# Effect of Air Velocity and Temperature on Energy and Effective Moisture Diffusivity for Russian Olive (*Elaeagnusan gastifolial* L.) in Thin-Layer Drying

***Abbaszadeh, Ahmad; Motevali, Ali; Ghobadian, Barat***+;***
***Khoshtaghaza, Mohammad Hadi; Minaei, Saeid***
*Department of Agricultural Machinery Engineering, Faculty of Agriculture, Tarbiat Modares University, Tehran, I.R. IRAN*

**ABSTRACT:** *Thin layer drying of Russian olive (Elaeagnusan gastifolial L.) fruit using a hot air dryer in order to calculate effective moisture diffusivity, activation energy and energy consumption has been evaluated in this article. The selected variables included three levels of air velocity of 0.5, 1 and 1.5 m/s and three air temperature levels of 50, 60 and 70°C. Increased air temperature increased effective moisture diffusivity but increase in air temperature had an inverse effect. Effective moisture diffusivity ($D_{eff}$) calculated for russian olive fruit in different temperatures and air velocities ranged between $5.56\times10^{-11}$ to $3.18\times10^{-10}$ ($m^2/s$). The resulting values for activation energy had a minimum of 48.18 kJ/mol for 1.5 m/s air velocity up to a maximum of 63.83 kJ/mol for 0.5 m/s air velocity. The values for total and energy consumption in thin layer drying russian olive ranged between 16.34-75.04 (kW.h).*

**KEY WORDS:** *Russian olive, Effective moisture diffusivity, Activation energy, Energy consumption.*

## INTRODUCTION

Russian olive (*Elaeagnusan gastifolial* L.) fruit is among orchard fruits produced in northeastern and southern parts of Iran with a cultivation area of 2708600 hectares with an average annual yield of 5443.45 metric tons mainly marketed as dry fruit drying process is among traditional post harvest activities. On the whole, the word drying refers to elimination of small amounts of relative moisture from dry matter or solid treatment through evaporation causing microbiologic stabilization and increased shelf life of materials. High energy consumption in drying industry has distinguished drying as an energy demanding function with immense industrial importance [1]. Therefore, physical and thermal properties of crops such as mass and heat transfer, diffusion, specific thermal conductivity coefficient and evaporation rate are important for designing a new system or improving the existing systems. Drying curves of drying experiments under controlled conditions gives useful information about moisture transfer mechanism and calculation of effective moisture diffusivity. Diffusivity is a property of crops and its value depends on internal material conditions. Many investigations have been performed on effective moisture diffusivity coefficient, activation energy, energy consumption and evaluation of various

* *To whom correspondence should be addressed.*
+ *E-mail: ghobadib@modares.ac.ir*
*1021-9986/12/1/75 5/$/2.50*

drying conditions in thin layer drying of different vegetables and fruits such as barberry [2], corn [3], plum [4] and kiwi [5]. However, there has been no research for calculation of effective moisture diffusivity, activation energy and energy consumption of Russian olive fruit. The aims of this research are: calculation of effective moisture diffusivity, activation energy and energy consumption of Russian olive fruit in thin layer drying conditions, evaluation of the effect of temperature and air velocity on effective moisture diffusivity, activation energy and consumption energy and presentation of relations based on temperature and air velocity for effective moisture diffusivity, activation energy and energy consumption.

## EXPERIMENTAL SECTION

### *Material preparation and drying conditions*

Freshly harvested Russian olive fruits were purchased from the local farms at Mayvan region of North Khorasan municipality (Iran) and stored in the refrigerator at about +5°C for experiments. The fresh Russian olive used in this investigation had 24% (w.b) initial moisture content. The temperature level in the dryer was fixed at mean free-stream temperatures of 50, 60 and 70°C and regulated to ±1°C by means of the temperature controller. For each temperature, a drying test was performed with the air velocity at the measurement point set constant at 0.5, 1 and 1.5 m/s.

### *The experimental facility*

A laboratory scale hot-air dryer was equipped whit an automatic temperature controller with accuracy of ±0.1°C deviation. Air velocity was kept at previously fixed values of (0.5, 1 and 1.5 m/s) with an accuracy of ±0.1m/s using a Ljt lutrun AM-4204 (Taiwan) Vane probe anemometerThe dried samples were manually weighted using an electronic balance having accuracy ±0.01 g, resolution 0.01 g and maximum capacity, 0.61 kg (AND GF-600, Japan).

### *Theoretical principles*

Effective moisture diffusivity is defined as a property of foodstuff as intrinsic moisture mass transfer and includes molecular diffusion, liquid diffusion, vapor diffusion, hydrodynamic flow and other possible mass transfer mechanisms [6, 7]. It is generally assumed that water transfer in solid matter takes place through molecular diffusion. Current method for studying mass transfer in an unstable condition when drying foodstuff is Fick's equations [8]. Most theoretical models studied in thin layer drying of various foodstuffs are a result of solving Fick's second law. Solution of general series of Fick's second law in spherical coordinates is shown (Eq. 1) in which moisture diffusion has been assumed constant, samples spherical, moisture in an equal level with equilibrium moisture and drying without shrinkage.

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-n^2\pi^2\frac{D_{eff}\,t}{r_0^2}\right) \qquad (1)$$

where n stands for the drying terms (1 and 2 and 3 and …) considered in equation, t drying time (sec), $D_{eff}$ efficient diffusivity coefficient ($m^2/s$), $r_0$ sphere radius (m) assumed constant in drying process, and $F_0 = \frac{D_{eff}\,t}{r_0^2}$ is Fick's number in mass transfer. The Eq. (1) is summarized as the following equation by considering the first term of Eq. (1) [2 and 9]. Eq. (2) can be simplified to a straight-line equation (Eq. 3).

$$MR = \frac{6}{\pi^2}\exp\left(-\pi^2\frac{D_{eff}\,t}{r_0^2}\right) \qquad (2)$$

$$\ln(MR) = \ln\left(\frac{6}{\pi^2}\right) - \left(\pi^2\frac{D_{eff}\,t}{r_0^2}\right) \qquad (3)$$

By drawing Eq. (3) against time a straight line with slope of $K_1$ is obtained. By drawing experimental data in term of ln (MR) versus time (s), effective diffusivity coefficient is determined as follows:

$$D_{eff} = \frac{-k_1 r_0^2}{\pi^2} \qquad (4)$$

Using Arrhenius equation, the relationship between temperature and effective diffusivity is shown in Eq (5) from which activation energy can be calculated.

$$D_{eff} = D_0\exp\left(-\frac{E_a}{R_g T_{abs}}\right) \qquad (5)$$

Where $D_0$ indicates Arrhenius coefficient ($m^2/s$), $E_a$ activation energy (kJ/mol), $T_{abc}$ absolute temperature (K) and $R_g$ universal gas constant. Eq. (5) can become linear by taking logarithm of both sides of equation (Eq. (6)).

Activation energy of $E_a$ can be determined by drawing the $\ln D_{eff}$ diagram against $1/T_{abc}$ and the slope of this line equals $K_2$ (Eq. (7)) and its origin distance is $\ln D_0$ [10].

$$\mathrm{Ln}D_{eff} = \mathrm{Ln}D_0 - \frac{E_a}{R_g} \cdot \frac{1}{T_{abs}} \tag{6}$$

$$K_2 = \frac{-E_a}{R_g} \tag{7}$$

During the experiment, total drying time and total energy consumption by heaters was calculated in each cycle of dryer use. Energy consumption in each cycle is measured using Eq. (8) [2, 11].

$$E_t = A\,\upsilon\,\rho_a\,C_a\,\Delta t\,D_t \tag{8}$$

where $E_t$ shows total energy consumption (kWh) in each drying course, A area of container in which the sample is placed ($m^2$), $\upsilon$ air velocity (m/s), $\rho_a$ air density ($kg/m^3$), $\Delta t$ temperature difference, $D_t$ total drying time of sample (hour) and $C_a$ specific heat (kJ/kg °C).

## RESULTS AND DISCUSSION

### *Calculation of effective moisture difusivity*

Fig. 1 display natural logarithms of moisture ratio ln (MR) against time (second) in constant air velocity and different temperature levels. As can be seen from all figures, russian olive fruit drying occurs only as a course with descending rate, and this means that liquid diffusion is the stimulus controlling drying process. Therefore, all curves are in the form of straight lines.

General range of effective moisture diffusivity for different foodstuffs is between $10^{-11}$ and $10^{-9}$ [12]. Effective moisture diffusivity ($D_{eff}$) calculated for russian olive fruit in different temperatures and air velocities has fluctuated between $5.56\times10^{-11}$ and $3.18\times10^{-10}$, with a minimum related to 70 °C and air velocity of 0.5 m/s and a maximum related to 50 °C and air velocity of 1.5 m/s.

### *Activation energy calculation*

Activation energy is calculated and the values shown together with respective correlation coefficients and Arrhenius coefficient ($m^2/s$) of in Table 1. The resulting values for activation energy have ranged between a minimum of 48.18 kJ/mol in 1.5 m/s air velocity up to a maximum of 63.83 kJ/mol in 0.5 m/s air velocity. The activation energy values for foodstuffs are in general

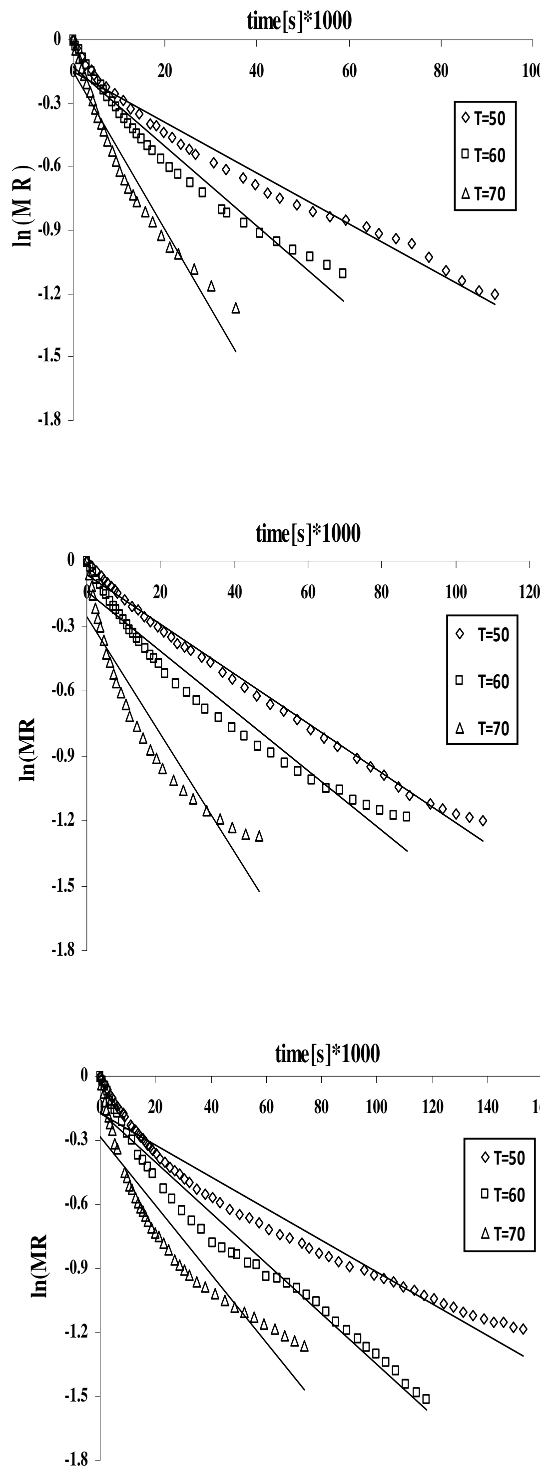


***Fig. 1: ln(MR) versus time (s) when different air velocity and temperatures.***

***Table 1: Activation energy and related correlation coefficient at different levels of air velocities for thin-layer drying of russian olive.***

| V(m/s) | 0.5 | 1 | 1.5 |
|---|---|---|---|
| Ea (kJ/mol) | 63.83 | 60.64 | 48.18 |
| $R^2$ | 0.9997 | 0.9799 | 0.9604 |
| $D_0$ | 1.657 | 0.376 | 0.024 |

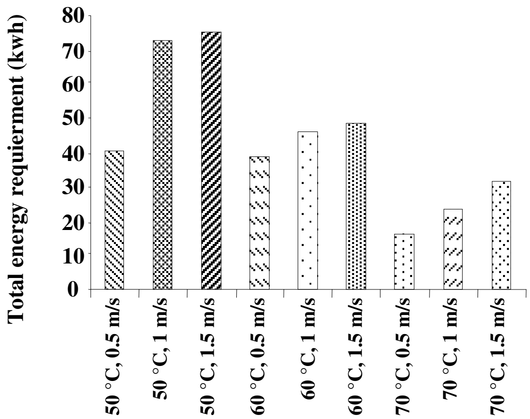


***Fig. 2: Total energy consumption at different levels of air temperatures and air velocities for thin-layer drying of russian olive.***

range of 110 to 127 kJ/mol [12]. Surface and chemical absorptions are the two forms of water existence in fruits because most of the russian olive fruits moisture is in the chemical absorption form, so high energy is needed to exhaust water and undesirable change in chemical properties is negligible if proper dryer is used for drying russian olive fruits.

### *Calculation of total energy consumption*

During drying step, total required energy by dryer in each application cycle can be determined using Eq. (8). Total energy consumption in different temperatures has been shown in Fig. 2.

## CONCLUSIONS

Drying behavior of russian olive fruit as thin layer in a hot air laboratory drier in 50, 60 and 70°C and 0.5, 1 and 1.5 m/s velocities were investigated in this research paper. The results are listed briefly:

1. It was demonstrated that drying of russian olive fruit only occurs in a course with falling rate.

2. Increased air temperature in constant air velocity increased the $D_{eff}$ value, but increased air velocity in constant temperature decreased $D_{eff}$ value. Effective moisture diffusivity ($D_{eff}$) calculated for russian olive fruit in different temperatures and air velocities ranged between $5.56\times10^{-11}$ and $3.18\times10^{-10}$ ($m^2/s$).

3. The resulting values for activation energy varied from a minimum of 48.18 kJ/mol in 1.5 m/s air velocity up to maximum of 63.83 kJ/mol in 0.5 m/s air velocity, and increased air velocity decreased activation energy.

4. Increased temperature and air velocity respectively increase and decrease total energy consumption required. Considering the results, the values obtained for total energy required for thin layer drying of russian olive fruit were in ranges of 75.04-16.34 kWh.

*Received : Feb. 8, 2010 ; Accepted : Apr. 25, 2010*

## REFERENCES

[1] Sahin A.Z., Dincer I., Graphical Determination of Drying Process and Moisture Transfer Parameters for Solids Drying, *International Journal of Heat and Mass Transfer,* **45** (16), p. 3267 (2002).

[2] Aghbashlo M., Kianmehr M., Samimi-Akhijahani H., Influence of Drying Conditions on the Effective Moisture Diffusivity, Energy of Activation and Energy Consumption During the Thin-Layer Drying of Berberis Fruit (Berberidaceae), *Energy Conversion and Management*, **49**, p. 2865 (2008).

[3] Doymaz I., Pala M., The Thin-Layer Drying Characteristics of Corn, *Journal of Food Engineering*, **60**, p. 125 (2003).

[4] Goyal R.K., Kingsly A.R.P., Manikantan M.R, Ilyas S.M., Mathematical Modeling of Thin Layer Drying Kinetics of Plum in a Tunnel Dryer, *Journal of Food Engineering*, **79**, p. 176 (2007).

[5] Simal S., Femenia A., Garau M. C., Rossello C., Use of Exponential, Page's and Diffusional Models to Simulate the Drying Kinetics of Kiwi Fruit, *Journal of Food Engineering*, **66**, p. 323 (2005).

[6] Karathanos V.T., Villalobas G., Saravacos, G.D. Comparison of Two Methods of Estimation of the Effective Diffusivity from Drying Data, *Journal of Food Science*, **55**(1), p. 218 (1990).

[7] Srinivasa Rao P., Satish B., Goswami T. K., Modelling and Optimization of Drying Variables in Thin Layer Drying of Parboiled Paddy, *Journal of Food Engineering,* **78,** p. 480 (2007).

[8] Vega A., Uribe E., Lemus R., Miranda M., Hot-air Drying Characteristics of Aloe Vera (Aloe Barbadensis Miller) and Influence of Temperature on Kinetic Parameter, *LWT*, **40**, p. 1698 (2007).

[9] Babalis S.J., Belessiotis V.G., Influence of Drying Conditions on the Drying Constants and Moisture Diffusivity During the Thin-Layer Drying of Figs, *Journal of Food Engineering*, **65**, p. 449 (2004).

[10] Barrozo M.A.S., Souza A.M., Costa S.M., Murata V.V., Simultaneous Heat and Mass Transfer Between Air and Soybean Seeds in a Concurrent Moving Bed, *International Journal of Food Science and Technology*, **36** (4), p. 393 (2001).

[11] Koyuncu T., Pinar Y., Lule F., Convective Drying Characteristics of Azarole red (Crataegus monogyna Jacq.) and Yellow (Crataegus Aronia Bosc.) Fruits, *Journal of Food Engineering*, **78**, p. 1471 (2007).

[12] Babalis S.J., Belessiotis, V.G., Influence of Drying Conditions on the Drying Constants and Moisture Diffusivity During the Thin-Layer Drying of Figs, *Journal of Food Engineering*, **65**, p. 449 (2004).

[13] Zogzas N.P., Maroulis Z.B., Marinos-Kouris D., Moisture Diffusivity Data Compilation in Foodstuffs, *Drying Technology*, **14**: p. 2225 (1996).