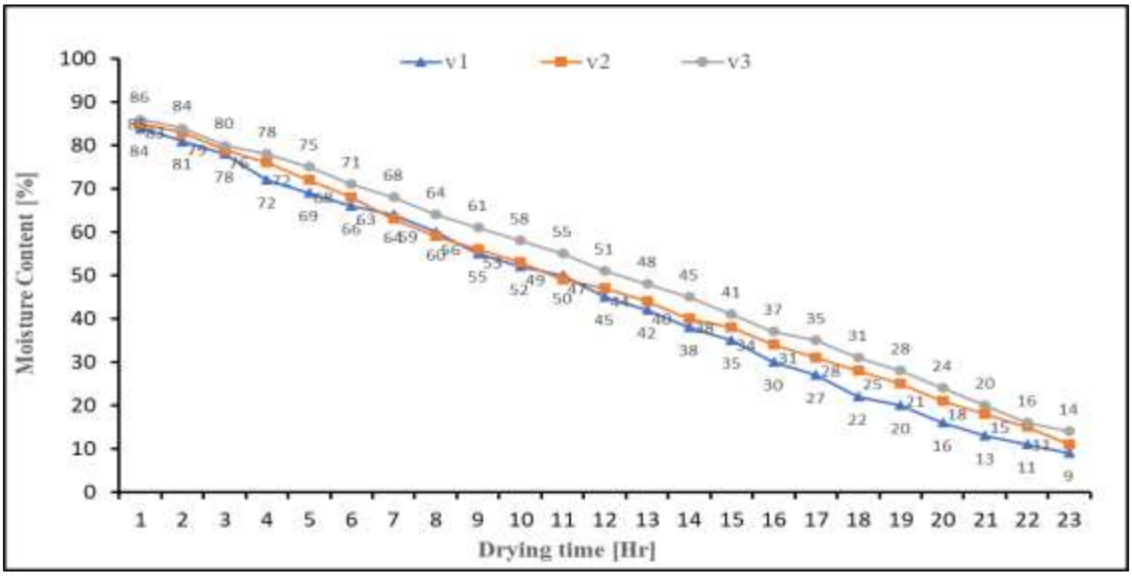

Figure 4.4 Moisture Loss per hour at 55 ^{o}C

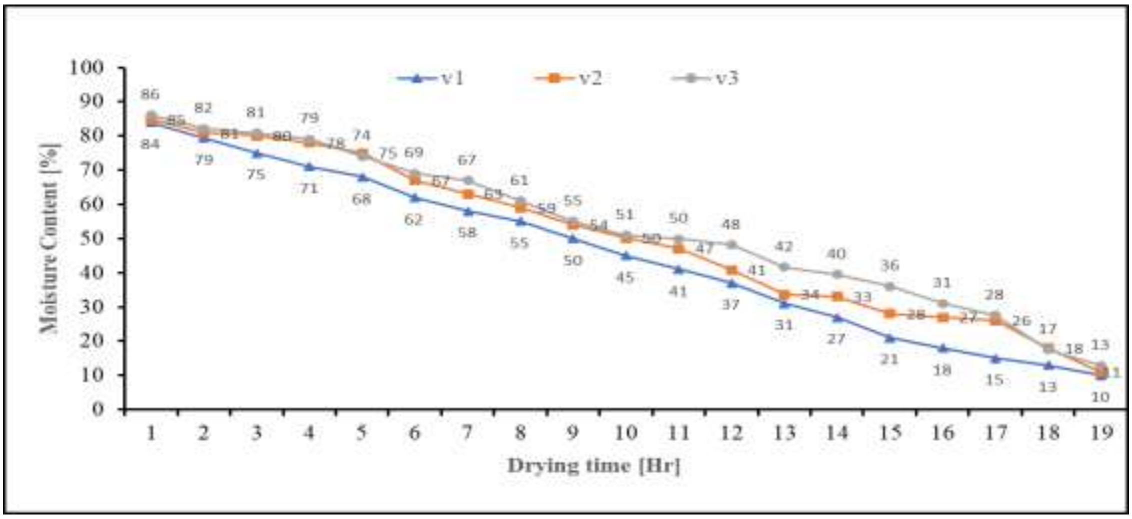

Figure 4.5 Moisture Loss per hour at 65 ^{o}C

4.4 Drying Rate on Wet basis (%)

The result of moisture loss on wet basis as affected by different temperatures and air velocities inside the dryer are given in Table 4.1. The analysis of variance (Appendix A1), showed that dryer temperature showed significant results on the moisture loss per hour while air velocities and the interaction between air velocities and drying temperature showed a non-significant result. The means of Air velocities showed that maximum moisture loss of 2.550 $gm.g^{-1}.H_2O$ was recorded at 0.5 $m.\ s^{-1}$ velocity followed by 2.549 % at 1.0 $m.\ s^{-1}$ air velocity while minimum moisture loss of 2.521 % was recorded at 0.1 $m.\ s^{-1}$ air velocity in the dryer. The means of dryer temperature showed that maximum moisture loss of 2.629 % was recorded at 65 °C while minimum of 2.459 % was recorded at 45 °C. The interaction effect showed that maximum moisture loss of 2.647 % was recorded at 65 °C and 0.5 $m.\ s^{-1}$ air velocity while minimum of 2.443 % was recorded at 45 °C dryer's temperature and $0.1 m.s^{-1}$ air velocity inside the dryer.

Table 4.1 Moisture lost wet basis (%) as affected by different drying temperatures (°C) and air velocities (ms^{-1}) in the dryer

Temperature	Air Velocity (ms^{-1})			
(°C)	1.0	0.5	0.1	Mean
65±1	2.633	2.647	2.607	**2.629a**
55±1	2.543	2.540	2.513	**2.532b**
45±1	2.470	2.463	2.443	**2.459c**
Mean	**2.549**	**2.550**	**2.521**	
Cv 11.56		*LSD for Temperature (T) = 0.015*		

4.5 Drying Rate on Dry Basis ($g_{H2O}.g_{DM}^{-1}.hr^{-1}$)

The means of Air velocities showed that maximum moisture loss of 0.142 $g_{H2O}.g_{DM}^{-1}.hr^{-1}$ was recorded at 1.0 ms^{-1} air velocity followed by 0.142 $g_{H2O}.g_{DM}^{-1}.hr^{-1}$ at 0.5 ms^{-1} air velocity while minimum moisture loss of 0.140 $g_{H2O}.g_{DM}^{-1}.hr^{-1}$ was recorded at 0.1 $m.s^{-1}$ air velocity in the dryer. The means of dryer temperature showed that maximum moisture loss of 0.147 $g_{H2O}.g_{DM}^{-1}.hr^{-1}$ was recorded at 65 °C while minimum of 0.136 $g_{H2O}.g_{DM}^{-1}.hr^{-1}$ was recorded at 45 °C. The interaction effect showed that maximum moisture loss of 0.150 $g_{H2O}.g_{DM}^{-1}.hr^{-1}$ was recorded at 65 °C and 0.5 ms^{-1} air velocity while minimum of 0.133 $g_{H2O}.g_{DM}^{-1}.hr^{-1}$ was recorded at 45 °C dry temperature and 0.5 $m.s^{-1}$ air velocity in the dryer.

Table 4.2 Moisture lost Dry basis ($g_{H2O}.g_{DM}^{-1}.hr^{-1}$) as affected by different drying temperatures (°C) and air velocities ($m.s^{-1}$) in the dryer.

Temperature	Air Velocity (ms^{-1})			
(°C)	1.0	0.5	0.1	Mean
65±1	0.147	0.150	0.143	**0.147a**
55±1	0.143	0.143	0.140	**0.142b**
45±1	0.137	0.133	0.137	**0.136c**
Mean	**0.142**	**0.142**	**0.140**	
Cv 11.62		*LSD for Temperature (T) = 0.001*		

4.6 Moisture Diffusivity (m^2s^{-1})

The means of Air velocities showed that maximum moisture diffusivity of 1.39×10^{-9} was recorded at 1.0 ms^{-1} air velocity followed by 1.29×10^{-9} at 0.1 ms^{-1} air velocity while minimum moisture loss of 1.24×10^{-9} was recorded at 0.5 ms^{-1} air velocity in the dryer. The means of dryer temperature showed that maximum moisture diffusivity of 1.76×10^{-9} was recorded at 65 °C while minimum of 0.91×10^{-9} was recorded at 45 °C.

The interactive effect showed that maximum moisture diffusivity of 1.85×10^{-9} was recorded at 65 °C and 0.1 ms^{-1} air velocity while minimum of 0.85×10^{-9} was recorded at 45 °C dry temperature and 1.0 ms^{-1} air velocity in the dryer.

Table 4.3 Moisture diffusivity (m^2s^{-1}) as affected by different drying temperatures (°C) and air velocities ($m.s^{-1}$) in the dryer.

Temperature	Air Velocity (ms^{-1})			
(°C)	1.0	0.5	0.1	Mean
65±1	1.78×10^{-9}	1.77×10^{-9}	1.85×10^{-9}	**1.76×10^{-9}a**
55±1	1.35×10^{-9}	1.20×10^{-9}	1.32×10^{-9}	**1.24×10^{-9}b**
45±1	0.85×10^{-9}	0.86×10^{-9}	1.11×10^{-9}	**0.91×10^{-9}c**
Mean	**1.39×10^{-9}**	**1.24×10^{-9}**	**1.29×10^{-9}**	

Cv2.75, *LSD for Temperature (T) = $0.015x10^{-9}$,*
LSD for Air Velocity (V) = $0.018x10^{-9}$

4.7 Activation Energy (KJ mol^{-1})

The means of air velocities showed that maximum activation energy of 45.07 $kJmol^{-1}$ was recorded at 0.1 ms^{-1} air velocity followed by 43.95 kJ mol^{-1} at 0.5 ms^{-1} air velocity while minimum activation energy of 37.61 $kJmol^{-1}$ was recorded at 1.0 ms^{-1} air velocity in the dryer. The means of dryer temperature showed that maximum activation energy of 46.97 $kJmol^{-1}$ was recorded at 65 °C while minimum of 38.19 $kJmol^{-1}$ was recorded at 45 °C.

The interaction effect showed that maximum activation energy of 49.87 $kJmol^{-1}$ was recorded at 65 °C and 0.1 ms^{-1}air velocity while minimum of 33.38 $kJmol^{-1}$ was recorded at 45 °C dryer's temperature and 1.0 ms^{-1} air velocity inside the dryer.

Table 4.4. Activation energy (KJ mol^{-1}) as affected by different drying temperatures (°C) and air velocities ($m.s^{-1}$) in the dryer.

Temperature	Air Velocity (ms^{-1})			
(°C)	1.0	0.5	0.1	Mean
65±1	42.71	48.32	49.87	**46.97a**
55±1	36.73	41.73	45.96	**41.47b**
45±1	33.38	41.80	39.40	**38.19c**
Mean	**37.61**	**43.95**	**45.07**	

CV 5.78 *LSD for Temperature (T) = 1.334*
LSD for Air Velocity (V) = 0.981

4.8 Applicability of Thin Layer Models on Moisture Loss Ratio

Based on the results of moisture loss from plums at different levels of temperature and air velocity, the model have been tested using the moisture ratio obtained at 65 ^oC temperature and 0.5 ms^{-1} air velocity in the dryer. we developed a physical model and applied on the moisture ratio, we also tested five other published models in terms of R^2, RMSE and χ^2. The results showed that among all the six models Modified Page gave us a better results with R^2 0.99, RMSE 0.01 and χ^2 2.12 while the physical scale model developed for the research showed poor results in terms of R^2 0.91, RMSE 0.10 and χ^2 2.12.

Table 4.5 Applicability of Thin Layer Models on Moisture Loss Ratio

Model Name	Model Equation	R^2	RMSE	χ^2
Logarithmic	MR = α exp (-kt) + c	0.95	0.08	1.80
Lewis	MR = exp (-kt)	0.96	0.06	1.73
Henderson andPabis	MR = α exp (-kt)	0.95	0.06	1.55
Page	MR = exp (-ktn)	0.97	0.04	1.28
Modified Page	MR = exp [-(kt)n]	0.99	0.01	0.62
Physical applied model of the research data	[MR = a+bx]	0.91	0.10	2.12

Discussion

Solar irradiance increased from 6 am to 12:00 pm and then decreased and became zero after 7 pm. This is due to the reason that sun light makes an angle (Azimath) with the sun power meter and according to Hanif *et al., (*2018), the solar irradiance is directly related with solar Azimath. As the Azimath increased so was the flux of solarirradiance. The same fact was reported by Khattak *et al*., (2019). They reported their results in line with findings of this research that solar flux increased with day timing and was recorded maximum at noon. The results also in accordance with findings of Fahimullah *et al*., (2019) who reported the same relation of solar irradiance with day timing.

Ambient temperature is relative to solar irradiance and day time the fact that temperature raised is that solar flux gave heat to the soil and environment causes increase in Enthalpy of air. Due to this reason the ambient air temperature increased. These results are in accordance with the finding of Muhammad *et al*., (2020). Who reported increased in ambient temperature with day time. Similarly, dryer temperature also increased with day time. The higher temperature values of the dryer than ambient air is due to the reason that heat was supplied from the Flat Plat Solar Collector to drying chamber. This caused more heat transfer to the dryer causing higher temperature. The results are in line with the findings of Hanif *et al.*, (2019) and Fahimullah *et al*., (2018). Who reported increased in dryer temperatures with day time. The results are also in accordance with the finding of Marin *et al*., (2017), who reported dryers temperature increase in relation with solar irradiance and day timing. Also, relative humidity is relative to enthalpy of the air present inside the dryer. Relative humidity decreased with increased in dryer temperatures. In due to this fact the result is in accordance with the findings of Hanif *et al*., (2018, 2015). These results are also in line with the relative humidity results reported by Chabane *et al*., (2019) The data of moisture loss per hour from plum slices showed that moisture loss is significantly affected by temperature but there was non-significant affect showed by plum slices for moisture loss at different air velocity. The reason behind this is that increasing temperature causes increase in anthalpy of the air causes more energy to be carried out by the air as medium to the dryer. There it easily gains moisture from the plum slices due to low relative humidity in the air. The results are in accordance with the findings of Hanif *et al*., (2016), who reported that increase in temperature increase moisture loss from plums and reduce drying time. The results are also in accordance with the findings of Hadi *et al*., (2016), who reported moisture loss results in line with the findings of this research and stated that temperature significantly affected the drying process and increase moisture loss per hour if increased.

The activation energy of plums was increased with increased in temperature and decreased with increase in air velocity. This was due to the fact that ata lowest air velocity (0.1 m. s^{-1}) among the treatments, the air has a better contactwith the sample surface which results in a greater absorption of moisture. These results are in accordance with the findings of Garau *et al*., (2006) who reported that increasing air velocity decreased activation energy in orange skin also at high air velocity, the air passing through sample is turbulent, therefore the moisture gradient tends to decreaseas well as activation energy accordingly reduces. The results of activation energy for the plum fruit in the drying experiments are in line with the findings of Mirzaee *et al*., (2009), who reported that temperature increases activation energy and increase in air velocity decreases activation energy in apricots.

The moisture diffusivity was affected by both air velocity and drying temperature. The reason for high moisture diffusivity is due to the fact that at high temperature the air enthalpy increased. This causes increase in capacity of the air to retain moisture in it. The air velocity played a vital role by speeding up the process of moving the hot air through the samples causing increased in moisture diffusivity. The results are in accordance with finding of Zivkovic *et al*., (2011) and Lopez *et al.*, (2017). It is also reported that increase in temperature and air velocity increased diffusivity effectively. The reason was that they dried plums at 75°C at 10-time higher air velocity. Zivkovic *et al.*, (2011) and Velic *et al*., (2004) reported that the average moisture diffusivity increased with airflow and temperature. The reason was that heat transfer increased with the increased of air flow velocity.

Conclusions

Increase in dryer temperature showed significant effect on increase moisture loss per hour, Activation Energy, and Moisture Diffusivity. Increasing air velocity showed significant effect on moisture diffusivity and decreasing activation energy. In thin layer drying kinetics models, Modified Page Models showed good results of drying kinetics. The developed and applied thin layer drying kinetic model for air flow and heat transfer through forced air showed poor results of R^2, RMSE, and χ^2 as compared to already published thin layer drying kinetics models.

Recommendations

It is recommended to dry plums at 65 °C dryer temperature and 0.5 m. s^{-1} dryer air velocity to get good results of drying of plums. It is also recommended to apply modified page model for getting good results of drying of plums.

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