ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

IJESRT
INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

Drying Characteristics of Red Chillies: Mathematical Modelling and Drying Experiments

D.Kamalakar [1] , Dr.L.Nageswara Rao *[2], P.Rohini Kumar [3] & Dr. M.Venkateswara Rao [4]
[1,3] Assistant Professor, Department of Chemical Engineering, R.V.R. & J.C.College of Engineering (A), Guntur-19, A.P, India
[2] Associate Professor, Department of Chemical Engineering, R.V.R. & J.C.College of Engineering (A), Guntur-19, A.P, India
[4] Professor, Department of Chemical Engineering, R.V.R. & J.C.College of Engineering (A), Guntur-19,A.P, India
lnrao1978@gmail.com

Abstract

The effects of drying conditions on the drying behaviour of Red Chillies (Capsicum annum) and the applicability of drying models to predict the drying curves of Red Chillies were studied. The experiments were conducted at different temperatures (90, 120, 140,160,180 and 200°C) with varying air velocities. Drying air temperature was found to be the main factor affecting the drying kinetics of Red Chillies; raising the drying temperature from 90°C to 200°C dramatically reduced the drying times. The effect of the relative humidity was lower than that of temperature; increasing the relative humidity resulted on longer drying times. Higher equilibrium moisture contents were obtained with high relative humidity's and low temperatures. Furthermore, drying was observed only in the falling-rate period. Statistical analysis was carried out and comparison among drying models was made to select the best-fitted model for the drying curves.

Keywords: Capsicum annum, air drying, mathematical models, kinetics.

Introduction

The Drying is one of the most common methods used to improve food stability, it is a complex process involving simultaneous coupled heat and mass transfer phenomena. However, the theoretical application of these phenomena to food products becomes difficult due to the complex structure and to the physical and chemical changes that occur during drying. Drying is one of the oldest methods of food preservation and it is a complex process. The temperature, drying time, moisture diffusivity and drying rate are vital parameters in the design of process like for instance drying, storage, aeration and ventilation, etc. Different conventional thermal treatments are used in the drying of biological products such as, hot-air drying, vacuum drying, sun-drying and freeze drying result in low drying rates in the falling rate period which leads to undesirable thermal degradation of the finished products [1, 2].

Drying is one of the most important unit operations in the food process engineering, and represents a feasible way in order to extend the shelf life of foods with high moisture contents, especially fruits and vegetables, by reducing their water content to an extension at which the microbial spoilage and undesirable reactions are minimized. Additionally, drying of foodstuffs is intended to improve product stability, decrease shipping weights and costs and minimize packaging requirements. Because drying is an energy intensive operation, a better understanding of the drying mechanisms is important to optimize both the quality of the product and the efficiency of the process.

Several models have been formulated to describe the heat and mass transfer processes during fixed bed drying. These models include either simplified or rigorous models.

In some products having a relatively high initial moisture content, an initial linear reduction of the average product moisture content as a function of time may be observed for a limited time, often known as a "constant drying rate period". Usually, in this period, it is surface moisture outside individual particles that is being removed. The drying rate during this period is dependent on the rate of heat

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

transfer to the material being dried. Therefore, the maximum achievable drying rate is considered to be heat-transfer limited. If drying is continued, the slope of the curve, the drying rate, becomes less steep (falling rate period) and eventually tends to nearly horizontal at very long times. The product moisture content is then constant at the "equilibrium moisture content", where it is in dynamic equilibrium with the dehydrating medium. In the falling-rate period, water migration from the product interior to the surface is mostly by molecular diffusion, i.e., the water flux is proportional to the moisture content gradient. This means that water moves from zones with higher moisture content to zones with lower values, a phenomenon explained by the second law of thermodynamics. If water removal is considerable, the products usually undergo shrinkage and deformation, except in a well-designed freeze-drying process. The drying rate in the falling-rate period is controlled by the rate of removal of moisture or solvent from the interior of the solid being dried and is referred to as being "mass-transfer limited"[3].

Drying of various feed stocks is needed for one or several of the following reasons: need for easy-to-handle free-flowing solids, preservation and storage, reduction in cost of transportation, achieving desired quality of product, etc. In many processes, improper drying may lead to irreversible damage to product quality and hence a non-salable product[4,5,6,7].

Materials and methods

Botanical name of red chili is *Capsicum annum L., Capsicum frutescens L* which comes under the family Solanaceae . Chili is a fruit which belongs to Capsicum genus. It has many varieties which are differentiated on its pungency measured on Scoville Scale. Chili fruit when ripened and dried becomes red chili, which is further grounded to form red chili powder. Red chili became famous all around the world because of its characteristics like pungency, taste and flavor matched black pepper, which was very expensive during old times and thus it became one of the most important and integral spices.Apart from its uses in cooking, it also used in medicines. It helps in digestion, it develops blood and is a very rich source of vitamin C, which helps in developing the immune system. It is used as spray weapon also for keeping away attackers and mobsters.

Chili crop grows well in deep loamy fertile soil with appropriate moisture content. Best time for sowing chilies is between April and June, i.e. in hot and humid weather. But dry weather is required at the time of harvesting. Major chili growing countries are India, China, Ethiopia, Myanmar, Mexico, Vietnam, Peru, Pakistan, Ghana, and Bangladesh. These countries produce approximately 85% of the total red chili in the world.

Among all the major producers, India dominates in chili production and is the largest exporter as well due to superior quality found here. In India major production comes from Andhra Pradesh, Maharashtra, Karnataka, Orissa and Rajasthan. Guntur is the major physical market for red chillies at Andhra Pradesh, India.

The Guntur district is the main producer and exporter of most varieties of Chilies and chili powder in India to countries like Sri Lanka, Bangladesh, Middle East, South Korea, U.K. and USA & Latin America. Chilies have various colors and flavors because of the level of Capsaicin in them. Guntur chilies form an important part of curries and various popular dishes of the state of Andhra Pradesh in India.Capsicum frutescence is a perennial chilly with small sized pods which are highly pungent. It is commonly known as 'bird chilly' and 'Tabasco'. Chilly is reported to be a native of South America and is widely distributed in all tropical and sub tropical countries including India. It was first introduced in India by Portuguese towards the end of 15th Century. Now it is grown all over the world except in colder parts.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

Nutritional value of chilli

PARAMETERS	CHILLIES DRY
Moisture	10.000 gm
Protein	15.000 gm
Fat	6.200 gm
Minerals	6.100 gm
Fibre	30.200 gm
Carbohydrates	31.600 gm
Energy	246.000 K cal
Calcium	160.000 mg
Phosphorus	370.000 mg
Iron	2.300 mg
Carotene	345.000 μg
Thiamine	0.930 mg
Riboflavin	0.430 mg
Niacin	9.500 mg
Vitamin C	50.000 mg
Sodium	14.000 mg
Potassium	530.000 mg
Phytin Phosphorus	71.000 mg
Magnesium	--
Copper	--
Manganese	--
Molybdenum	--
Zinc	--

Tray drying

In an industry so diversified and extensive as the food industry, it would be expected that a great number of different types of dryer would be in use. This is the case and the total range of equipment is much too wide to be described in any introductory book such as this. The principles of drying may be applied to any type of dryer, but it should help the understanding of these principles if a few common types of dryers are described.

The major problem in calculations on real dryers is that conditions change as the drying air and the drying solids move along the dryer in a continuous dryer, or change with time in the batch dryer. Such implications take them beyond the scope of the present book, but the principles of mass and heat balances are the basis and the analysis is not difficult once the fundamental principles of drying are understood. Obtaining adequate data may be the difficult part. Drying of material is considered to occur in two stages , a constant rate period followed by a falling rate period. In the constant rate period the rate of drying corresponds to the removal of water from the surface of material. The falling rate period corresponds to the removal of water from the interior of the material. The rate in either case is dependent on a).Flow rate of air b). Material characteristics c). Tray material.

In tray dryers, the food is spread out, generally quite thinly, on trays in which the drying takes place. Heating may be by an air current sweeping across the trays, by conduction from heated trays or heated shelves on which the trays lie, or by radiation from heated surfaces. Most tray dryers are heated by air, which also removes the moist vapours.A typical drying procedure was applied with tray dryer to investigate properties of tray dryers, its advantages or disadvantages, drying kinetics of foods that are dried in tray dryers. For these purposes, equilibrium moisture content, drying rate, mathematical and experimental drying time were calculated with some engineering formulas. Red chili was used as sample for this aim.

Drying procedure:

Red chili slices weighting about 50 g were placed in a stainless steel tray (20.7 cm x 14.7 cm) in

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

a tray drying unit, which is placed in the middle of the drying unit. Air flowed parallel to the horizontal drying surfaces on the samples. The mass flow rate of the drying air was regulated by a blower driven via a variable speed motor and the temperature was regulated using a rheostat. The initial moisture content of slices was determined by weight loss in a drying chamber at atmospheric pressure and 105 ºC until constant weight. Each drying experiment was independent, and the chilies used for all trials were from the same farm and had the same average initial moisture content. During the experiments, the sample weight and temperature (ambient, before and after the tray) were recorded at every 10 minutes. Furthermore, the velocity of the air was measured by an orifice meter at the end of the unit dryer.

Drying rate curve determination

Due to differences in initial mass of fresh red chilies, the sample moisture content (M) was expressed in a dry basis. The drying curve for each experiment was obtained by plotting the moisture (M) of the sample as a function of the drying time, t, measured in minutes. The drying rate (-d(Mt+Dt-Mt)/dt) was used to characterize the drying kinetics of red chilies and the results were plotted against t, in minutes, and with respect to average moisture (Mm) between the interval t and t+Dt. Apart from the drying rate, the data obtained experimentally for the different temperatures and air velocity studied were plotted in the form of moisture ratio (MR) versus time, being MR defined as:

$MR = (M-Me)/(M_0-M_e)$

where M, Me and M_0 are, respectively, the moisture content at time t, the equilibrium moisture content and the initial moisture content, all expressed in dry basis (g water/ g dry solids).

Drying Model for Red chilli Drying in Tray Dryer:

The published literature revealed that there is no single drying model which is suitable for describing the drying kinetics of all products. However, the mathematical models listed in Table.

S.No	Model name	Model equation	Products
1	Newton	MR=exp(-kt)	Apple slices
2	Page	MR=exp(-kt^2)	Bananas
3	Henderson and Pabis	MR=a.exp(-kt)	Shrimp and fish cake
4	Logarithmic	MR=a.exp(-kt)+c	Prawn and Chelwa fish
5	Two term	MR=aexp(-k_0t)+bexp(-k_1t)	Rice
6	Two-term exponential	MR=aexp(-kt)+(1-a) exp(-k_at)	Corn ears
7	Wang and Singh	MR=1+at+bt^2	Rough rice, lemon grass
8	Diffusion approach	MR=aexp(-kt)+(1-a)exp(-kbt)	Sultana grape
9	Verma *et* al.	MR=aexp(-kt)+(1-a)exp(-gt)	Rice
10	Modified Henderson and Pabis	MR=aexp(-kt)+bexp(-gt)+cexp(-ht)	Fresh and semi dried Fruits
11	Midilli model	MR=aexp(-kt^n)+bt	Red chili, Pistachio

Applications:

- Dry chilly is extensively used as spice in curried dishes. It is also used as an ingredient in curry powder and in seasonings. Bird chilly is used in making hot sauces as pepper sauce and Tabasco sauce.
- Paprika, Bydagi chilly, Warangal chapatta and similar high colour less pungent varieties are widely used for colour extraction. This colour is highly popular among food and beverage processors for its use as a colourant, since this being a 'natural plant colour'.
- As a medicine it is used as an counter irritant in Lumbago, Neuralgia, and Rheumatic disorders. Capsicum has a tonic and carminative action. Taken inordinately it may cause gastro-enteritis. The enzyme isolated from chilly is used in the treatment of certain type of cancers. Oleoresin capsicum is used in pain balms and vaporubs. Dehydrated green chilly is a good source of vitamin 'c'

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

Different Varieties of Chillies:

Type	Area of cultivation	Harvesting season	ASTA colour value	Capsaicine %
Birds Eye Chilli(Dhani)	Mizoram & some areas of Manipur	October to December	41.7	0.589
Byadagi(Kaddi)	Dharwar Karnataka	January to May	159.9	Negligible
Ellachipur Sannam-S4 Type	Amaravathi District of Maharashtra	September to December	70.40	0.2
Guntur Sannam-S4 Type	Andhra Pradesh	December to May	32.11	0.226
Hindpur-S7	Andhra Pradesh	December to March	33.00	0.24
Jwala	Kheda, Mehsana & in South Gujarat	September to December		0.4
Kashmir Chilli	Himachal Pradesh	November to February	54.10	0.325
Madhya Pradesh G.T.Sannam	Madhya Pradesh	January to March	--	-

Experimental procedure

- Tray dryer (TD) is popular for drying chili due to a relatively short drying time, uniform heating and more hygienic characteristics.
- The temperature ranges from 90 to 180ºC (approximately 20% of moisture content).
- This temperature range gives maximum colour values and minimizes the loss of volatile oils and discolouration.
- Selected fresh chilies(50 grams) were processed in a tray dryer and the chilies were dried under controlled temperature and parallel air flow until constant weight.
- The water removed during the drying process was determined by periodic weighing of the samples using an analytical balance.
- The weight loss was evaluated in each of these experiments separately and its value correlated with drying air temperature and velocity.
- The response surface methodology was used to evaluate the optimum drying conditions.
- A Factorial design, three level two parameter, was proposed to analyze the dried chilli quality as function of air temperature and air flow.
- The drying tests were conducted at temperatures of 90, 120,150 and 180ºC and air velocity of 10, 15 and 20 m/s for three hours.

Results and discussion

Drying process of red chilies has been determined, at different temperatures and air velocity, in a tray dryer until constant weight. Note that, although the raw material is the same, the initial moisture content of samples slightly differs because drying is the second stage in the red chilies processing. Two drying stages were observed: a constant rate period (controlled by convective heat and mass transfer) followed by a falling rate period (controlled by mass diffusion). At the first stage, moisture moves to the surface, by capillary suction, rapidly enough to maintain a uniformly wet surface and thus, the drying rate is constant. In the later stages, water is inside of the porous and consequently the wet area on the food surface decreases gradually and the falling rate period starts.

The initial percentage of moisture content in fresh chillies samples was 437.972 g water/g dry solids. Before the drying experiments of chillies, the equipment was run for about one hour to achieve the steady state conditions of temperature and air velocity.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

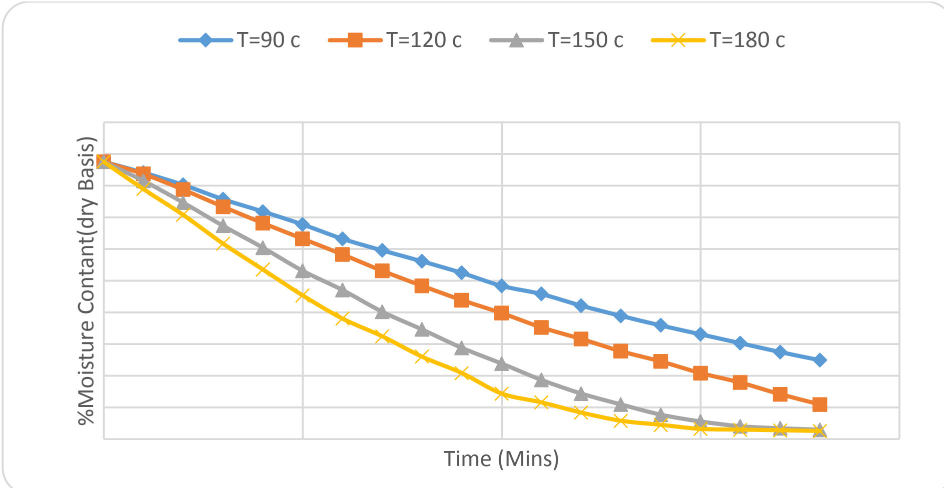

Figure 1: Profiles of percentage of moisture content in dry basis for temperatures of 90, 120, 150, and 180 ºC and air velocity of 20m/s.

Figure 1 revels the percentage of moisture content in dry basis of red chillies samples during the air drying at the different temperatures were studied. The drying curves obtained for the air velocity of 20 m/s and temperatures of 90 ºC,120 ºC, 150 ºC and 180 ºC reveal a similar kinetic behavior. As expected, there is an acceleration of the drying process due to the increase in the temperature of the drying from 90 ºC to 180 ºC. However, in the early stages of drying the temperature of 180 ºC shows a much faster decrease of percentage of moisture content in dry basis as compared to the temperature of 90 ºC, 120 ºC and 150 ºC.

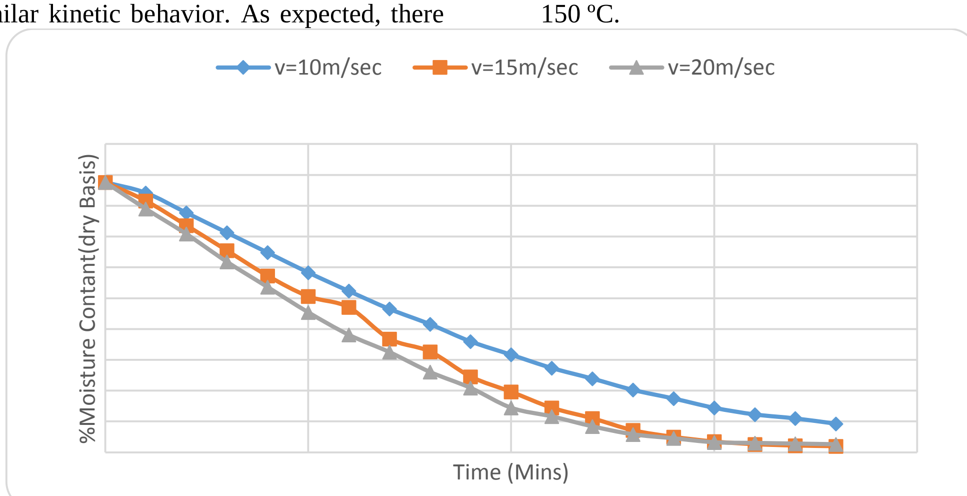

Figure 2: Profiles of percentage of moisture content in dry basis for air velocities of 10, 15, and 20 m/sec and air temperature of 180 ^{0}C.

Figure 2 shows that the air velocity had a significant influence on the moisture ratio at the temperature of 180 ºC, particularly in the early stages of drying. However, as the airflow velocity has increased, the loss of moisture was not proportional. In fact, the loss of moisture from the red chillies was much slower at air velocity of 10 m/s than at higher values of air velocity. As the drying time increased the difference in moisture of the samples dried at the different air velocities was much less pronounced. Moreover, an increase in air velocity results in decreasing of drying time due to the increase of heat and mass transfer between the air and the red chillies.

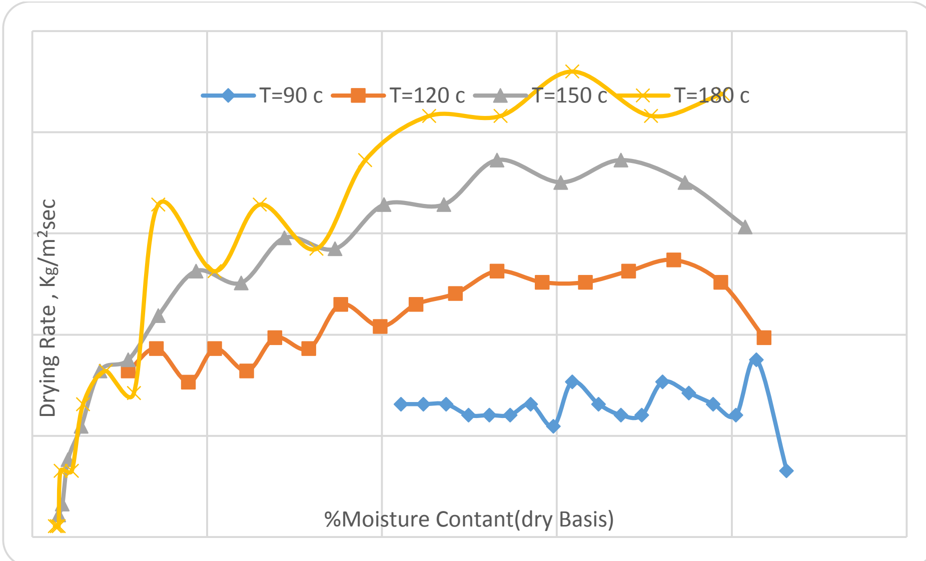

Figure:3 Profiles of drying rate curve versus moisture content for temperatures of 90, 120, 150, and 180 ºC and air velocity of 20m/s.

Figure 3 shows that the period of constant drying rate, which sometimes is observed in fruits, is very small or does not exist for the four temperatures studied. In addition, the rise in temperature allowed an increase in the drying rate.

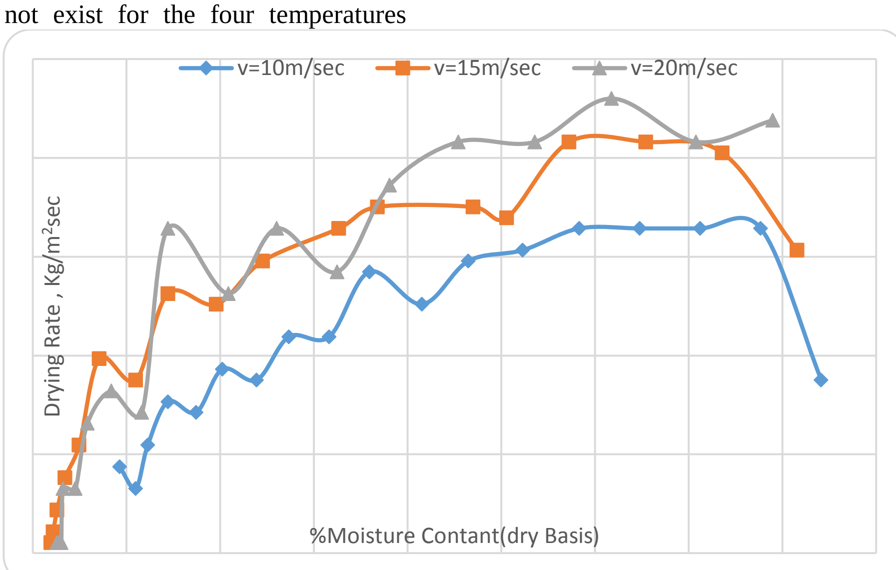

Figure: 4 Profiles of drying rate curve versus moisture content for air velocities of 10, 15, and 20 m/s and temperature of 180ºC.

Figure 4 shows that the deviation in the drying rates between 10 m/s and 15 m/s is high when compared with the deviation between 15 m/s and 20 m/s. so increase in air velocity beyond 15 m/s does not have much effect on drying

Model development

The model was developed from Y.Tulek et.al.The moisture ratio (MR) was calculated using the following equation:

$$\mathbf{MR}=\frac{M_t-M_e}{M_0-M_e} \qquad \textbf{(1)}$$

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

As the equilibrium moisture is very small compared to the values of M and M_0, the value can be neglected and the dimensionless moisture ratio can be written as M_t/M_0 only.

The drying rates of red chillies were calculated by using

$$\mathbf{DR} = \frac{M_{t+dt} - M_t}{dt} \qquad \mathbf{(2)}$$

Where, *Mt* and *Mt*+d*t*, are moisture content at *t* and moisture content at *t*+d*t*, respectively, and *t* is drying time (min). The drying curves obtained were processed for drying rates to find the most convenient model among the seven different expressions proposed by earlier authors. The regression analysis was performed using the Minitab 13 statistical software. The correlation coefficient (*R*2) was one of the primary criteria for selecting the best equation to define the drying curves of the dried red chillies. In addition to *R*2, various statistical parameters such as reduced chi-square and root mean square error (RMSE) were used to determine the best of the fit. When the calculated reduced values are close to zero, compatibility is better. The RMSE gives the deviation between the predicted and the experimental values and is required to reach zero. These statistical parameters can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - z}$$

(3)

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

(4)

Where *i MR*exp, is the *i*th experimental moisture ratio, *pre i MR* , is the *i*th predicted moisture ratio, *N* is the number of observations, and *z* is the number of constants in the drying model.

Effective Moisture Diffusivity and Activation Energy:

Drying of most food materials occurs in the falling rate period, and moisture transfer during drying is controlled by internal diffusion. For most biological materials, Fick's second law of diffusion has been widely used to describe the drying process during the falling rate period as follows:

$$\frac{\partial M}{\partial t} = \nabla\left[D_{\text{eff}}\left(\nabla M\right)\right]$$

(5)

Where, *D*eff is the effective moisture diffusivity representing the conductive term of all moisture transfer mechanisms. This parameter is usually determined from experimental drying curves. Assuming moisture migration being only by diffusion, constant temperature and effective moisture diffusivity, and negligible shrinkage:

$$\text{MR} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{\text{eff}} t}{4L^2}\right)$$

(6)

In practice, only the first term of Equation is used, yielding:

$$\text{MR} = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{\text{eff}} t}{4L^2}\right)$$

(7)

The effective moisture diffusivity can be determined from the slope of the normalized plot of the unaccomplished moisture ratio, ln (MR) versus time, using the following equation:.

$$D_{\text{eff}} = \frac{-\text{Slope}4L^2}{\pi^2}$$

(8)

Temperature dependence of the effective diffusivity has been shown to follow an Arrhenius relationship

$$D_{\text{eff}} = D_0 \exp\left(\frac{-E_a}{RT}\right)$$

(9)

Where, *D*0 is the pre-exponential factor of the Arrhenius equation (m2s-1), *E*a is the activation energy (kJ mol-1), *R* is the universal gas constant (kJ mol-1 K), and *T* is the absolute air temperature (K). The activation energy is determined from the slope of the Arrhenius plot, ln (D_{eff}) vs. 1/*T*.

Effective Diffusivities and Activation Energy Red Chillies:

Effective diffusivities of dried red chillies at different temperatures and air velocities were

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

obtained from the gradient of the graph as shown in Figures 8, 9 and 10. Plots of ln (MR) versus drying time (t) gave straight lines for 90, 120, 150, 180 ^{0}C with slopes -4.2083e^{-3}, -7.4572e^{-3}, -0.0107, and -0.01433 respectively at velocity 10 m/s , -5.8704e^{-3}, -8.1321e^{-3}, -0.01671, and -0.0266 respectively at velocity 15 m/s and -7.3507e^{-3}, -0.0118, -0.0270, and -0.0337 respectively at velocity 20 m/s. The respective Correlation Coefficients (R^2) from the regression analyses of the straight lines were 0.9916, 0.9771, 0.9730 and 0.9795 at velocity 10 m/s, 0.9900, 0.9818, 0.9018 and 0.8772 at velocity 15 m/s, 0.9887, 0.9532, 0.8953 and 0.9071 at velocity 20 m/s at the four temperatures tested, respectively. The effective diffusivities obtained by Eq. (8) at 100, 120,140,160 ^{0}C were 0.07097, 0.125, 0.00018 and 0.000242 respectively at velocity 10 m/s, 0.09901, 0.13716, 0.000282 and 0.000449 respectively at 15 m/s, 0.1239, 0.000201, 0.000456 and 0.000569 respectively at velocity 20m/s. The relationship of the effective diffusivities and drying temperatures follow the Arrhenius equation as shown in Eq. **(9)**. The logarithm of effective diffusivity (D_{eff}) as a function of the reciprocal of the absolute temperature (T) is plotted in Figures 11, 12 and 13 is shown as a linear relationship between (ln D_{eff}) and (1/T). The activation energy for red chillies at velocities 10 m/s, 15 m/s and 20 m/s (Ea) were 10.027 kJ mol^{-1}, 9.591 kJ mol^{-1} and 8.088 kJ mol^{-1} respectively.

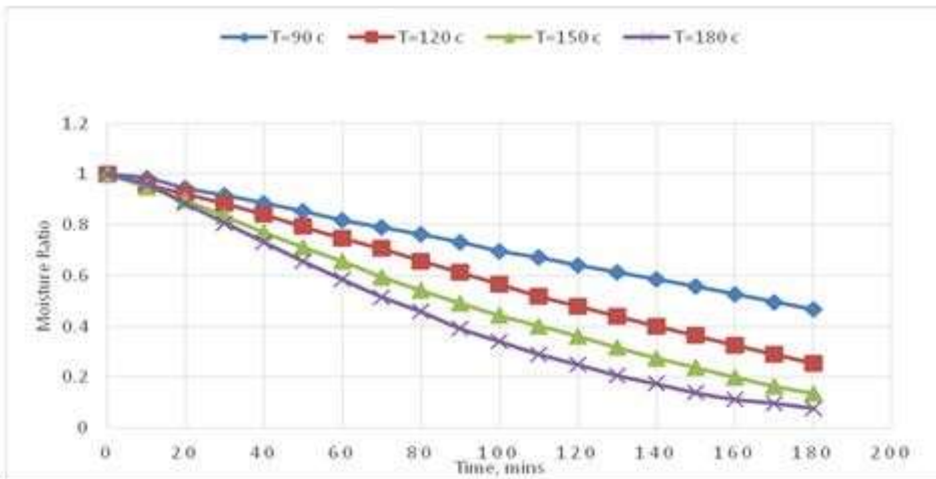

Figure: 5: Moisture ratio Vs time at velocity 10 m/sec.

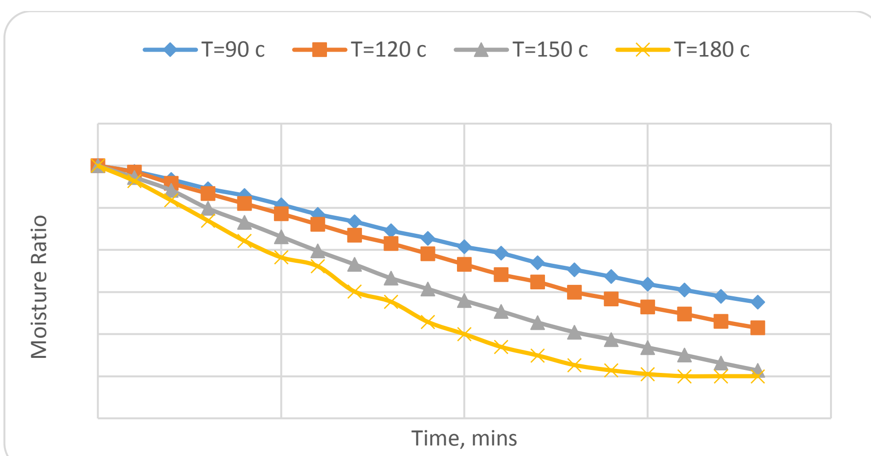

Figure: 6 Moisture ratio Vs time at velocity 15 m/sec

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

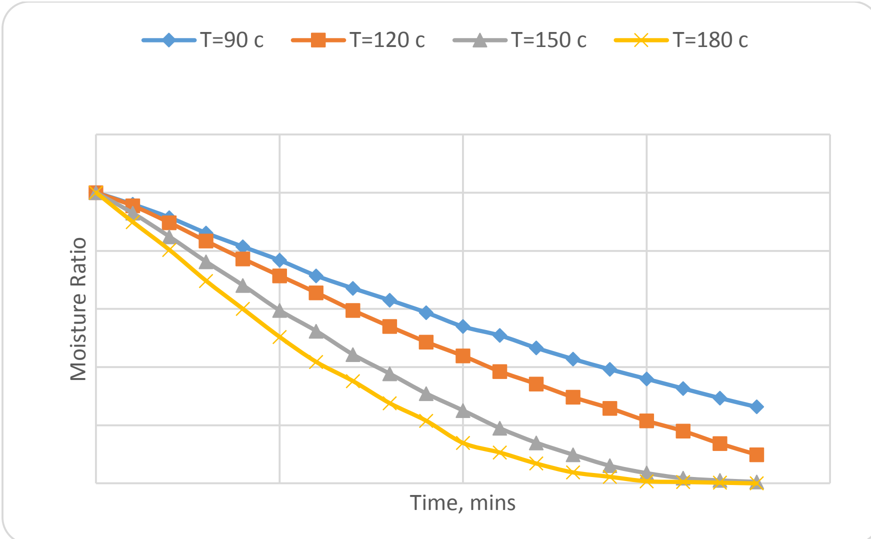

Figure: 7 Moisture ratio Vs time at velocity 20 m/sec

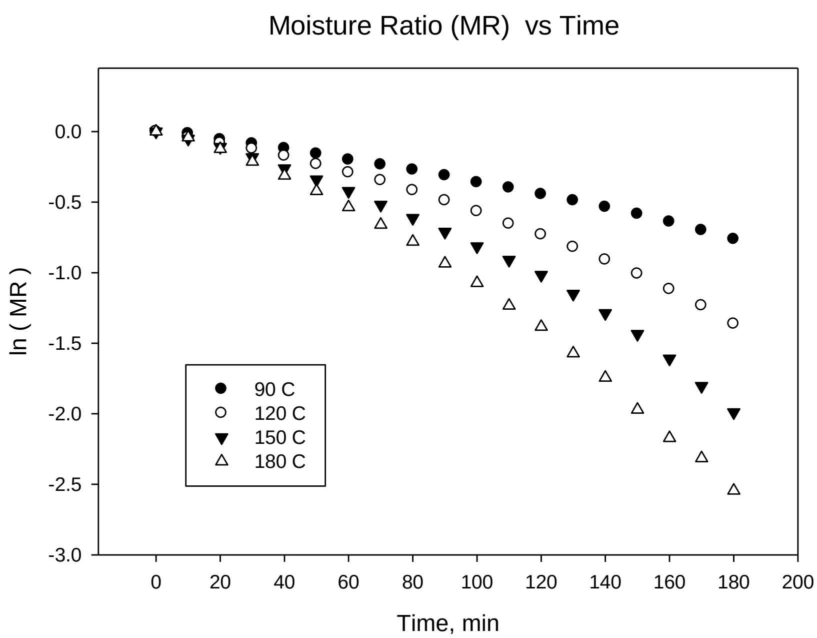

Figure: 8 Moisture ratio Vs time at velocity 10 m/sec.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

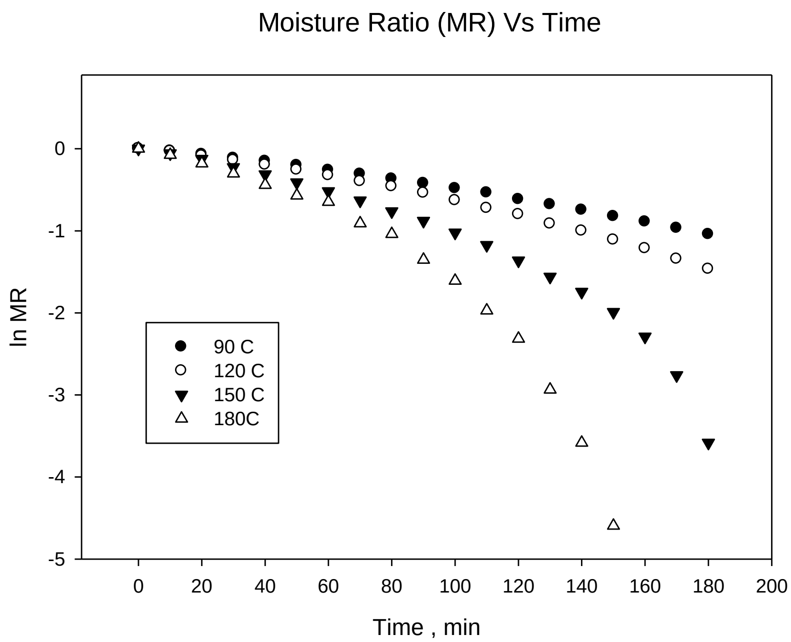

Figure: 9 moisture ratio Vs time at velocity 15 m/sec.

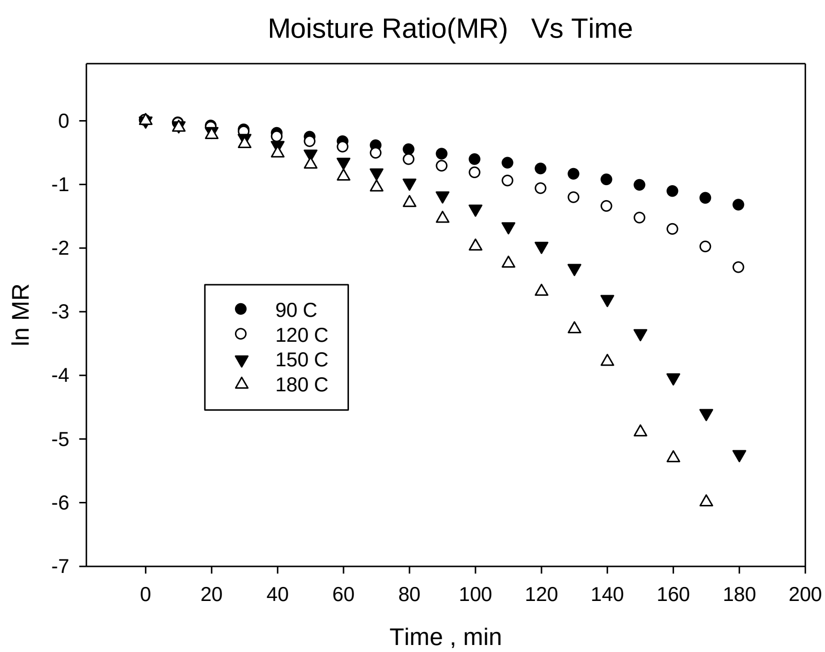

Figure: 10 Moisture ratio Vs time at velocity 20 m/sec.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 1.852

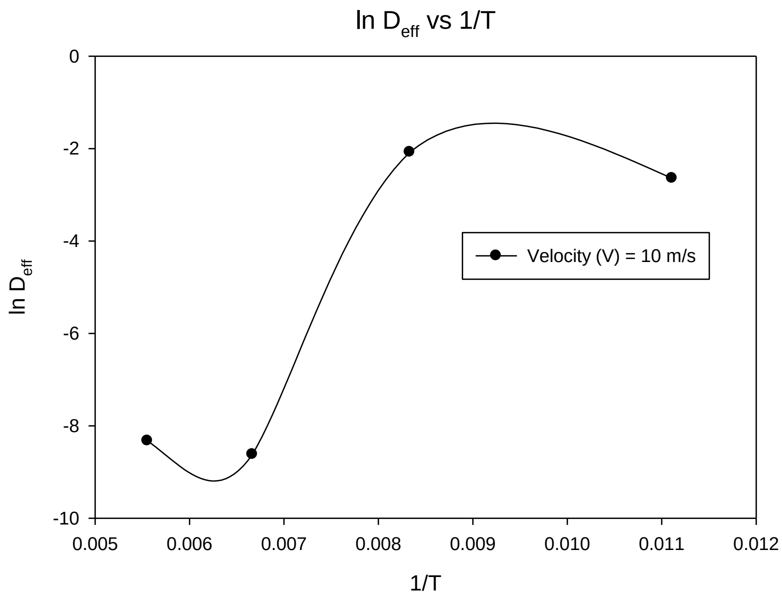

Figure: 11 ln D_{eff} Vs 1/T at velocity 10 m/s.

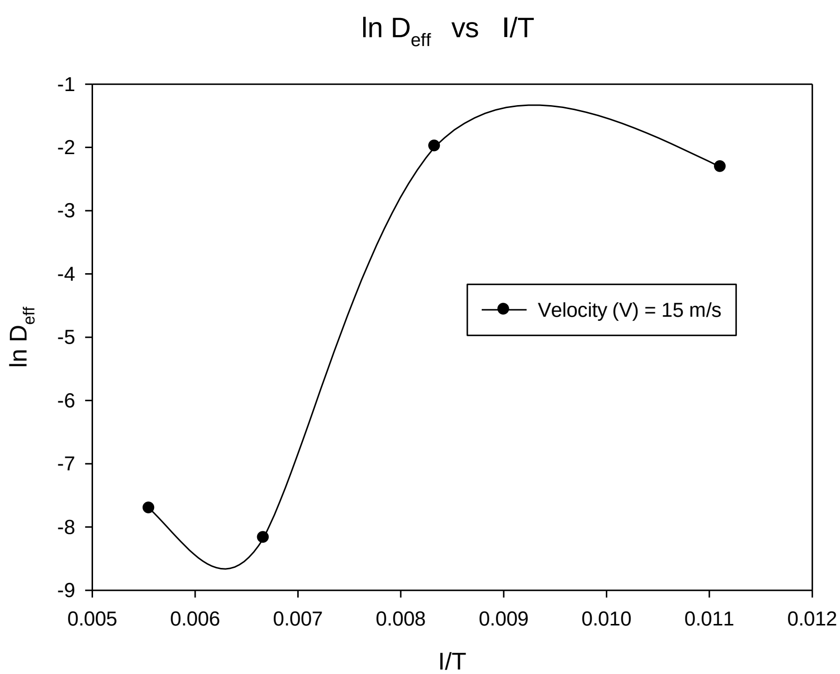

Figure: 12 ln D_{eff} Vs 1/T at velocity 15 m/s.

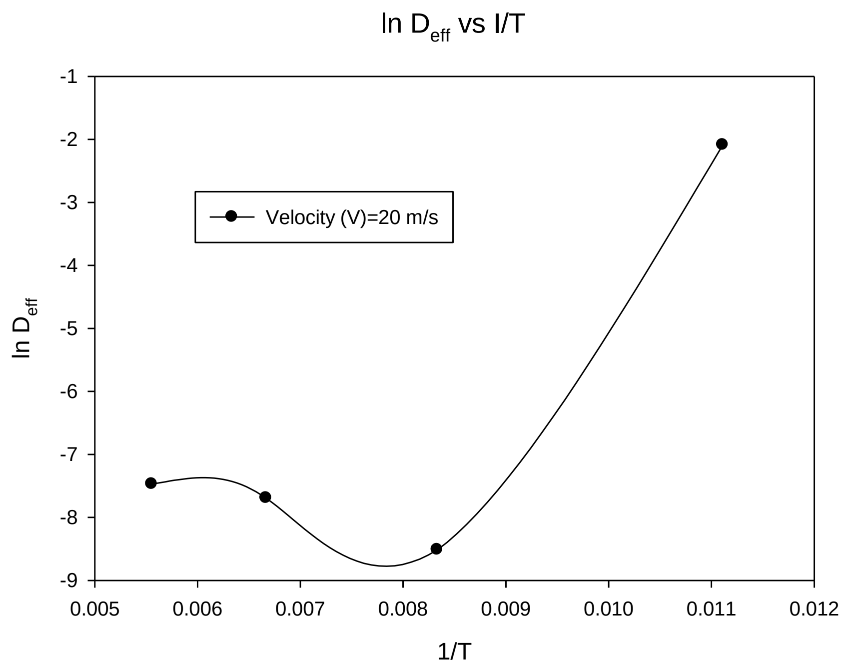

Figure: 13 ln D_{eff} Vs 1/T at velocity 20 m/s.

Conclusions

- This study experimentally investigated the effect of various parameters i.e., inlet dry air temperature and inlet air velocity, on the drying kinetics at various time intervals on red chillies.
- Moisture content in dry basis and drying rates at regular intervals of time are found we observed effective drying at temperature 180^{o}C and velocity 15m/s for red chillies.
- The effective moisture diffusivity of red chillies was found to range between 0.07097 to 2.4169 X 10^{-4} at velocity 10 m/s, 0.09901 to 4.4915 X 10^{-4} at velocity 15 m/s and 0.1239 to 5.689 X 10^{-4} at velocity 20 m/s within the temperature range of 90, 120, 150 and 180^{o}C .
- The effective moisture diffusivity could be represented in an Arrhenius-type relationship with good accuracy. The activation energy for red chillies at velocities 10, 15 and 20 m/s were 10.027 kJ mol^{-1}, 9.591 kJ mol^{-1} and 8.088 kJ mol^{-1} respectively.

References

1. *The Need for Fundamental Research on Drying as Perceived by Slangen, H.J.M., European Chemical Industry, to appear in Drying Technology – An International Journal, 18(6), 2000.*
2. *Drying technologies in Food Processing by Xiao Dong Chen and Arun S. Mujumdar*
3. *Drying Performance, Quality Characteristics, and Financial Evaluation of Indian Mackerel (Rastrilliger Kangurta) Dried by a Solar Tunnel Dryer B. R. Chavan, A. Yakupitiyage, and S. Kumar*
4. *Van't Land, C.M., 1991, Industrial Drying Equipment: Selection and Application, Marcel Dekker, New York.*
5. *Study of Drying Kinetics of Quince Maria João Barroca, Raquel P. F. Guiné*
6. *Drying of municipal sewage sludge: from a labouratory scale batch indirect dryer to the paddle dryer by P. Arlabosse, S. Chavez1 and C. Prevot*
7. *Shrimp Drying Characterizes Undergoing Microwave Treatment by Asie Farhang Department of Veterinary Medicine, Tehran University, Tehran, Iran*
8. *Drying methods and quality of shrimp dried in a jet-spouted bed dryer by Rungtip tapaneyasin, Sakamon devahastin and Ampawan tansakul.*