**Journal of Thermal Engineering** *http://eds.yildiz.edu.tr/journal-of-thermal-ngineering/Articles*
**Yildiz Technical University Press, Istanbul, Turkey** *Manuscript Received October 13, 2014; Accepted October 30, 2014*
**Vol. 1, No. 4, pp. 236-244, October, 2015.**

*This paper was recommended for publication in revised form by Assigned Editor Sergio Nardini*

# INFLUENCE OF DRYING CONDITIONS AND MATHEMATICAL MODELS ON THE DRYING CURVES AND THE MOISTURE DIFFUSIVITY OF MUSHROOMS

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*Keywords: Drying curves, drying of mushrooms, drying methods*
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## ABSTRACT

In the present research, experimental data from several studies about drying behavior of mushrooms have been selected and used to compare different drying methods and different mathematical thin layer drying models to simulate mushroom drying rates. The white button (Agaricus Bisporus), the oyster (Pleurotus Ostreatus) and the milky mushroom slices have been considered for drying in different dryers with different slice thicknesses, drying air temperatures (45 °C to 90 °C) and drying air velocities (0.2 m/s to 5 m/s). The entire drying process has taken place in the falling rate period, assuming that internal mass transfer occurred by diffusion in mushroom slices. Additionally, the effective moisture diffusivity was calculated by using the method of slopes. The diffusivity increases with drying air temperature. The study shows that the drying air temperature and the drying air velocity have an effect on the moisture removal from mushrooms and also on the drying time. Mathematical models have been proved to be useful for design and analysis of heat and mass transfer during drying processes. All the drying models considered in this study could adequately represent the thin layer drying behavior of mushrooms. Furthermore, as it is obvious, any type of mushrooms has its own most suitable model.

## 1. INTRODUCTION

Mushrooms are of commercial importance due to their nutritional and medicinal value (Çelen,et al., 2010). White button mushroom (Agaricus bisporus), oyster mushroom (Pleurotus ostreatus) and milky mushroom are the major species of mushrooms grown in Greece (Tulek, 2011).

Mushrooms contain moisture in the range of 6.75 to 18.9 kg/kg dry basis (87% to 95% wet basis) (Arora,et al., 2003). Due to their high moisture content they cannot be stored for more than 24 hours at ambient conditions. Hence they need to be preserved by some method.

Drying is the most commonly used method for long term preservation of agricultural products including mushrooms, because it extends the food self-life, preserving all of their features (Tulek, 2011; Pandey, et al., 2000). Drying can be defined as the process of moisture removal due to simultaneous heat and mass transfer between the product and the drying air by means of evaporation. The major objective of drying process of foods is the reduction of the moisture content until reaching the desired level, which allows safe storage over an extended period (Walde, et al., 2006). Several drying techniques such as sun/solar drying, hot air drying in conventional tray/cabinet dryers, fluidized bed drying, microwave drying, freeze drying and osmotic drying have been used successfully for mushrooms. Each technique has advantages and drawbacks but hot air drying is the most widely known technique (Gothandapani, Pavathi and Kennedy, 1997).

There are three different drying periods:

I. Preheating period (drying rate is almost zero). When the product is exposed to hot air, initially, only a very slight change in water content is observed. This happens because all the heat provided in the drying air is used to heat up the solid to the drying temperature.

II. Constant rate period (drying rate is constant). When the temperature of the solid has reached the drying temperature value, water starts to evaporate from the surface of the product. During this period, the rate of drying is established by a balance of the heat requirements for surface moisture evaporation. It should be emphasized, that the amount of moisture removed, as well as the temperature of the solid remain constant.

III. Falling rate period.
Drying of most food materials takes place in the last period, the falling rate period, where the surface temperature starts increasing. This increase continues as the drying process progresses; the absence of constant rate period should be

noted. The drying rate approximates to zero at a moisture ratio called equilibrium moisture content, $M_{eq}$ , which is the smallest amount of moisture that can remain in the solid at the given conditions of the process of drying (Xanthopoulos, Lambrinos and Manolopoulou, 2007). Simulation models are fundamental for the design, construction and operation of drying systems. Thin layer drying equations contribute to the understanding of the drying characteristics of agricultural materials (Toğrul and Pehlivan, 2004). Many researchers have developed thin layer equations to estimate drying times of several agricultural products and to generalize drying curves. Some examples are: apricot (Toğrul and Pehlivan, 2004; Toğrul and Pehlivan, 2003), grape (Doymaz and Pala, 2002; Yaldiz, Ertekin and Uzun, 2001; Pangavhane, Sawhney and Sarsavadia, 1999), apple (Menges and Ertekin, 2006; Meisami and Rafiee, 2009), black tea (Panchariya, Popovic and Sharma, 2002; Temple and Van Boxtel, 1999), potato (Diamante and Munro, 1993), carrot (Doymaz, 2004), pistachio (Midilli and Kucuk, 2003), rough rice (Basunia and Abe, 2001; Agrawal and Singh, 1977), corn (Zhang and Litchfield, 1991), mulberry (Maskan and Cogus, 1998), hazelnuts (Özdemir and Devres, 1999), green pepper, stuffed pepper, pumpkin, green bean and onion (Yaldiz and Ertekin, 2001), eggplant (Ertekin and Yaldiz, 2004) and figs (Babalis, et al., 2006). Especially for mushrooms, numerous studies can be found in the literature related to their drying behavior (Çelen, et al., 2010; Tulek, 2011; Arora, et al., 2003; Pandey, et al., 2000; Walde, et al., 2006; Gothandapani, Parvathi and Kennedy, 1997; Xanthopoulos, Lambrinos and Manolopoulou, 2007; Kulshreshtha, et al., 2009; Pal and Chakraverty, 1997; Wakchaure, et al., 2010; Arumuganathan, et al., 2009).

This work brings related issues into a clearer focus with reference to (Tulek, 2011; Xanthopoulos, Lambrinos and Manolopoulou, 2007; Kulshreshtha, et al., 2009; Pal and Chakraverty, 1997; Wakchaure, et al., 2010). A study is carried out to compare the available bibliographic drying data with emphasis on the effect of air drying temperature and velocity, slice thicknesses and thin layer drying model on mushrooms drying curves. Computational drying curves for white button mushroom are also plotted by using the type of logarithmic model $MR = a \cdot \exp(-k \cdot t) + c$ and related regression analysis coefficients a, k, c.

Our article presents simulation results establishing guidance for the drying process of various species of mushrooms with parameters the air drying temperature, humidity and velocity, the slice thicknesses and the thin layer drying model. In addition, the influence of these parameters on the effective moisture diffusivity has been determined.

## 2. MATHEMATICAL MODELING

Thin layer drying models may be classified as theoretical, semi-theoretical and empirical ones. The first category considers simultaneous heat and mass transfer equations. The semi-theoretical models combine the theoretical equations with simplifications.

Finally, the empirical models describe drying curves for experiment conditions (Özdemir and Devres, 1999). As we have already mentioned, the internal moisture transfer principally occurs during the falling rate period of drying process; so it may be controlled by liquid diffusion mechanism which is described by the Fick's law (Panchariya, Popovic and Sharma, 2002):

$$\frac{\partial M}{\partial t} = D_{eff} \nabla^2 M \tag{1}$$

Where is the effective moisture diffusivity and $M$ the moisture content at any time % d.b.

Drying of many food products has been successfully predicted using Fick's law with slab geometry to calculate effective moisture diffusivity as follows (Tulek, 2011; Wakchaure, et al., 2010):

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

Where MR stands for $\frac{M-M_{eq}}{M_0-M_{eq}}$ the dimensionless form of moisture content, L the thickness of the slab (m), n a positive integer and t the drying time in (s). Practically, only the first term of Eq. 2 is used giving us the form:

$$MR = \frac{8}{\pi^2} exp\left(-\frac{\pi^2 D_{eff} t}{4L^2}\right) \tag{3}$$

The natural logarithm in both sides of Eq. (3) yields the linear solution Eq. (4):

$$lnMR = ln\frac{8}{\pi^2} - ln\frac{\pi^2 D_{eff} t}{L^2} \tag{4}$$

The diffusion coefficient k is determined by the diagram of natural logarithm of $MR$ in relation to time t by using the slope of Eq. (4).

$$k = \frac{\pi^2 D_{eff} t}{L^2} \tag{5}$$

Below the most widely used semi-theoretical drying models are presented:

*Lewis model* for the drying of wheat has the general form (O' Callaghan, Menzies and Bailey, 1971):

$$MR = \exp(-k \cdot t) \tag{6}$$

Drying of peanut was reported by Henderson and Pabis as (Moss and Otten, 1989):

$$MR = a \cdot \exp(-k \cdot t) \tag{7}$$

The *logarithmic model* which is used for fruits (Toğrul and Pehlivan, 2004), mushrooms (Xanthopoulos, Lambrinos and Manolopoulou, 2007) and sultana grapes (Yaldiz, Ertekin and Uzun, 2001):

$$MR = a \cdot \exp(-k \cdot t) + c \tag{8}$$

with a, k,c constants depended on the model.

The *two-term exponential* model was presented by Sharaf-Eldeen et al. for ear corn drying (Sharaf-Eldeen, Blaisdell and Hamdy, 1980) and figs (Babalis, et al., 2006) as follows:

$$MR = a \cdot \exp(-k_0 \cdot t) + b \cdot \exp(-k_1 \cdot t) \tag{9}$$

based on the classical solution of the liquid diffusion equation.

The *Page* model is a modification of Lewis model:

$$MR = \exp(-k \cdot t^n) \quad (10)$$

It has produced good fits in drying of rough rice (Basunia and Abe, 2001; Wang and Singh, 1978) with k and n parameters depended on drying air temperature and dew point.

The *modified Page* equation for drying of sweet potato (Diamante and Munro, 1993) is:

$$MR = \alpha \cdot [\exp(-k \cdot t^n)] \quad (11)$$

*Midilli et al.* model was used to describe the drying of eggplant (Ertekin and Yaldiz, 2004) and oyster mushrooms (Tulek, 2011).

$$MR = a \cdot \exp(-k \cdot t^n) + b \cdot t \quad (12)$$

In literature, two empirical models have been found as applicable:

The model proposed by Wang and Singh (Wang and Singh, 1978):

$$MR = 1 + \alpha \cdot t + b \cdot t^2$$
(13)

The *Thompson* model (Thompson, Peart and Foster, 1968):

$$t = a \cdot lnMR + b \cdot (lnMR)^2 \quad (14)$$

The thin layer drying equations on Table 1 consist a useful literature survey in mathematical modeling and may be tested to select the best model for drying curves of mushrooms (Meisami and Rafiee, 2009). The mushrooms drying curves obtained were processed to find the most suitable thin-layer drying model by regression analysis.
The correlation coefficient $(r)$ was one of the primary criteria for selecting the best equation expressing drying curves for mushrooms. Furthermore the statistical parameters: reduced chisquare $(\chi^2)$ , mean bias error (MBE) and root mean square error (RMSE) were used to clarify the result. These parameters are calculated by:

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp,i} - MR_{pre,i})^2}{N-n} \quad (15)$$

$$MBE = \frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i}) \quad (16)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(MR_{pre,i} - MR_{exp,i})^2\right]^{1/2} \quad (17)$$

$MR_{exp,i}$ is the experimental moisture ratio found in any measurement and $MR_{pre,i}$ is the moisture ratio predicted for the measurement under consideration. N and n are the number of observations and the number of constants respectively (Pangavhane, Sawhney and Sarsavadia, 1999).

**TABLE 1 MATHEMATICAL MODELS FOR THE DRYING CURVES.**

| Model equation | Name |
|---|---|
| $MR = \exp(-k \cdot t)$ (O' Callaghan et al., 1971) | **Lewis** |
| $MR = a \cdot \exp(-k \cdot t)$ (Moss et al., 1989) | **Henderson and Pabis** |
| $MR = a \cdot \exp(-k \cdot t) + c$ (Xanthopoulos et al., 2007 and Yaldiz et al., 2001) | **Logarithmic** |
| $MR = a \cdot \exp(-k_0 \cdot t) + b \cdot \exp(-k_1 \cdot t)$ (Babalis et al., 2006 and Sharaf-Eldeen et al., 1980) | **Two-term exponential** |
| $MR = \exp(-k \cdot t^n)$ (Basunia and Abe, 2001) | **Page** |
| $(MR = \alpha \cdot [\exp(-k \cdot t^n)]$ (Diamante and Munro, 1993) | **Modified Page Equation** |
| $MR = 1 + \alpha \cdot t + b \cdot t^2$ (Wang and Singh, 1978) | **Wang and Singh** |
| $MR = a \cdot \exp(-k \cdot t^n) + b \cdot t$ (Tulek, 2011 and Ertekin and Yaldiz, 2004) | **Midilli et al**. |
| $MR = a \cdot \exp(-k \cdot t) + (1-a) \cdot \exp(-k \cdot b \cdot t)$ (Çelen et al., 2010) | **Diffusion approach** |
| $MR = a \cdot \exp(-k \cdot t) + b \cdot \exp(-g \cdot t) + c \cdot \exp(-h \cdot t)$ (Thompson et al., 1968) | **Modified Henderson and Pabis** |
| $MR = a \cdot \exp(-k \cdot t) + (1-a) \cdot \exp(-g \cdot t)$ (Verma et al., 1985) | **Verma et al**. |

## 3. LITERATURE DRYING CURVES

Three species of mushrooms and their drying curves from different studies have been selected to be examined in our article.
Each researcher, based on regression analysis, has proposed the most convenient thin-layer drying model depending on drying conditions and results from analysis. Using these experimental data of literature studies and fitting them to the proposed model we have constructed the necessary drying curves (moisture content versus drying time). Thus, the following figures show the differences among the drying curves under different air velocities and temperatures, slice thicknesses and drying method.

### *3.1 Oyster mushrooms*

- Pal and Chakraverty in their experimental study *"Thin Layer Convection Drying of Mushrooms"* [29] have developed the following equations by regression analysis for untreated oyster pleurotus mushrooms to correlate the equilibrium moisture content $(M_{eq})$ with the relative humidity at a particular temperature.

$$1 - RH = exp\left(-2.072 \cdot TM_{eq}{}^{1.654}\right) \quad (18)$$

$$MR = 0.874 \cdot exp(-k \cdot t) \quad (19)$$

$$k = 8.969 \cdot 10^{-3} exp(0.0195 \cdot t) \quad (20)$$

- Tulek in his study *"Drying Kinetics of Oyster Mushroom (Pleurotus ostreatus) in a convective Hot Air Dryer"*

(Tulek, 2011) presented drying kinetics of oyster mushrooms using a cabinet-type convective dryer. The experimental data were fitted to different thin-layer drying models. Among all the models, as nonlinear regression analysis was performed, the model of *Midilli et al.* was found to have the best fit.

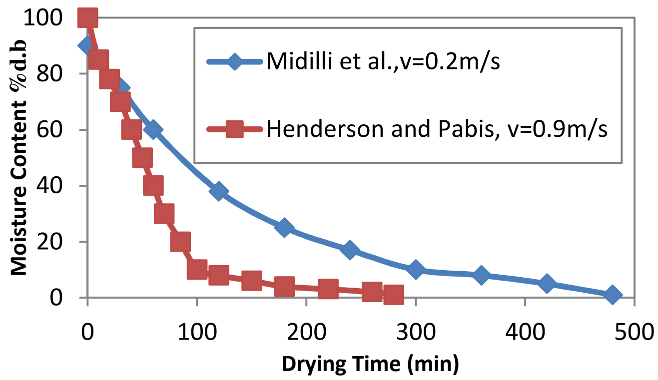



**FIGURE 1 EFFECT OF AIR VELOCITY ON DRYING TIME OF OYSTER MUSHROOM UNDER DIFFERENT AIR VELOCITIES AT THE SAME AIR TEMPERATURE 50 °C.**

In both studies, the drying process occurred in a convective hot air dryer, but different simulation models were used; apparently there are differences at drying times.

### *3.2 Button mushrooms*

- Wakchaure et al, in their study *"Kinetics of Thin layer drying of button mushroom"* [30] presented drying kinetics of white button mushroom in a fluidized bed dryer. The logarithmic model fitted best to experimental data after a regression analysis.

- Xanthopoulos et al, in *"Evaluation of thin-layer models for mushroom (Agaricus bisporus) drying"* [7] simulated convective drying of button mushroom by using the logarithmic model in a hot air cabinet dryer.

In both studies the logarithmic model has been used and the drying has occurred at the same air drying velocity. In Figure 3, the two drying curves are almost coincided, although the experiments have been carried out at different kind of dryers and at different drying air temperatures, indicating that fluidized bed dryer requires much less drying time to complete the drying process than hot air cabinet convective dryer.

### *3.3 Milky mushrooms*

Kulshreshtha, A. Singh et al. in *"Effect of drying conditions on mushroom quality"* [28] analyzed the drying characteristics and quality of the dried milky mushrooms in a fluidized bed dryer by using the exponential model: $MR = a \cdot \exp(-k \cdot t)$

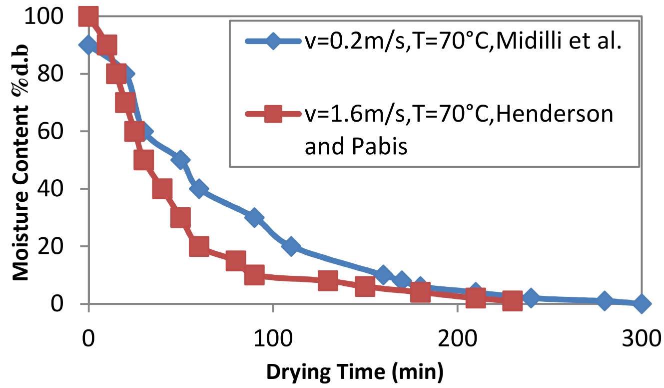



**FIGURE 2 EFFECT OF AIR TEMPERATURE AND AIR VELOCITY ON DRYING TIME OF OYSTER MUSHROOM.**

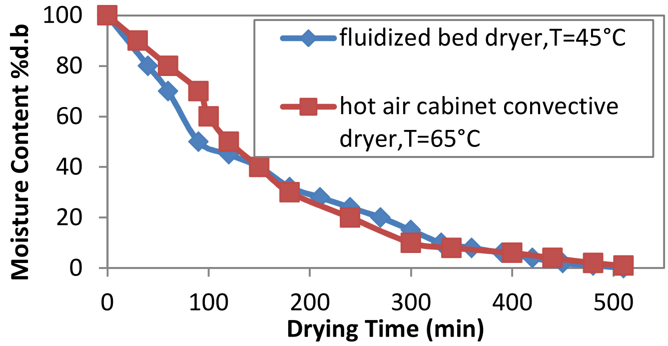



**FIGURE 3 VARIATION IN MOISTURE RATIO OF BUTTON MUSHROOM WITH DRYING TIME AT AIR VELOCITY 2.5 m/s.**

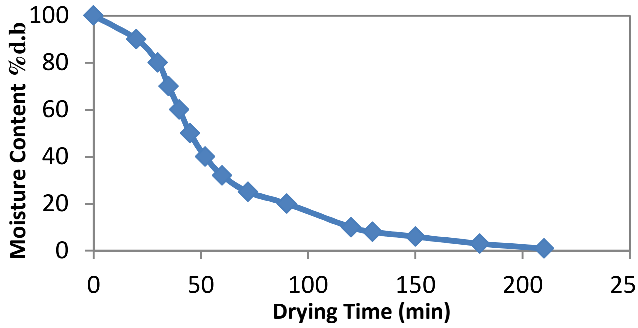



**FIGURE 4 VARIATION IN MOISTURE RATIO OF MILKY MUSHROOM WITH DRYING TIME AT AIR VELOCITY 2.13 m/s AND AIR TEMPERATURE 90 °C IN MUSHROOM SLICES 5-8 mm.**

## 4. DRYING CURVES MODELING

An attempt has been made to build computational drying curves for white button mushroom by using the *logarithmic model* $MR = a \cdot \exp(-k \cdot t) + c$. The mushrooms initial water content was considered equal to 91.92 % w.b., the final water content about 10 % w.b, the absolute humidity of drying air $10 g/m^3$ and the slice thickness 10 mm (Xanthopoulos, Lambrinos and Manolopoulou, 2007).

The absolute humidity can be calculated using (21):

$$A = C \cdot P_w / T \qquad (21)$$

$C$ = Constant 2.16679 gK/J
$P_w$ = Vapor pressure in Pa
$T$ = Temperature in K

The following formula gives the water vapor saturation pressure:

$$P_{ws} = B \cdot 10^{\left(\frac{m \cdot T}{T+T_n}\right)} \qquad (22)$$

$B$ , $m$ , $T_n$ = constants
$T$ = Temperature (° C)

Relative humidity is defined as the ratio of the water vapor pressure to the saturation water vapor pressure at the gas temperature (Eq. 23):

$$RH = P_w / P_{ws} \cdot 100\% \qquad (23)$$

Multiple regression analysis has been carried out to calculate model constant $k$ and $a, c$ coefficients described by Eqs. (24) - (26).

$$a = 1.09468 - 0.00276495 \cdot P_w \qquad (24)$$

$$k = -0.00901177 + 0.0138167V + 0.0152371 \cdot P_w \qquad (25)$$

$$c = -0.00936895 - \frac{0.870188}{P_w} \qquad (26)$$

**TABLE 2 REGRESSION ANALYSIS COEFFICIENTS FOR LOGARITHMIC MODEL = $a\,\exp(-k \cdot t) + c$ .**

| T | V | Coefficients $(a, k, c)$ |
|---|---|---|
| 50 | 1 | $a = 1{,}053463,\ k = 0{,}231942\ ,\ c = -0{,}06774$ |
| 50 | 2 | $a = 1.053463,\ k = 0.245759\ ,\ c = -0.06774$ |
| 50 | 3 | $a = 1.053463\ ,k = 0.259575\ , c = -0.06774$ |
| 50 | 5 | $a = 1.053463\ ,k = 0.287209\ ,\ c = -0.06774$ |
| 60 | 1 | $a = 1{,}052187,\ k = 0{,}238974\ ,\ c = -0{,}06599$ |
| 60 | 2 | $a = 1.052187, k = 0.252791,\ c = -0.06599$ |
| 60 | 3 | $a = 1.052187, k = 0.266608,\ c = -0.06599$ |
| 60 | 5 | $a = 1.052187, k = 0.294241,\ c = -0.06599$ |
| 65 | 1 | $a = 1{,}051549,\ k = 0{,}24249\ ,\ c = -0{,}06515$ |
| 65 | 2 | $a = 1{,}051549,\ k = 0{,}256307\ , c = -0{,}06515$ |
| 65 | 3 | $a = 1{,}051549,\ k = 0{,}270124\ , c = -0{,}06515$ |
| 65 | 5 | $a = 1{,}051549,\ k = 0{,}297757\ , c = -0{,}06515$ |

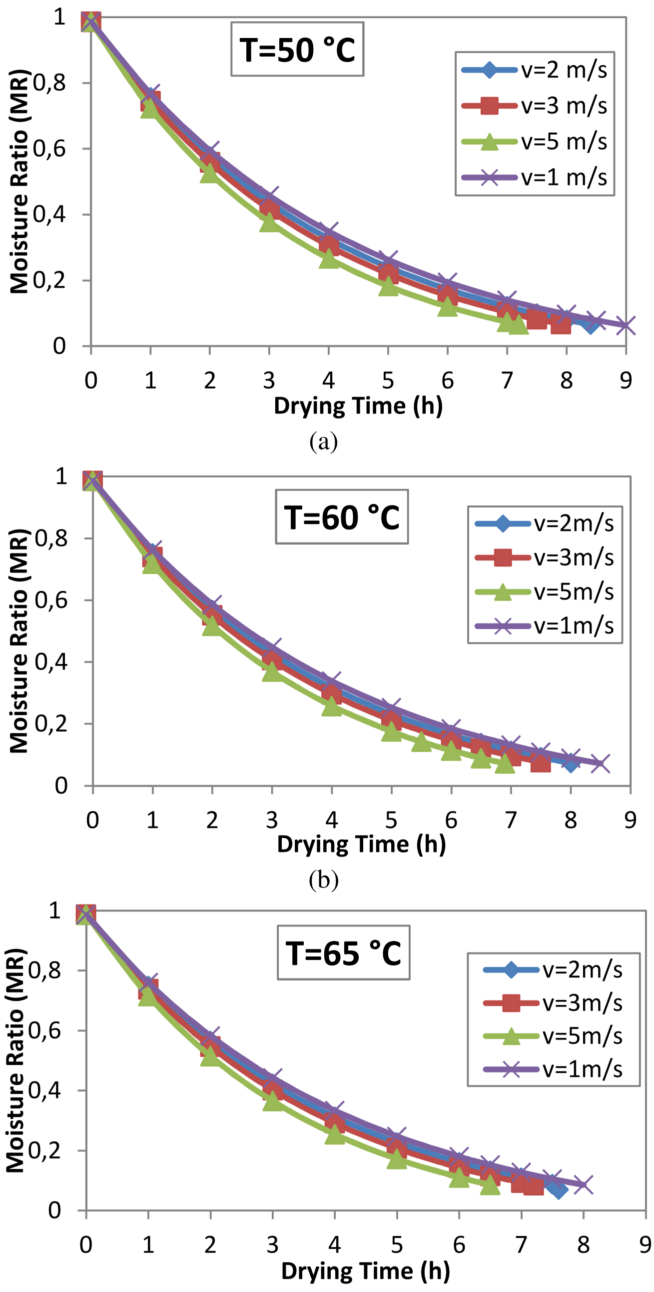



**FIGURE 5 DRYING CURVES FOR DIFFERENT AIR VELOCITIES AT 50, 60, 65 °C.**

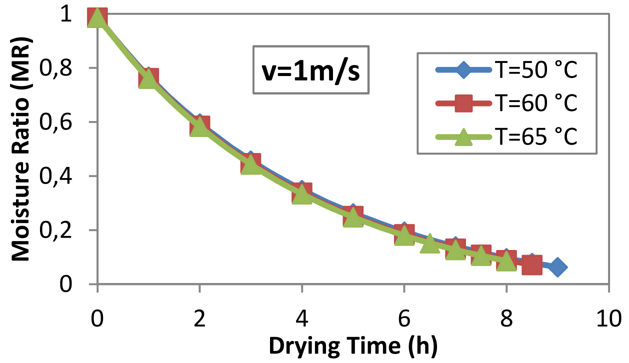
Figure 5 presents the drying curves based on logarithmic model for different air velocities at air temperatures 50, 60, 65 °C, respectively.

The total drying time under different air drying temperatures and different air drying velocities is presented in Table 3.

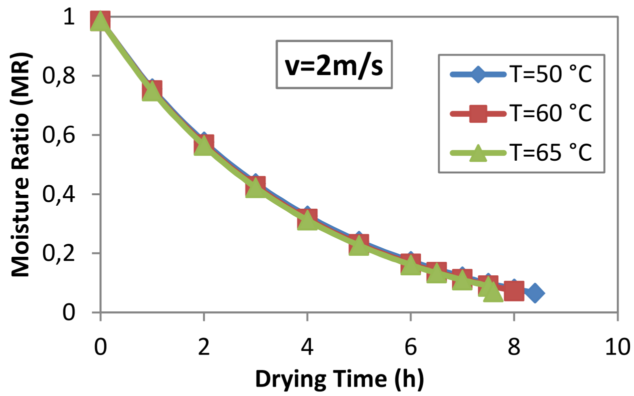
The moisture ratio decreases with increase in drying time and also as the air velocity increases the drying time becomes shorter. Drying air velocity plays an important role in the total drying time, but at higher temperature, 65 °C, there is no significant difference between air velocities 2 and 3 m/s. In addition, the moisture ratio reduces more rapidly at higher air temperatures, as we can observe in Figure 5. At 65 °C the drying curves for different air velocities are closely positioned.

Figure 6 illustrates the drying curves for different air temperatures at air velocities 1, 2, 3 and 5 m/s, respectively. It is obvious that air temperature has a significant effect on the drying time, as shorter drying times are achieved by higher air drying temperatures. However, high drying temperatures are not suggested due to harmful effects on food ingredients.

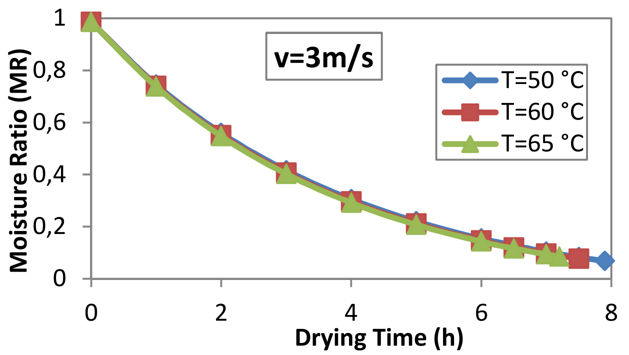
Figure 7 depicts the drying behavior of mushrooms at the minimum and the maximum drying parameters (velocity, temperature). The drying process requires less drying time to reach the desired level of the moisture content at high temperature and velocity.



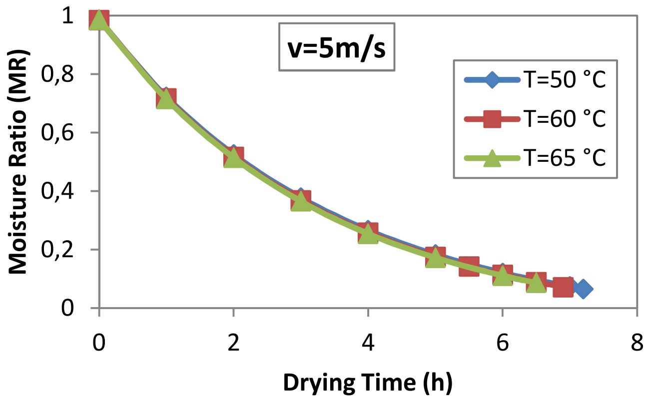

(a)




(b)




(c)




(d)

**FIGURE 6 DRYING CURVES FOR DIFFERENT AIR TEMPERATURES AT 1, 2, 3, 5 m/s.**

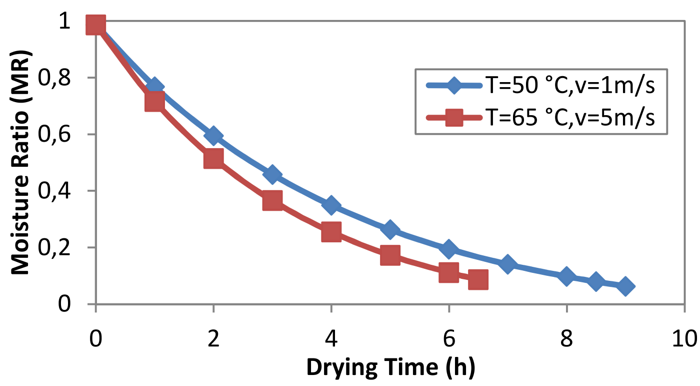



**FIGURE 7 DRYING CURVES FOR DIFFERENT AIR TEMPERATURES AND VELOCITIES.**

**TABLE 3 TOTAL DRYING TIME (h) UNDER DIFFERENT DRYING CONDITIONS.**

| Drying air temperature, T(°C) | Drying air velocity, V(m/s) | Drying time (h) |
|---|---|---|
| 50 | 1 | 9 |
| 60 | 1 | 8,5 |
| 65 | 1 | 8 |
| 50 | 2 | 8,4 |
| 60 | 2 | 8 |
| 65 | 2 | 7,6 |
| 50 | 3 | 7,9 |
| 60 | 3 | 7,5 |
| 65 | 3 | 7,2 |
| 50 | 5 | 7,2 |
| 60 | 5 | 6,9 |
| 65 | 5 | 6,5 |

The drying rates of white button mushrooms have been calculated by using (Eq. 27):

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{27}$$

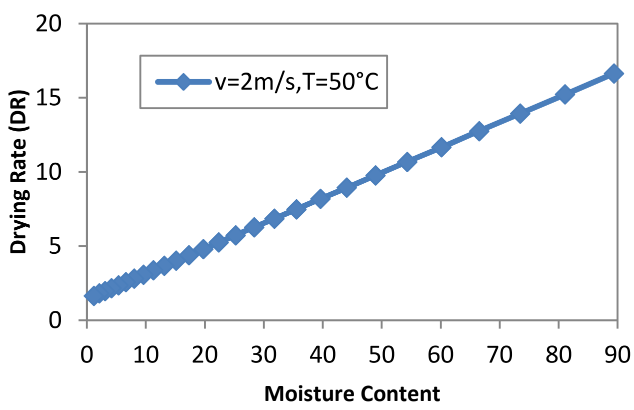



**FIGURE 8 DRYING RATE OF MUSHROOMS VERSUS MOISTURE CONTENT AT AIR VELOCITY 2 M/S AND AIR TEMPERATURE 50 °C.**

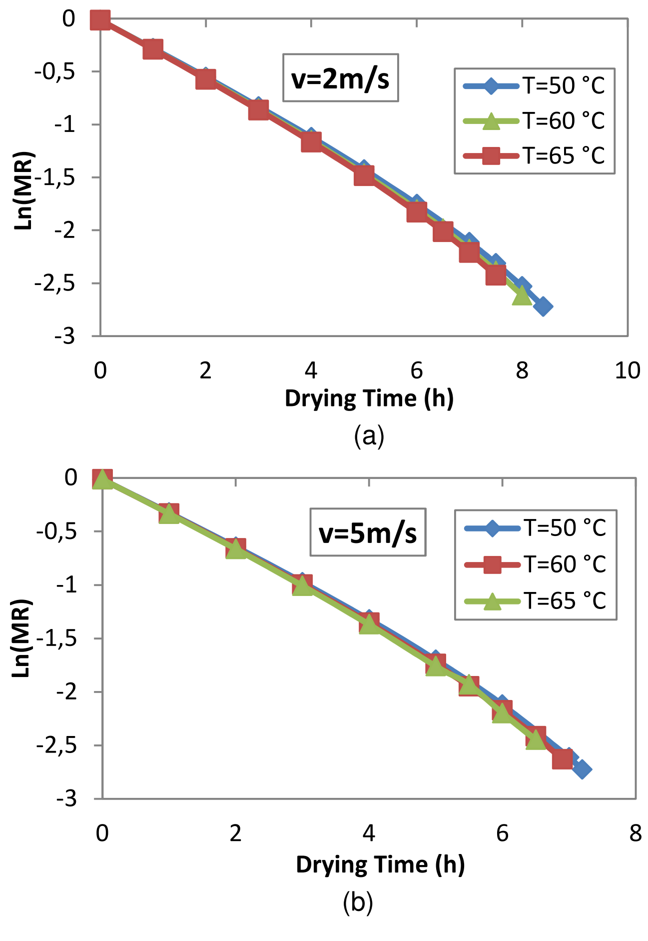



**FIGURE 9 LN (MR) VERSUS DRYING TIME (h) AT AIR VELOCITY 2 AND 5 m/s RESPECTIVELY.**

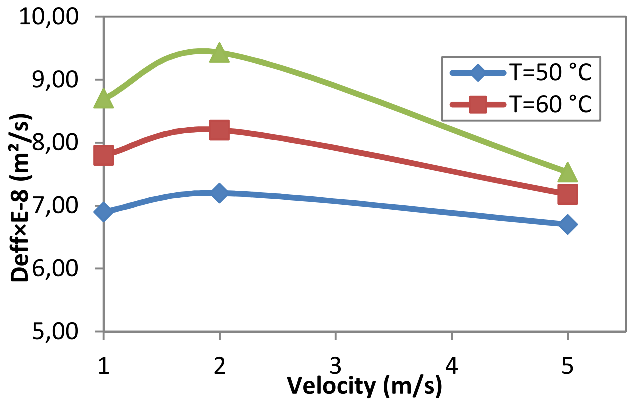



**FIGURE 10 $D_{eff}$ VERSUS AIR VELOCITY AT AIR TEMPERATURE 50, 60 AND 65 °C RESPECTIVELY.**

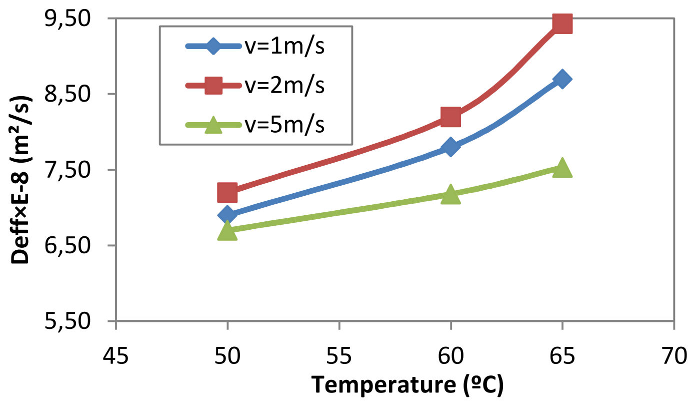



**FIGURE 11 $D_{eff}$ VERSUS AIR TEMPERATURE AT AIR VELOCITY 1, 2 AND 5 m/s RESPECTIVELY.**

The drying rate as a function of moisture content is given in Figure 8 for constant drying air temperature and velocity. The drying rate increases with the increase of the drying air temperature as well as with air velocity and decreases continuously with decreasing moisture content.

Figure 9 shows the Ln(MR) versus time (h) in constant value of velocity and different levels of temperatures. Plotted curves show that the increase in temperature increases the slope of straight line, in other words the effective moisture diffusivity.

In Figure10 the plot of the effective moisture diffusivity $D_{eff}$ versus air velocity at different levels of air temperature is illustrated. In addition Figure 11 presents the effective moisture diffusivity $D_{eff}$ versus air temperature at different levels of air velocity.

**TABLE 4 EFFECTIVE MOISTURE DIFFUSIVITY UNDER DIFFERENT DRYING CONDITIONS**

| $D_{eff}$ ($\times 10^{-8}$) | T (°C) | V (m/s) |
|---|---|---|
| 6,9 | 50 | 1 |
| 7,8 | 60 | 1 |
| 8,7 | 65 | 1 |
| 7,2 | 50 | 2 |
| 8,2 | 60 | 2 |
| 9,43 | 65 | 2 |
| 6,7 | 50 | 5 |
| 7,18 | 60 | 5 |
| 7,53 | 65 | 5 |

## 5. CONCLUSIONS

In the present research, experimental data from several studies about drying behavior of mushrooms have been selected and used to compare different drying methods and different mathematical thin-layer drying models to simulate mushroom drying rates. We produce some conclusions resulting from our study.

- Mathematical models have been proved to be very useful for design and analysis of heat and mass transfer during drying processes.
- The drying process has been simulated on the basis that it takes place in the falling rate period, with internal moisture diffusion in mushroom slices.
- An increase in air temperature reduces the drying time and increases the drying rate.
- The drying air temperature, the slice thickness and the drying air velocity have an effect on the

moisture removal from mushrooms and also on the drying time.

- The effective moisture diffusivity ranged up to 9,43 $\times 10^{-8}$ , with higher values at high drying air temperature.

## NOMENCLATURE

$M$ Moisture content at any time % d.b [g$H_2$O/g dry solid]
$M_{eq}$ Equilibrium moisture content % d.b [g$H_2$O/g dry solid]
$M_0$ Initial moisture content % d.b [g$H_2$O/g dry solid]
$MR$ Moisture ratio, dimensionless
$D_{eff}$ Effective moisture diffusivity $(m^2/s)$
$DR$ Drying rate [g$H_2$O/h]
$T$ Air temperature (°C)
$V$ Air velocity (m/s)
$RH$ Effective relative humidity
$L$ Slab thickness $(m)$
d.b Dry weight basis
w.b Wet weight basis
$a$,,,,$g$,$h$ Constants of models
$k, k_0, k_1$ Constants of models
$t$ Drying time $(s)$

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