THIN LAYER DRYING KINETICS OF KIWIFRUITS(var. Monty)

Boris Huirem, Babu Ram Shakya

Abstract - **The study of drying kinetics for fruits is necessary to give information about the time required for drying and choosing an appropriate drying model. With regards to this fact, thin layer drying kinetics of Kiwifruit slices was experimentally investigated in a laboratory scale vacuum oven. Experiments were done to dry kiwifruit slices from initial moisture content of about 86± 0.5% (wet basis) to 2 – 3% (w.b.) at three different temperatures i.e., 50 ^{0}C, 60 ^{0}C, 70 ^{0}C under 630 mm Hg vacuum (i.e., 17.33 KPa pressure).Time required for drying kiwifruit slices at 50 ^{0}C, 60 ^{0}C and 70 ^{0}C plate temperatures were 12 h, 9 h and 6 h 30min respectively. Results indicated that drying took place in the falling rate period.Four drying models viz. Lewis, Page, Modified page and Henderson &Pabis model were used to fit the moisture reduction data obtained as a function of drying time. The effect of drying temperature on the model's parameters was predicted by regression analysis.The mathematical model were investigated according to the three statistical parameters of coefficient of determination(R^2), reduced chi-square(χ^2) and Root Mean Square Error(RMSE) between the observed and predicted moisture ratios. Page model gave the highest value of R^2(0.93813), and lowest values of χ2(0.00760) and RMSE(0.08061).Thus Page model was the best model to describe vacuum drying characteristics of Kiwifruits. The values of diffusion coefficients at different drying temperatures were calculated from the Fick's mass diffusion equation for infinite slab material. Change in moisture diffusivity with temperature was correlated using Arrhenius equation and activation energy was found as 23.687 KJ/mol.**

Index Terms- **Drying models, Kiwifruit slices,Thin layer drying, Vacuum.**

I. INTRODUCTION

Kiwifruit or Chinese gooseberry (*Actinidiadeliciosa*) is known as as 'China's miracle fruit' and 'the horticultural wonder of New Zealand'. From China it was spread to New Zealand where it was recognized as a potential fruit and became a popular backyard vine. In India, the area under this fruit is negligible being a new exotic introduction. With extensive research and development support, its commercial cultivation in India has been extended to the mid hills of Himachal Pradesh, Jammu and Kashmir. In North-East, it is being cultivated in Arunachal Pradesh in some sizable area but other states like Sikkim, Meghalaya, and hills of Manipur have vast potential for successful cultivation of kiwifruit.

A ripe kiwifruit is refreshing, delicate flavour with pleasing aroma and high nutritive value. Kiwifruits are an excellent source of vitamins A, C and E , minerals, fibres, omega -3 fatty acids, etc. Kiwifruits have very short shelf-life because ofsoftening and vitamin loss during storage even atrefrigerated conditions. In order to extend theirshelf-life, kiwifruits like most fresh fruits, needpreservation in some form. A growing resistance ofconsumers to the use of chemicals for food preservationand the increasing popularity of high quality fast-driedfoods with good rehydration properties are now leadingto a renewed interest in drying operations. From atechnological point of view, dehydration is often thefinal step in an industrial food process and determines,to a large extent, the final quality of the product beingmanufactured.

Drying is a way to reduce post-harvest loss of fruits and also a process to produce dried fruits, which can be directly consumed or become part of foodstuffs. It also increases shelf life of the fruit. Drying reduces water activity through the decrease of water content, inhibiting deterioration during storage periods. Drying of food is a complex operation including simultaneous heat and mass

ISSN: 2278 – 7798

transfer. Transport processes are mostly in the unsteady state mode. Preserving the delicate properties of raw foods requires accurate design and skillful operation of the dryer which demands in-depth understanding of the drying process. Removal of moisture prevents the growth and reproduction of decay causing microorganisms and minimizes many moisture induced deteriorative reactions. Dehydration also brings about substantial reduction in weight and volume; this reduces packaging, storage and transportation costs and enables storability of the product under ambient temperature. There are many methods of drying viz: sun drying, hot air drying, oven drying, vacuum drying, fluidized bed drying, freeze drying etc. In sun drying there are certain disadvantages like, significant losses in product due to reabsorption of moisture during inadequate climatic conditions, contamination by pathogens, rodents, birds and insects as well as by inorganic materials such as dust and sand. Convective hot air drying methods can have drawbacks like quality losses regarding colour, flavour and texture due to high drying temperature.

Vacuum drying and freeze drying are two low temperature drying methods. Due to the bulk of the product required to be dried, freeze drying of kiwifruits is not a feasible option. In vacuum drying, evaporation of water proceeds rapidly at lower temperature as the product is kept at low pressure and heat is supplied by direct contact with hot metallic surface. The most common method used in the drying of heat-sensitive products is the vacuum drying method. Vacuum drying is widely used to dry various heat-sensitive products in which the colour, structure, and vitamins are impaired with increasing temperatures (Methakhup*et al.*, 2005). Vacuum drying results in better product quality with respect to characteristics such as flavour, fragrance, and rehydration (Drouzas and Schubert, 1996). The vacuum drying process has been successfully used for the drying of fruit, vegetables, and heat-sensitive products. A high quality product is obtained due to the retention of flavour and nutritive value in the structure of materials. The characteristics of this drying technique, such as high drying rate, low drying temperature and oxygen deficient drying environment may help to maintain the qualities such as colour, aroma, flavour and nutritive values of the dried product (Alibas, 2007).

Hence considering all the information, following objectives were taken up for this study

1) To study the vacuum drying kinetics of kiwifruit under different temperatures.
2) To choose a suitable drying model for describing the whole drying process.
3) To calculate moisture diffusivity during vacuum drying at different temperatures and study the effect of drying temperature on shrinkage, rehydration characteristics and sensory properties of kiwifruit.

II. MATERIALS AND METHODS

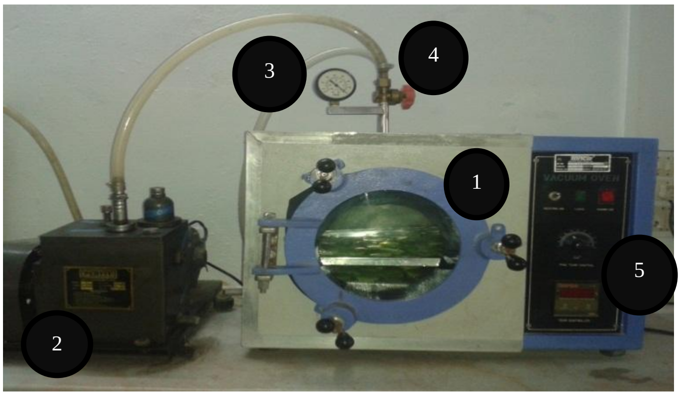
2.1 Vacuum oven

A laboratory vacuum oven (TANCO ^{R} COMPANY, OVV-7 MODEL) in the Department of Food Process Engineering Lab, Vaugh School of Agricultural Engineering and Technology, SHIATS, Allahabad, was used for drying the kiwifruits. A picture of the vacuum oven is shown in Fig. 2.1. It consists of an insulated drying chamber made of stainless steel inside which two perforated trays are placed. Heating elements embedded around the drying chamber is used to heat the product placed on the trays. The door is provided with rubber gasket for proper sealing fitted with heavy hinges and door closing device. A transparent window of toughened glass is provided at the front for inspection. The water vapour removed from the products in the drying chamber is condensed at the bottom and gets removed while opening the door. An oil sealed rotary vane type high vacuum pump (Discharge: 50 l / min) was used to create vacuum in the system. The pump consists of rotor, with two spring loaded vanes mounted eccentrically in the stator body, which rotates inside a stationary casing... Adjustable two air controlling valves are provided for creation of the vacuum and release of vacuum inside the chamber by introducing the atmospheric air at the end of drying. The level of vacuum created is indicated by a vacuum gauge. A control panel is provided with ON/OFF switch for mains (220/230volts AC, 50 hertz) as well as

ISSN: 2278 – 7798

heater. Temperature is controlled by electronic digital temperature indicator cum controller from 50°C to 130 °C ± 2 °C fitted in the front panel for easy operation.

Reduction of boiling point of moisture by way of pressure reduction principle helps the food materials to dry faster in the drying chamber.



1.Drying Chamber2. Vacuum pump3. Vacuum gauge

4. Valves 5. Control panel

Fig. 2.1 Vacuum Oven

2.2 Experiments

2.2.1 Sample collection and preparation

About 5kg of fresh kiwifruits (var. Monty) were obtained from the market (Mao, Manipur) and stored in the refrigerator at 5°C to conduct vacuum drying experiments before the experiment.

Kiwifruits were washed and wiped clean before each experiment. During the experiment, it was peeled using a knife and sliced into 5± 0.2mm thick pieces with a sharp knife on a plate. The samples were not treated with any chemical for conducting the experiment. Generally, Kiwifruits of relatively uniform size and weight were used in the tests.The length, thickness and diameter of the kiwifruits were measured using a scale.

2.2.2 Analysis of moisture content

Initial moisture contents of the kiwifruits were determined by the oven drying method as prescribed by AOAC (1990) for fruits. About 2g of sliced samples were dried in a hot air oven at 105 °C for 5 h till the weight became constant. Moisture content was calculated in wet basis from the weight loss.

2.2.3 Drying

Before each experiment, vacuum oven was run for at least 15 minutes to obtain the desired steady temperature of the trays. Kiwifruits were dried to reduce the moisture content to 2 – 3% w. b. for safe storage.

About 300 g of fresh sliced kiwifruits samples were taken on the trays for each experiment. Drying experiments were conducted at 50, 60 and 70 °C tray temperatures and a vacuum level of 630 mm Hg (i.e. 17.33 k Pa pressure). Kiwifruits were weighed at each 30 minutes interval during drying with a digital weighing balance with an accuracy of ± 0.01 g. Each experiment was replicated one more time and the average values were used for data analysis.

Fig. 2.2 weighing of sliced kiwifruits after peeling

2.3 Modeling of moisture reduction from kiwifruits.

The experimental drying data was graphically analyzed in terms of reduction in moisture content and moisture ratio with drying time. The moisture ratio curve can better explain the drying behaviour than that of moisture content curve, as the initial was one in each of the experiment. To understand the influences of drying temperature on the drying rate, relationship between moisture ratio, *MR* and drying time was plotted. Moisture ratio *MR* was calculated as,

$$\boldsymbol{MR = \frac{M_t - M_e}{M_{in} - M_e}} \qquad (1)$$

Where, M_t is moisture content of kiwifruits at time t, M_e is equilibrium moisture content of kiwifruits at the drying conditions and M_{in} is initial moisture content of kiwifruits.

ISSN: 2278 – 7798

The values of equilibrium moisture content M_e in vacuum drying are relatively small compared to M_t or M_{in} (Taniguchi and Nisshio, 1991) and the expression of moisture ratio was reduced to,

$$\boldsymbol{MR} = \frac{\boldsymbol{M_t}}{\boldsymbol{M_{in}}} \quad (2)$$

Selected thin-layer drying models were fitted to the drying curves (*MR* versus drying time). The models presented in Table 2.1 were fitted to describe vacuum drying characteristics of kiwifruits.

Table 2.1Thin-layer models applied to the drying curves

Name of Model	Model	References
Lewis	*MR* = exp(– *k t*)	Demir*et al*. (2007)
Page	*MR* = exp(– $k\,t^n$)	Yaldiz and Ertekin (2001)
Modified Page	*MR* = exp(– $k\,t)^n$	Demir*et al*. (2007)
Henderson and Pabis	*MR* = *a*exp(– *k t*)	Henderson and Pabis (1961)

2.3.1 Statistical analysis

These models were fitted in the experimental data in their linearized form using regression technique. The coefficient of determination R^2 was one of the main criteria for selecting the best equation. In addition to the coefficient of determination, the goodness of fit was determined by various statistical parameters such as reduced chi square $\chi 2$ and root mean square error RMSE. For quality fit, R^2 value of the selected model should be highest and $\chi 2$ and RMSE values should be lowest. The above parameters were calculated using the following equations.

$$\boldsymbol{\chi^2} = \frac{\mathbf{1}}{\boldsymbol{N-z}} \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{N}} (\boldsymbol{MR_{experimental,i}} - \boldsymbol{MR_{predicted,i}})^{\mathbf{2}} \quad (3)$$

Where, MR $_{exp,i}$ is the experimental moisture ratio, MR $_{pred,i}$ is the predicted moisture ratio,χ^2 is reduced chi square, *N* is number of readings and *z* is number of constants in the model.

$$\boldsymbol{RMSE} = [\frac{\mathbf{1}}{\boldsymbol{N}} \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{N}} (\boldsymbol{MR_{experimental,i}} - \boldsymbol{MR_{predicted,i}})^{\,2}]^{1/2} (4)$$

Where, RMSE is root mean square error, *N* is number of readings.

2.4Estimation of moisture diffusivity

Diffusivity of moisture from the kiwifruits during drying was calculated using Fick's diffusion equation. The effects of total pressure and temperature gradients are neglected in estimation of moisture diffusivity using this equation. The analytic solution of Fick's second law for an infinite slab is expressed as follows (Van Arsdel& Copley, 1963):

$$\boldsymbol{MR} = \frac{\boldsymbol{X_t - X_e}}{\boldsymbol{X_o - X_e}} = \frac{\mathbf{8}}{\boldsymbol{\pi^2}} \sum_{\boldsymbol{n}=\mathbf{0}}^{\infty} \frac{\mathbf{1}}{(\mathbf{2}\boldsymbol{n}+\mathbf{1})^{\mathbf{2}}} \mathbf{exp}\left(-(\mathbf{2}\boldsymbol{n} + \mathbf{1})^{\mathbf{2}} \boldsymbol{\pi^2} \frac{\boldsymbol{D_{eff}.t}}{\mathbf{4}\boldsymbol{L^2}}\right) (5)$$

In the above equation, MR, X $_t$, X_o and X $_e$ represents moisture ratio (dimensionless), moisture content at time t, initial moisture content, and equilibrium moisture content (dry weight) , respectively, and D_{eff} is the effective diffusion coefficient (m^2/s), L the half-thickness of the sample (m), and t the drying duration (min). We can use the first term of the above expansion (equation 5) with good approximation. Therefore, by replacing n = 1 and by taking the log of both sides of equation 5, we have:

$$\mathbf{ln}\boldsymbol{MR} = \mathbf{ln}\frac{\mathbf{8}}{\boldsymbol{\pi^2}} - \frac{\boldsymbol{\pi^2}}{\mathbf{4}\boldsymbol{L^2}} \boldsymbol{Deff.t} (6)$$

The diffusion coefficient $D_{eff}$was calculated by plotting experimental drying data in terms of ln*MR* versus drying time *t*. Moisture diffusivity D_{eff} was calculated from the slope of the best fit straight line as,

$$\textbf{Slope}=-\frac{\boldsymbol{\pi^2}}{\mathbf{4}\boldsymbol{L^2}} \boldsymbol{Deff} \quad (7)$$

Moisture diffusivity $D_{eff}$was related to the temperature by a simple Arrhenius equation (Lopez et al., 2000) as given below.

$$\boldsymbol{Deff} = \boldsymbol{D_o} \,\mathbf{exp}(-\frac{\boldsymbol{E_a}}{\boldsymbol{RoT}}) \quad (8)$$

Where, D_{eff} is moisture diffusivity in m^2/s, D_o is the constant equivalent to the diffusivity at an infinitely high temperature in m^2/s,E_a is the activation energy in kJ/mol, $R_o$is the universal gas constant in kJ/mol.K, and *T* is the absolute temperature in K. Eq. (8) was linearised as,

ISSN: 2278 – 7798

$$\ln(Deff) = \ln(D_o) - \frac{E_a}{Ro}\left(\frac{1}{T}\right) \quad (9)$$

The activation energy E_a and the constant D_o were determined by plotting $\ln(D_{eff})$ versus $1/T$.

2.5Measurement of shrinkage of kiwifruits during drying

Shrinkage of the kiwifruits during drying was measured by liquid displacement method (Maskan, 2001; Artnaseaw et al., 2010). Measurements were made as quickly as possible (less than 30 s) to avoid water uptake by samples. Shrinkage of the was evaluated in terms of percentage change of the volume of the sample, calculated as,

$$\%\ \text{Shrinkage} = \frac{(V_o - V)}{V_o} \quad (10)$$

Where, V_o and V are initial and final volumes of the kiwifruits sample respectively.

2.6Rehydration ratio

The ability of dried samples to reconstitute to their original state when immersed in water is described by their rehydration ratio. The rehydration ratio, measured in terms of the mass ratio, was evaluated by immersing a weighed sample of dried kiwifruits (approximately 10 g) in hot water (75 ^oC). After 10 min the sample was taken out and blotted with paper towel to eliminate excess water on its surface. The mass of the dried and rehydrated sample were measured by an electronic balance with an accuracy of ± 0.01 g. The rehydration ratio of the sample was then calculated by,

$$R = \frac{m_{after}}{m} \quad (11)$$

Where, m and m_{after} are the mass of the dried and rehydrated samples respectively.

2.7Sensory evaluation

Dried kiwifruits were evaluated for visual appearance/colour, aroma, taste, product acceptability and buying intention using a 9-point scale (hedonic scale) with 10 judges. On the hedonic scale, 9 corresponded to like extremely, 5 to neither like nor dislike and 1 to extremely dislike. The judges were first trained with the quality parameters of dried kiwifruits. Three dried kiwifruits samples from drying at different temperatures (50, 60 and 70 ^oC) were given to each assessor for evaluation. Evaluation of the samples was done in a clean, quiet, air-conditioned and odour free room where each assessor used separate tables during testing.

III. RESULTS AND DISCUSSIONS

3.1 Moisture content and size of fresh cherry peppers

Moisture content of kiwifruits was measured by oven drying method. Average moisture content of the fresh kiwifruits was found to be 86 ± 0.5%. Length and diameter of fresh kiwifruits were found to be 4.4 ± 0.2 cm and 4.0 ± 0.2 cm, respectively.

3.2 Effect of tray temperature during vacuum drying on drying time

Fig. 3.1shows reduction of moisture content of kiwifruits with drying time at different tray temperatures (50, 60, 70 ^oC) at 630 mm Hg vacuum level (i.e., 17.33 KPa pressure) inside the drying chamber. The time required to dry the kiwifruits from initial moisture content of around 86±0.5% (w. b.) to moisture content of around 2 – 3% (w. b) during vacuum drying at 50, 60 and 70 ^0C was 12 h, 9 h and 6 h 30 min respectively. As expected, the experimental results show the drying rate was higher for high temperature drying. Dimensionless moisture ratio was calculated using Eq. (2).Fig. 3.2 presents the change in moisture ratio (*MR*) with drying time at different drying temperatures during vacuum drying.

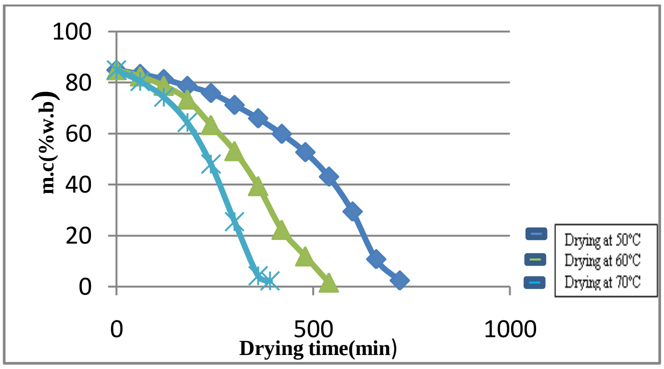


Fig. 3.1 Reduction in moisture content with drying time at different tray temperatures during vacuum drying.

ISSN: 2278 – 7798

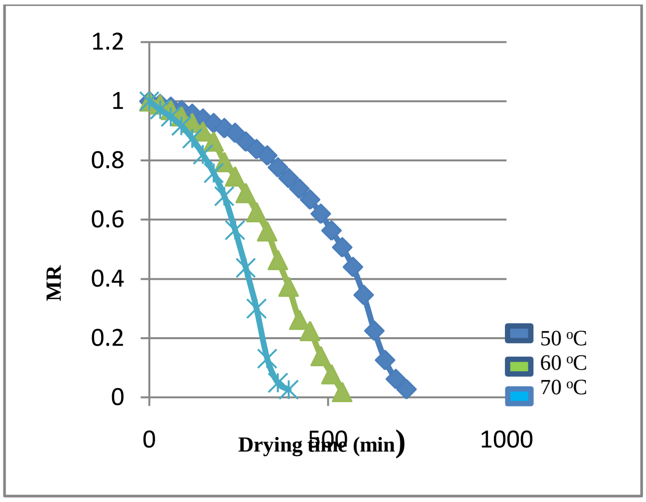


Fig. 3.2 Drying time Vs moisture ratio (*MR*) at different temperatures

The moisture ratio of kiwifruits reduced as the drying time increased. In these curves, an increase of drying rate, given by the curve slope, with increase in temperature was observed.

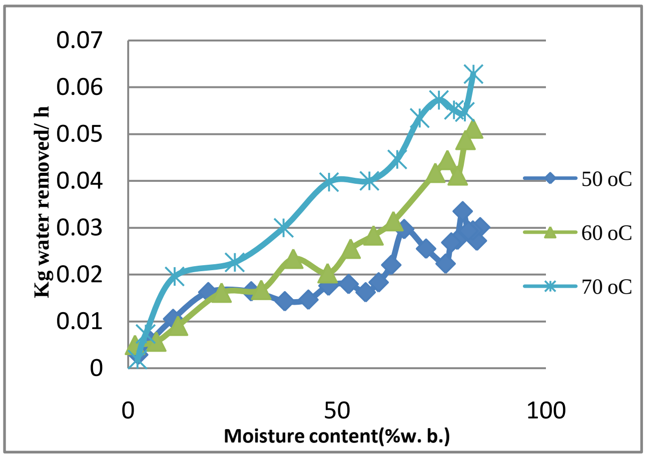


Fig. 3..3 Drying rate Vs moisture content at different drying temperatures

Fig. 3..3 shows change in drying rate with moisture content of kiwifruits at different drying temperatures. Kiwifruits did not exhibit a constant rate period of drying. The entire drying took place in the falling rate period. The constant drying rate period was absent due to the quick moisture removal from the surface of sliced kiwifruits. At the beginning, when moisture was high, drying rate was very high, and as moisture content approached to equilibrium moisture content, drying rate was very low. This is in agreement with the results of the study on onions (Mazza&Maguer, 1980), garlic (Madamba et al., 1996) and lettuce and cauliflower leaves (Lopez et al., 2000). It should be mentioned here that Pinedo and Murr (2007) found a similar dryingbehaviour during vacuum drying of carrot and pumpkin.

3.3 Modeling of moisture reduction during drying

Four selected drying models (Lewis, Page, Modified page and Henderson &Pabis model), presented in Table 3.1, were used to fit the moisture reduction data obtained in order to estimate the moisture ratio as a function of drying time. Values of the drying constants k and coefficients a and$n$ obtained from the models are given in Table 3.1. The statistical parameters for goodness of fit of the models, such as coefficient of determination R^2, reduced chi-square χ^2, and root mean square error RMSE were calculated using Eq. (3) and (4). The lower the value of chi-square (χ^2), the higher the value of correlation coefficient (R^2) and the lower the value of RMSE indicates better goodness of fit. The details of the statistical analysis are presented in Table 3.2.

From Table 3.2, it can be observed that the average value of R^2 obtained for all the models varied from 0.61843 to 0.93813, whereas the R^2 values for Page and Modified Page model were found to be the highest i.e., 0.93813. The higher values of R^2 for Page model and Modified Page model shows that it represents a better correlation between the moisture ratio and drying time than the other models. Value of reduced chi-square χ^2 was lowest for Page model and Modified Page model. Also the lowest RMSE value was obtained for Page model. This shows that Page model gave best fit for vacuum drying of kiwifruits. It was also observed that the drying constants (k) of the Page model varied with drying temperature. Value of the drying constant (k) increased with increase in drying temperature, which shows the effect of drying temperature of the drying process of kiwifruits was significant. Fig. 3.4 shows the change in drying constant (k) in Page model with drying temperature.

ISSN: 2278 – 7798

Table 3.1 Drying constants and coefficients for different models at different temperatures.

Model	T (^oC)	Constant
Lewis	50	k = 0.0025
	60	k = 0.0040
	70	k = 0.0064
Page	50	k = 0.00000234
		n = 2.0345
	60	k = 0.00000255
		n = 2.1735
	70	k = 0.00000312
		n = 2.2776
Modified Page	50	k = 0.00170943
		n = 2.0345
	60	k = 0.00267303
		n = 2.1735
	70	k = 0.00382766
		n = 2.2776
Henderson and Pabis	50	k = 0.00380
		a = 1.9444
	60	k = 0.00580
		a = 1.9376
	70	k = 0.00880
		a = 2.0456

Table 3.2 Statistical values for different drying models at different temperatures.

Model	T (^oC)	R^2	χ^2	RMSE
Lewis	50	0.54770	0.05525	0.23030
	60	0.62320	0.05099	0.21980
	70	0.68440	0.06771	0.25075
	Avg	0.61843	0.05798	0.23361
Page	50	0.91380	0.01092	0.10024
	60	0.95800	0.00380	0.05837
	70	0.94260	0.00808	0.08324
	Avg	**0.93813**	**0.00760**	**0.08061**
Modified Page	50	0.91380	0.01092	0.10025
	60	0.95800	0.00381	0.05838
	70	0.94260	0.00809	0.08328
	Avg	0.93813	0.00760	0.08063
Henderson and Pabis	50	0.65210	0.084053	0.27808
	60	0.71410	0.095911	0.29294
	70	0.76830	0.149234	0.35765
	Avg	0.71150	0.109732	0.30955

ISSN: 2278 – 7798

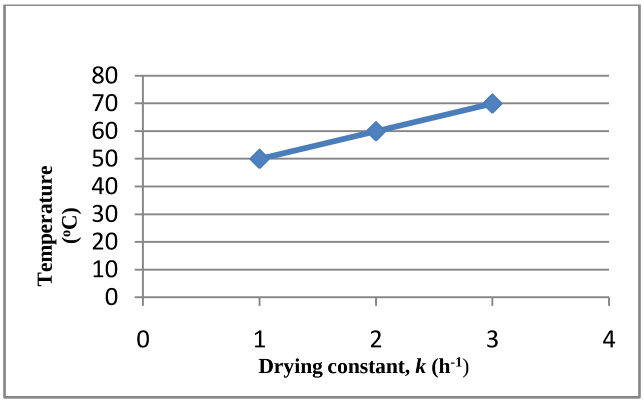


Fig. 3.4 Effect of drying temperature on drying constant (*k*) in Page model

It can be concluded that Page model gave the best results than the other models to describe the drying characteristics of vacuum drying of kiwifruits. Thus, this model may be assumed to represent the drying behaviour of kiwifruits in thin layers.

3.4 Moisture diffusivity and activation energy

Moisture diffusivity during vacuum drying of kiwifruits was calculated using Eq. (6) and (7). Plot of drying time t with ln(MR) at 70 °C drying temperature is shown in Fig. 3.5.

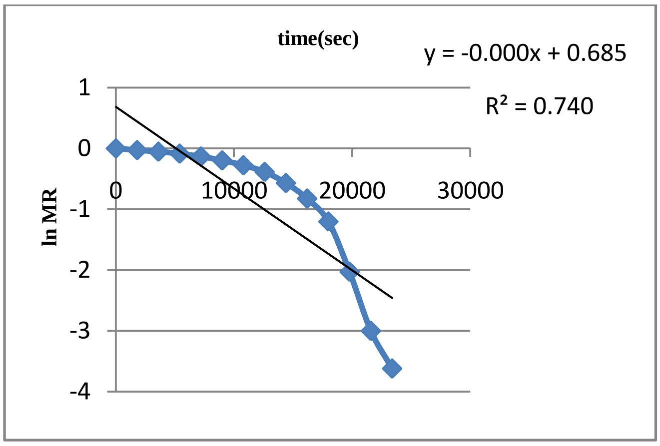


Fig. 3.5 ln(MR) Vs drying time *t* at 70 °C

Moisture diffusivity, D_{eff} was calculated from the slopes of the best fit straight lines. From Eq. (8), we know, slope = $-\frac{\pi^2}{4L^2}D$. At 70 °C, slope of the best fit line is equal to – 0.0001. Average half thickness of kiwifruits is, L= 2.5 × 10^{-3} m. Moisture diffusivity at 70 °C is calculated as,

$$D_{eff} = 0.0001 \times 4 \times (2.5 \times 10^{-3})^2 / \pi^2$$

$$= 2.535 \times 10^{-10} \text{ m}^2/\text{s}.$$

Similarly, values of D_{eff} at 50 and 60 °C drying temperatures were calculated. Values of moisture diffusivity D_{eff} at different drying temperatures are presented in Table 3.3. It can be observed that effective moisture diffusivity for vacuum drying of kiwifruits was increased as the tray temperature increased from 50 to 70 °C.

Table 3.3 Diffusion coefficients at different temperatures

Temperature (°C)	Moisture diffusivity (m^2/s)
50	1.521×10^{-10}
60	2.282×10^{-10}
70	2.535×10^{-10}

From Table 3.3, it can be observed that moisture diffusivity during vacuum drying of kiwifruits increased with increase in temperature. Moisture diffusivity was related to the temperature by Arrhenius equation as given in Eq. (8).

When ln(D_{eff}) was plotted against the inverse of temperature (1/T) (Fig. 3.6), a satisfactory fit of Eq. (9) was observed (R^2 = 0.9067).

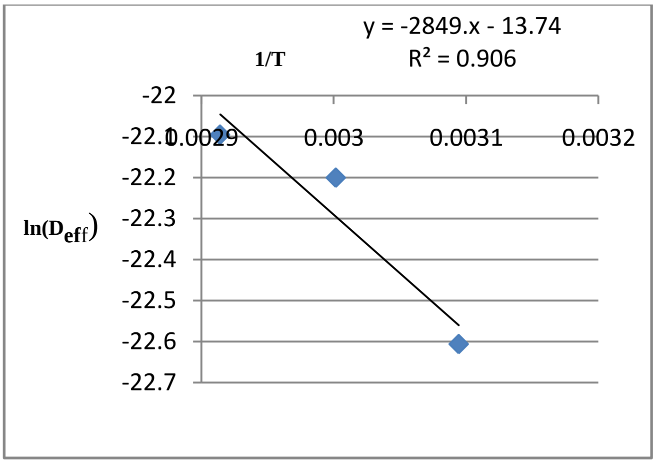


Fig 3.6 Plot of ln(D_s) vs (1/T)

From the equation of the linear fit of the plot, values of activation energy E_a and the constant D_o were calculated using Eq. (10). The value of the activation energy E_a inferred from the plot was found to be 23.687 KJmol^{-1} and also the constant D_o as 1.0752 × 10^{-6} m^2/s.

3.5 Effect of drying on shrinkage, rehydration ratio and sensory characteristics of kiwifruits

Table 3.4 shows the values of percentage shrinkage and rehydration ratio of vacuum dried kiwifruits at three different temperatures as calculated using Eq. (10) and (11). Shrinkage of the kiwifruits was found to be minimum at 60 ^{0}C i.e. 83.53%, for better quality of the dried product low percentage of shrinkage is required. At 60 ^{0}C drying temperature, exposure time of the kiwifruits under vacuum is less. That may be the reason to obtain less shrinkage of kiwifruits at 60 ^{o} C. The rehydration ratio was found to be highest at 50 ^{0}C, i.e. 1.96, similarly for better quality of dried product maximum value of rehydration ratio is desired. Higher the value of rehydration ratio, more the probability of the product to come to its original form.

Table 3.4 Average shrinkage and rehydration ability at different temperatures

Temperature (^{o} C)	Average shrinkage (%)
50	87.65
60	83.53
70	85.55

For the sensory evaluation, a nine point hedonic scale was considered where five quality parameters i.e., appearance, aroma, taste, overall acceptability and buying intensions were considered. There was a slight difference in visual appearance and aroma between the samples but the product dried at 60 ^{0}C can be selected as the most suitable drying treatment concerning buying intensions since it gave the highest score (7.4). Table 3.5 shows the sensory evaluation chart.

Table 3.5 Sensory test Hedonic scale readings

Drying temperature of kiwifruit (^{o}C)	Quality Parameters				
	Appearance/ Color	Aroma	Taste	Overall acceptability	Buying intentions
50	7.0	7.8	7.4	7.4	7.3
60	7.3	6.9	7.5	7.4	**7.4**
70	7.2	7.3	7.4	6.6	7.2

IV. CONCLUSIONS

Based on the experimental results reported herein, the following conclusions can be made:

1. Time required to dry kiwifruits from a moisture content of around 86±0.5% (w. b) to 2 – 3% (w. b.) under vacuum at 50 ^{0} C, 60 ^{0}C and 70 ^{0}C plate temperatures were 12 h, 9 h and 6 h 30 min respectively.
2. Drying curves of kiwifruits did not show a constant-rate drying period under the experimental conditions employed and only falling-rate drying period could be observed.
3. According to the statistical analysis, Page model gave highest values of coefficient of determination (R^2) i.e. 0.93813 and lowest values of reduced chi-square (χ^2) i.e. 0.00760and RMSE i.e. 0.08061. Thus, Page was considered the best for predicting the vacuum drying characteristics of kiwifruits.
4. Moisture diffusivity (D) of kiwifruits increased from 1.521×10^{-10} to 2.535×10^{-10} m^2/s as the drying temperature increased from 50 to 70 ^{o} C and the activation energy (E_a) of diffusion was calculated as 23.687 KJ/mol.
5. The average Shrinkage of the kiwifruits was found to be minimum at 60 ^{o} C i.e. 83.53% (for better quality of the dried product low percentage of shrinkage is required) and the rehydration ratio was found to be maximum at 50 ^{o} C, i.e. 1.96 which is desirable.
6. The kiwifruits sample dried at 60 ^{o} C was selected the best, when the quality attributes viz., appearance / colour, aroma, taste, overall acceptability and buying intentions were considered, as suggested by 10 number of panelists after sensory evaluation test.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Dept. of Food Process Engineering, Vaugh School of Agril. Engg and Technology, SHIATS, for supporting this project.

ISSN: 2278 – 7798

REFERENCES

[1] S. E.Agarry, A. O. Ajani and M. O. Aremu, “Thin Layer Drying Kinetics of Pineapple: Effect of Blanching Temperature – Time Combination,”*Nigerian Journal of Basic and Applied Science*, Volume 21, no. 1, pp. 1-10, March 2013.

[2] A. Ahmad, M. Ali, G. Barat, K. M. Hadi, and M. Saeid, “Effect of Air Velocity and Temperature on Energy and Effective Moisture Diffusivity for Russian Olive (Elaeagnusangastifolial L.) in Thin-Layer Drying,”*Iran journal of Chemical Engineering*, Volume 31, No. 1, pp. 75-79, 2012.

[3] A.Ayadi, R. F. Mechlouch, C. Bessaoud, H. Bennour, and M. Debouba, “Effect of microwave and solar drying methods on the physico-chemical properties of kiwifruit,”*Journal of Agricultural Technology*, Volume 10, No. 5, pp. 1065-1073, 2014.

[4] S.Doymaz, A. Guizani, W. Jomaa, and A. Belghith, “Moisture diffusivity and drying kinetic equation of convective drying of grapes,” *Journal of Food Engineering*, Volume 55, pp. 323–330, 2002.

[5] R. A.Chayjan, M. H. Peyman, M. E. Ashari, and K. Salari, “Influence of drying conditions on diffusivity, energy and color of seedless grape after dipping process,”*Australian Journal of Crop Science*, Volume5, No. 1, pp. 96-103, 2011.

[6] H. Darvishi,and E. Hazbavi, “Mathematical modelling of thin-layer drying behaviour of date palm,”*Global Journal of Science Frontier Research Mathematics and Decision Sciences*, Volume12, No. 10, pp. 28-37, 2012.

[7] L. Doymaz, M. Durand, G. Savage, and L. Vanhanen, “Effect of temperature on the drying characteristics, colour and ascorbic acid content of green and gold kiwifruits,” *International Food Research Journal*, Volume 17, pp. 441-451, 2010.

[8] A. Doymaz,and M. Pala, “Hot-air drying characteristics of red pepper,”*Journal of Food Engineering*, Volume 55, pp. 331–335, 2002.

[9] A. E. Drouzas, and Schubert. H,“Microwave application in vacuum drying of fruits,” *Journal of Food Engineering*, Volume 28, pp. 203-209, 1998.

[10] A. E.Ekow, M. A. Haile, O. John, and E. F. Nark, “Microwave-vacuum drying effect on drying kinetics, lycopene and ascorbic acid content of tomato slices,” *Journal of Stored Products and Postharvest Research, Volume*4, No. 1, pp. 11 – 22, 2013.

[11] A. T.Garavanda., S. Rafieea, and A. Keyhania, “Mathematical modelling of thin layer drying kinetics of tomato influence of air dryer conditions,”*International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies*, Volume 2, No. 2, pp. 147-160, February 2011.

[12] A. A.Kabiru, A. A. Joshua, and A. O. Raji,“Effect of slice thickness and temperature on the drying kinetics of mango *(mangiferaindica),”International Journal of Research and Reviews in Applied Sciences,* Volume15, No. 1, pp. 41-50, April 2013.

[13] A. Kouchakzadeh, and K. Haghighi, “Modeling of vacuum-infrared drying of pistachios,”*Agricultural Engineering International: CIGR Journal*, Volume 13, No. 3, pp. 1-7, September 2011.

[14] M.Maskan, “Drying rate, shrinkage and rehydration characteristics of kiwifruits during hot air and hot air-microwave drying,”*Journal of Food Engineerin,* Volume 48, pp. 177-182, 2001.

[15] E.Meisami-asl., S. Rafiee, A. Keyhani, and A. Tabatabaeefar,“Determination of suitable thin layer drying curve model for apple slices (variety-Golab),” *Plant Omics Journal*, Volume 3, No. 3, pp. 103-108, 2010.

[16] E.Meisami-asl, and S. Rafiee,“Mathematical modelling of kinetics of thin-layer drying of Apple (var. Golab),”*Agricultural Engineering International: the CIGREjournal*, Manuscript 1185. Volume. XI, September 2009.

[17] S.Methakhup, N. Chiewchan, and S.Devahastin, “Effects of drying methods and conditions on drying kinetics and quality of Indian gooseberry flake,” *LWT - Food Science and Technology*, Volume 38, No. 6, pp. 579–587, 2005.

[18] E.Mirzaee, S. Rafiee, and A. Keyhani, “Evaluation and selection of thin-layer models for drying kinetics of Apricot (cv.*NASIRY*),”*Agricultural Engineering International,* Volume 12, No. 2, pp. 111-116, 2010.

ISSN: 2278 – 7798

[19] A.Mohammadi, S. Rafiee, A. Keyhani and Z. Emam-Djomeh, "Estimation of thin-layer drying characteristics of Kiwifruit (cv. Hayward) with use of Page's Model," *American-Eurasian Journals of Agriculture and Environment Science*, Volume 3, No. 5, pp. 802-805, 2008.

[20] A.Mohammadi, S. Rafiee, Z. Emam-Djomeh, and A. Keyhani, "Kinetic models for colour changes in kiwifruit slices during hot air drying," *World Journal of Agricultural Sciences*, Volume 4, No. 3, pp. 376-383, 2008.

[21] A.Mohammadi, S. Rafiee, A. Keyhani, and Z. Emam-Djomeh, "Moisture content modelling of sliced kiwifruit(cv. Hayward) during drying,"*Pakistan Journal of Nutrition*, Volume 8, No. 1, pp. 78-82, 2006.

[22] S.Seiiedlou, H. R. Ghasemzadeh, N. Hamdami†, F. Talati, and M. Moghaddam, "Convective Drying of Apple: Mathematical modeling and determination of some Quality Parameters,"*International Journal of Agriculture & Biology*,Volume 12, pp. 171–178, 2010.

[23] M. M. N Shahi, M. Mokhtarian, and A. Entezari, "Optimization of thin Layer drying kinetics of Kiwifruit slices using genetic algorithm,"*Advances in Natural and Applied Sciences*, Volume 8, No. 11, pp. 11-19, August 2014.

[24] G. D.Saravacos, and G. S.Raouzeos, "Diffusivity of moisture in air-drying of raisins,"*Hemisphere Publ. Co, New York*, Volume 86, No. 15, pp. 487–491, 1986.

[25] T.Y. Tunde-Akintunde, A. A. Afon, "Modelling of Hot-Air Drying of Pre-treated Cassava Chips,"*Agricultural Engineering International: the CIGRE journalmanuscript* 1493, pp. 1-7, 2009.

BIOGRAPHY

Boris Huirem belonging to Lamdengkhunoumamangleikai, Imphal west, Manipur received his Bachelor of Technology degree from CAEPHT (CAU), Ranipool, Sikkim in 2013. He is pursuing his M.Tech in Agril. Engg(APFE) from SHIATS, Allahabad, UP, India.

Babu Ram Shakya presently working as Professor Emeritus in Department of Food Process Engg.at Sam Higginbottom Institute of Agriculture, Technology, and sciences, Allahabad, UP, India. Secured B. Sc degree in Ag.Engg.from University of Allahabad in 1971 and M. Tech in Process Engg. from GB Pant University in 1977.

ISSN: 2278 – 7798