International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Impact Factor (2012): 3.358

Activation Energy Kinetics in Thin Layer Drying of Basil Leaves

N. C. Shahi[1], Anupama Singh[2], A. E. Kate[3]

[1]Ph. D Scholar, Department of Post Harvest Process & Food Engineering, College of Technology
G. B. Pant University of Agril. & Tech., Pantnagar, U.S. Nagar (Uttarakhand)-263145, India

[2]National Fellow, Department of Post Harvest Process & Food Engineering, College of Technology
G. B. Pant University of Agril. & Tech., Pantnagar, U.S. Nagar (Uttarakhand)-263145, India

Abstract: ***Basil leaves are well known for the medicinal values and grown widely in India. To investigate the effect of different drying conditions on activation energy kinetics of basil leaves, the solar and vacuum dryers were employed and air temperatures of 45, 55 and 65°C were considered for the drying. Drying of basil leaves prominently occurred in falling rate period and it was found that basil leaves dried faster in solar dryer. The effective moisture diffusivity (D_{eff}) of basil leaves increased with the increase in drying air temperature. The D_{eff} values were higher for solar dryer than those dried in the vacuum dryer. . Effective moisture diffusivity of basil leaves ranged from 4.54×10^{-10} to 1.08×10^{-9} m²/s. An Arrhenius relation was employed to ascertain activation energy for the samples dried in both types of dryers and activation energy for basil leaves drying ranged from 38.54 to 20.32 kJ/mol.***

Keywords: Basil leaves, Solar dryer, vacuum dryer, Activation energy, Diffusivity.

1. Introduction

Basil (*Ocimum sanctum*) which is popularly known as *Tulsi* is a widely grown, sacred plant of India. It belongs to the Labiateae family and called Holy Basil in English. Dark or *Shyama tulsi* and light or *Rama tulsi* are the two main varieties of basil and the former one possesses higher medicinal values. *Tulsi* is a branched, fragrant and erect herb having hair all over. It attains a height of about 75 to 90 cm when mature. Its leaves are nearly round and up to 5 cm long with the margin being entire or toothed. Basil leaves are aromatic because of the presence of a kind of scented oil.

Apart from basil leaves' religious significance, it is a source of many medicinal characteristics and usually used in "Ayurvedic" treatment to cure a number of diseases. Marked by its strong aroma and a stringent taste, *Tulsi* is a kind of "the elixir of life" as it promotes longevity. The plant extracts can be used to prevent and cure many illnesses and common ailments like common cold, headaches, stomach disorders, inflammation, heart disease, various forms of poisoning and malaria. *Tulsi* leaves contain a bright yellow volatile oil, which is useful against insects and bacteria. The principal constituents of the oil are eugenol, eugenol methyl ether and carvacrol. The oil is reported to possess anti-bacterial properties and acts as an insecticide. It has marked insecticidal activity against mosquitoes. The juice of leaves, and or a concoction, called jushanda, a kind of tea, gives relief in common cold, fever, bronchitis, cough, digestive complaints, etc. When applied locally, it helps in eradicating ringworms and other skin diseases. *Tulsi* oil is also used as eardrops in case of pain. The seeds are used in curing urinary problems. Aphrodisiac virtue has been attributed to it and powdered *Tulsi* root with clarified butter (ghee) is prescribed for the same in "Ayurvedic "treatment.

Drying is one of the oldest methods of food preservation and it represents a very important aspect of food processing. The main aim of drying products is to allow longer periods of storage, minimize packaging requirements and reduce shipping weights [15], the drying process should be undertaken in closed equipment to improve the quality of the final product [25] [26].

Thin layer equations describe the drying phenomena in a united way, regardless of the controlling mechanism. They have been used to estimate drying time of several products and to generalize drying curves. In the development of thin layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions is measured and correlated to the drying parameters [14] [24]. Thin layer drying equations do not require evaluation of many models parameters as common in more complex representations [12].

Earlier studies indicated the significant effect of type of dryer on drying kinetics of basil leaves as well as theirs characteristic properties, so the presented study was conducted to calculate the effective moisture diffusivities and activation energy, and investigate the influence of drying methods (Sun, Solar and vacuum drying) with different drying air temperature (55, 60 and 65°C) on activation energy kinetics of basil leaves.

2. Theoretical Considerations

2.1 Mathematical formulation

The initial moisture content of mint leaves was determined using a standard method [1], by vacuum drying at 70ºC for 24 h over a magnesium sulphate desiccant. This was repeated three times to obtain a reasonable average.

$$M_c = \frac{W_1 - W_2}{W_0} \quad (1)$$

where, W_c = Moisture content of the sample, %(d.b), W_0 = Weight of the dry matter, g, W_1 = Weight of the sample and dish with cover before drying, g, W_2 = Weight of the sample and dish with cover after drying, g

The moisture contents of basil leaves were expressed in dimensionless form as moisture ratios MR with the following equation [14] [7].

$$MR = \frac{M - M_e}{M_0 - M_e} \quad (2)$$

Where: M is the mean basil moisture content; M_o is the initial value; and M_e is the equilibrium moisture content. The M_e values were neglected because the values were very small as compared to those of M_o and M and the moisture ratio was simplified as per the following relationship [4] [8] [18]:

$$MR = \frac{M}{M_0} \quad (3)$$

2.2 Effective Moisture Diffusivity

Fick's diffusion equation, for particles with slab geometry, was used for calculation of effective moisture diffusivity. The basil leaves were considered as slab geometry [5] for the purpose. The following equation was used for the purpose [2]:

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

Eq^n (4) can be rewritten as:

$$\ln MR = D_{eff} k_0 + \ln\frac{8}{\pi^2} \quad (5)$$

Where, the slope (k_o) is calculated by plotting ln(MR) versus time according to Equation (5) to determine the effective diffusivity for different temperatures.

$$k_o = -\left(\frac{\pi^2 D_{eff}}{4\, L^2}\right) \quad (6)$$

2.3 Activation energy

The effective diffusivity can be related with temperature by Arrhenius equation [23]:

$$D_{eff} = D_0 \exp\left[-\frac{E_a}{R(T+273.15)}\right] \quad (7)$$

where, D_0 is the constant in Arrhenius equation in m^2s^{-1}, Ea is the activation energy in kJ. mol^{-1}, T is the temperature in °C and R is the universal gas constant in kJ. $mol^{-1}.K^{-1}$. Equation (7) can be rearranged in the form of :

$$\ln(D_{eff}) = \ln(D_0) - \frac{E_a}{R(T+273.15)} \quad (8)$$

The activation energy can be calculated by plotting a curve between $\ln(D_{eff})$ versus 1/(T+273.15).

3. Materials and Methods

3.1 Experimental material

Basil or *Tulsi* leaves (*Ocimum sanctum*) were harvested from MRDC, GBPUAT Pantnagar farm and properly washed in tap water. Excess surface water from washed basil leaves was removed using blotting paper with slight pressing. Clean leaves were weighed using electronics balance (least count of 0.01 mg) and put in trays of solar dryer for drying and vacuum dryer. To establish the influence of air temperature on activation energy, experiments were conducted at 45, 55 and 65°C. The initial moisture content of basil leave was 932.87% d.b. Basil leave average thickness was 0.33 ± 0.08 mm) and were dried on the same day.

3.2 Drying equipment and procedure

The drying experiments on basil leaves were performed in a PID controlled polyhouse type solar dryer developed in Department of PHPFE, GBPUAT Pantnagar and a laboratory model of vacuum dryer.PID controlled solar dryer consisted a drying chamber in which perforated screen tray, electrical heater, blowers and a PID and temperature controller are fitted. A hemi-cylindrical dome is fitted at the top of drying chamber for collection and transmition of solar radiation inside. Drying experiments were conducted at 45, 55 and 65°C (± 1°C) in both the drying methods. The dryer was allowed to run for to reach the set drying air temperature conditions. Basil leaves loading density was 2 kg/m^2 for all runs were uniformly spread in rectangular trays and kept in the solar and vacuum dryer for drying. Moisture loss was recorded at 30 min interval by a digital balance with lease count of 0.01 mg (Citizen Instruments, India). The drying was continued till there is no large variation in the moisture loss. Experiments were conducted in triplicate.

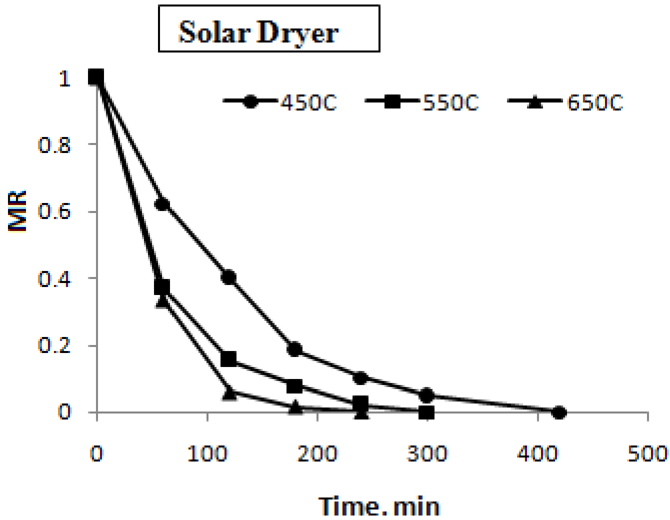
4. Result and Discussion

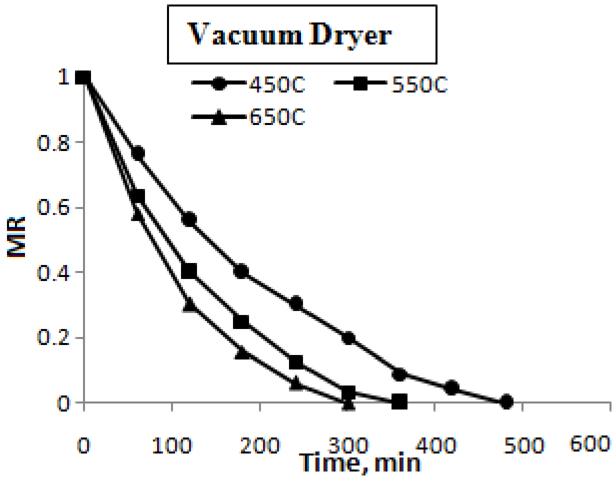
The effect of various drying conditions in two different types of dryers on the diffusion coefficients are shown in Table (1). Figure 1 present relation between moisture ratio and drying time for all three drying temperature in both type of dryers. Constant rate-drying period was not detected in drying curves and the curves typically demonstrated smooth diffusion controlled drying behaviour under all run conditions. Drying rate increased with the increase of air drying temperature in both drying methods. Highest drying rates were observed for the samples dried at 65°C of the drying air for both dryers. Similar observations have been reported for the drying of red chillies, onion slices [21] and apricots [4] and mint leaves [10]. The drying of basil leaves occurred primarily in falling rate period and that showed that internal mass transfer occurred by diffusion. Drying time differed with respect to the type of dryer (table 1). The samples dried in solar dryer took lesser time than those dried in the vacuum dryer. It is evident that the drying air temperature has an important effect on drying. When the temperature was increased, the drying time reduced.

Activation energy is the minimum energy required to initiate moisture diffusion from a product. The effective diffusivities were estimated from the experimental drying curves. To estimate diffusion coefficients (D_{eff}), the slope of ln(MR) versus time (Fig. 1), as given by Eq. (5) was used. The effective diffusivity was determined to be 4.54E-10 to 1.08E-09 m^2/s for the solar drying and 3.09E-10 to 4.85E-09 m^2/s for vacuum drying in the temperature range of 45–65 ºC. The curves between ln(D_{eff}) and 1/(T+273.15) plotted to calculate activation energy for the drying methods were shown in Figure (3). The plots were found to be essentially the straight lines in the temperature range investigated indicating Arrhenius dependence. From the slop of the straight lines described by the Arrhenius equation, the activation energy was found to be 38.5437 and 20.31942 kJ/mol respectively for tray and tunnel drying of basil leaves.

Table 1: Drying times and diffusion coefficients in different dryer and drying temperature

Sr. No	*Type of Dryer*	*Drying Temperature, ºC*	*Drying time (min)*	*D_{eff} (m^2/s)*
1	Solar Dryer	45	420	4.54E-10
		55	300	6.88E-10
		65	236	1.08E-09
2	Vacuum Dryer	45	480	3.09E-10
		55	360	4.41E-10
		65	300	4.85E-10





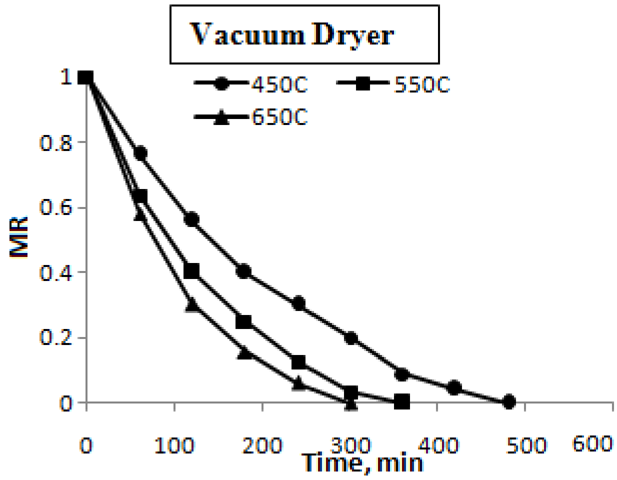
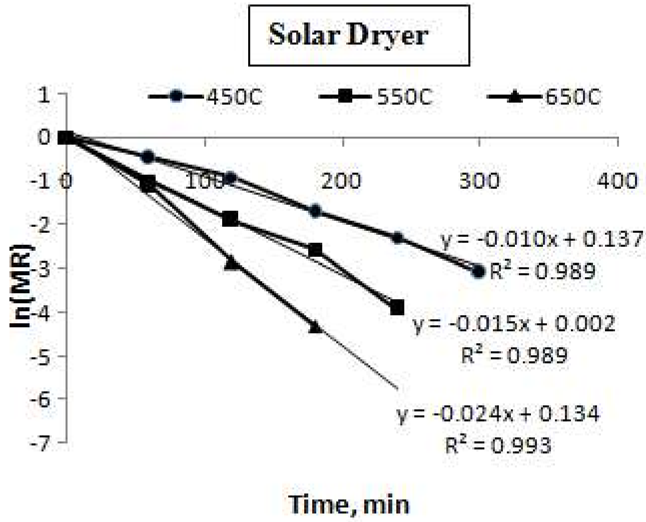


Figure 1: Effect of drying temperature on drying time of basil leaves in different dryers



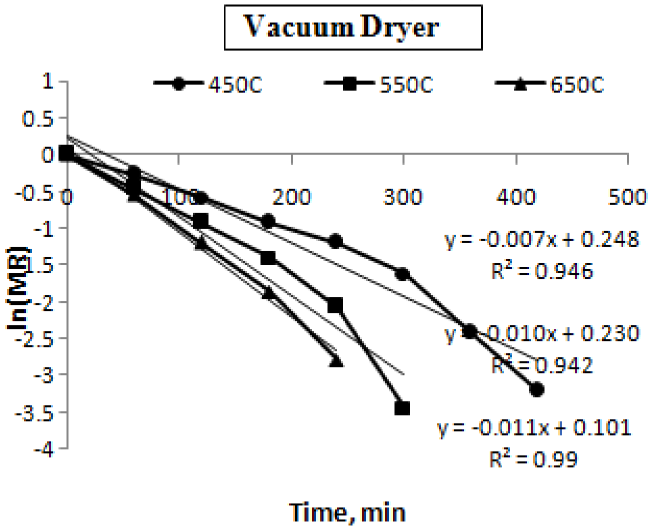


Figure 2: Experimental and predicted ln(MR) vs time.

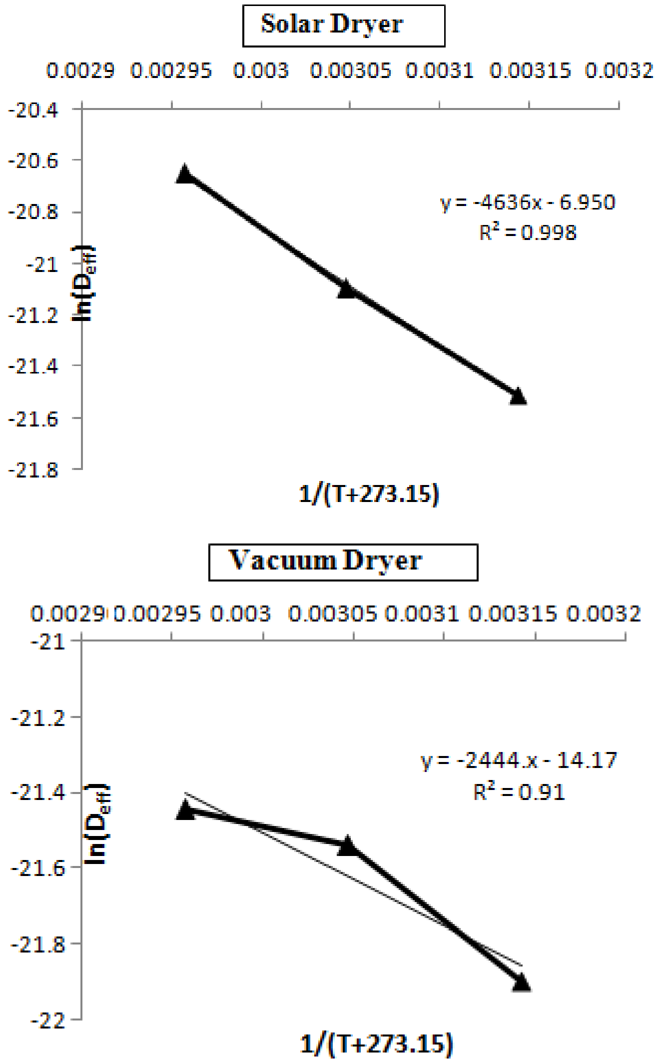


Figure 3: Relationship between effective diffusivity and reciprocal of absolute temperature.

5. Conclusions

Drying of basil leaves study was carried to determine the effect of drying methods (Solar and Vacuum dryers) and drying air temperature on activation energy. The results show that the increase in drying air temperature decreased the drying time in both the drying methods. About 420, 300 and 236 min are required to dry the basil at air temperature of 45, 55 and 65°C, respectively, in tray dryer. Logarithmic thin layer drying equation represented the thin layer drying behaviour of basil leaves. Effective moisture diffusivity of basil leaves ranged from 4.54×10^{-10} to 1.08×10^{-9} m^2/s. Effective moisture diffusivity of basil leaves was higher in solar dryer as compared to that of vacuum dryer irrespective of drying air temperature. Activation energy was 38.54 and 20.32 kJ/mol for drying of basil leaves samples in solar and vacuum dryer, respectively. This activation energy will be the main basic consideration for design of any drying system and calculation of required drying energy.

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Author Profile

Er. N. C. Shahi, (M.Tech) presently pursuing in-service Ph.D with major in Process and Food Engineering and working as Associate professor in the Department of Post Harvest Process and Food Engineering G. B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand), India. He is working in the areas of development of food processing machineries, fruit and vegetable processing, drying and dehydration etc. He has published several research papers in various nationals and international journals. He is life member of many professional societies.

Dr. Anupama Singh, (Ph.D) presently working as National Fellow in the Department of Post Harvest Process and Food Engineering G. B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand), India. She is working in the areas of Food Biotechnology, fruit and vegetable processing, Bioprocess engineering, development of food products etc. She is reviewer and has been published several research papers in various nationals and international journals. She is life member of many professional societies.

Er. A E. Kate, (M.Tech) presently pursuing Ph.D with major in Process and Food Engineering in the Department of Post Harvest Process and Food Engineering G. B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand), India. He is recipient of ICAR-JRF during his post graduation, awarded ICAR-SRF and ASRB-NET-2013. He has published several research papers in various nationals and international journals.