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Mass transfer simulation of pistachio nuts using computational fluid dynamic (CFD) during fluid bed drying

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Abstract

The drying of food can extend the shelf life of food, reduce transportation and storage costs. Fick's second law is commonly used to evaluate the mass data in the drying process in a standard way and is based on many assumptions. Understanding the meaning of mass transfer in products can improve the drying process and product quality. Computational fluid dynamics (CFD) models fluid flow situations utilizing powerful computer and applied mathematics in order to predict mass transfer in industrial processes. The aim of this research was numerical study of the drying behavior of pistachio nut using CFD method and evaluating the numerical results in the bed condition of fluid, semi fluid and fix bed as well as air temperatures of 90, 75, 60 and 45°C. During drying using computational fluid dynamic and the Fluent CFD code, the external flow and temperature fields around the cylindrical object (7.5× 10 millimeter) will be predicted in the numerical analysis. A laboratory fluid bed dryer was used for drying experiments. The main parts of the dryer are forward radial fan, drying chamber, electrical heater, inverter, temperature controller. The dryer attachment tools are input and output temperature sensors, anemometer and computer. The numerical part was verified and juxtaposed with the experimental data. The numerical solution result at 60, 75 and 90°C were so close to experimental results except for air temperature of 45°C. Mean absolute error in fix bed, at 60, 75 and 90°C were 0.2123, 0.1257 and 0.0337 which were lower than 45°C temperature and R^2 values for these temperatures were 0.9903, 0.9705 and 0.9807, respectively. As the temperature decreased, the values of E_{abs} and X^2 increased in all bed conditions. The average value of R^2 for all applied bed conditions was 0.9850. This value showed high correlation between experimental and numerical results.

Keywords: Semi fluid bed drying, Fluid bed drying, Fix bed drying, Experimental results, Modeling, Numerical solution.

Introduction

Nuts are rich in nutrients, fiber, protein, phytosterols and antioxidants (Fantino *et al.*, 2020). The edible seeds harvested from the pistachio tree are pistachios. Among the different species of the genus Pistachio, pistachio (Pistacia Vera) is the only known commercially edible nut. Its main cultivation areas include the Mediterranean region. It is not affected by drought and salinity (Noguera Artiaga *et al.*, 2020). For consumers to consider it an edible nut, the fruit of the Pistacia Vera variety must be large enough (Shokraii and Esen, 1998). Pistachios are used as ingredients

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in the confectionery, snacks, ice cream and pastry industries. Pistachios were originally grown in the United States, the Middle East, and especially in Iran (Kouchakzadeh and Shafeei, 2010).The quality of pistachios depends on proper harvesting and post-harvest processing. Drying is very important in the marketing of the final product. The optimal moisture content for storing pistachios is 7%-9% (w.b.) (USDA Std., 1990).

Studies have shown that drying methods and different changes are key factors in determining the quality of dried food products (Naidu *et al*., 2016). In other words, the deterioration and damage of certain characteristics, including their color, structure, aromatic compounds and nutrients, may lead to a decline in product quality (Izli and Isik, 2015). The most common method used to dry pistachios is the hot air drying method. Fluidized bed drying is a profitable drying method for pistachios. When passing through the pistachio bed, a fixed bed is formed when a low-velocity airflow flows upward. When the highest air velocity is applied, the whole pistachio starts to float, which is called minimum fluidization (AmiriChayjan *et al*., 2012). The semi-fluidized bed condition occurs at the maximum static pressure drop. When the inflow airflow increases, a bubbling fluidized bed is created, causing the mixing of pistachios (Kunii and Levenspiel, 1991; Kaveh and AmiriChayjan, 2015).

In the drying mechanism of a system, the phenomenon of simultaneous transmission (energy, momentum and mass) will occur. Drying can extend the shelf life of food, reduce transportation and storage costs, and develop new consumption methods (Lindsay Rojas and Augusto, 2018). Fick's second law (Fick, 1855) is commonly used to evaluate the mass data process in the drying process in a standard way and is based on many assumptions (Lindsay Rojas and Augusto, 2018). Understanding the meaning of mass transfer in products can improve the drying process and product quality. External factors include temperature, relative air humidity, and air velocity. However, internal factors include factors such as the density and permeability of the material, as well as thermophysical properties (Kaya *et al*., 2006).

Compared with experimental research, numerical simulation is a common method applied for drying process analysis due to lower cost and time (Kaya *et al.*, 2006). Numerical methods for describing food drying mechanisms can provide useful information to help understand temperature and humidity requirements more clearly (Haghighi *et al.*, 1990; Rafiee and Kashaninejad, 2005; Rafiee *et al.*, 2005). In computational fluid dynamics (CFD), numerical methods are often used to approximate the equation that governs fluid dynamics in the target fluid region. It uses numerical methods to predict chemical reactions, mass transfer, heat transfer, fluid flow, and related phenomena by solving mathematical equations that control these processes (Puma Chandra, 2017). CFD technology can also help solve complex transmission phenomena and make drying process more cost and time-effective (Kaya *et al*., 2006; Kaya *et al*., 2008a).

Many researchers studied numerical modeling of mass transfer for a wide variety of agricultural and food products. These include hazelnut (Topuz *et al*., 2004), garlic (AbbasiSouraki and Mowla, 2008), kiwi fruit (kaya *et al*., 2008b), apple slices (Mabrouk *et al*., 2012), soybean meal (Silva et al., 2012), shrinkable products such as lentils (Carmo and Lima, 2004), fruits and vegetables (Kowalski and Mierzwa, 2013). However, no studies have specifically examined numerical modeling for pistachio during convective drying of fluid, semi fluid and fix bed.

Researchers around the world have studied the drying of various products using CFD simulation (Malekjani and Jafari, 2018; Demissie *et al.,* 2019).Studies have also been performed on the simulation of pistachio nuts drying by finite element (Rafiee *et al*., 2007; Rafiee *et al*., 2009). No study has been done on simulating the drying of pistachio nuts using CDF simulation. The aim of this research was numerical study of the drying behavior of pistachio nut using CFD method and e evaluating the numerical results in the bed condition of fluid, semi fluid and fix bed as well as air temperatures of 90, 75, 60 and 45°C. During drying process using computational fluid dynamic and the Fluent CFD code, the external flow and temperature fields around the cylindrical object (7.5× 10 millimeter) were predicted in the numerical analysis. The numerical part was verified and the experimental data relevant to the method of thin-layer drying were juxtaposed.

Materials and method

Experimental setup and procedure

Ohadi cultivar of pistachio was selected for conducting the study. The initial moisture content of the samples collected was 50.3±0.2% (d.b.), at 130°C and 24 h using the oven process (AOAC, 1995).

To indicate bed conditions (air velocities) in tests, the increasing air velocity against pressure drop were recorded and then plotted as Fig. 1. An estimating and recording unit for differential digital manometer and a vane type advanced anemometer (StandardST-8897) was utilized to get the fluidization curve. To accomplish the net air pressure drop across the pistachio bed, from the start, total static pressure drop because of pistachio column and bed plate was estimated, and afterward was deducted from air pressure drop because of empty chamber.

The greatest value of static pressure drop against a specific air velocity in fluidization curve is characterized as least fluidization point or semi fluidized bed (Kunii and Levenspiel, 1991). Fluidization tests were acted in three recreates for thin layer drying of pistachio tests with around 100 g load. In the wake of getting the semi fluid bed point (air velocity about 2.6 ms^{-1}), two focuses with air velocities of 1.6 ms^{-1} and 4.1 ms^{-1} were chosen as fix and fluid bed conditions, respectively.

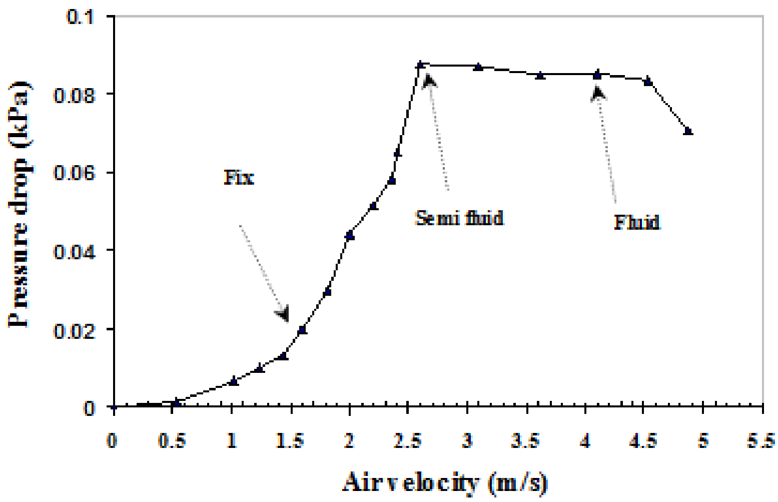


Fig. 1. Pistachio nuts' fluidization curve

The drying process was ended, when the moisture content of the samples reached an average of about 9 percent (d.b.) (Amirichayjan *et al.*, 2012). The air relative humidity and air temperature were 21%-33% and 28-32°C, respectively. A laboratory fluid bed dryer was used for drying experiments. This apparatus was fabricated in agricultural machinery engineering of Bu-Ali Sina University (Figure 2). The main parts of the dryer are forward radial fan, drying chamber, electrical heater, inverter, and temperature controller. The dryer attachments tools are input and output temperature sensors, anemometer and computer. 45, 60, 75 and 90°C air temperature levels and fix, semi fluid and fluid bed conditions were used as input variables in the experiments. Each experiment was replicated three times (Amirichayjan *et al.*, 2012).

In each drying test, around 100 g pistachio sample was stacked in drying chamber. Pistachio nuts were extended in a thin layer form in the drying chamber and the test was begun. The ambient air temperature, input and output air temperature, air velocity, air relative humidity and sample weight were consistently checked and recorded during drying process. A digital balance (AND GF-6000) with 0.01 g accuracy was used to online weighing the nuts during the drying experiments. Moisture content of the pistachio samples in each drying run was calculated based on the initial and final moisture content of the samples and initial samples mass.

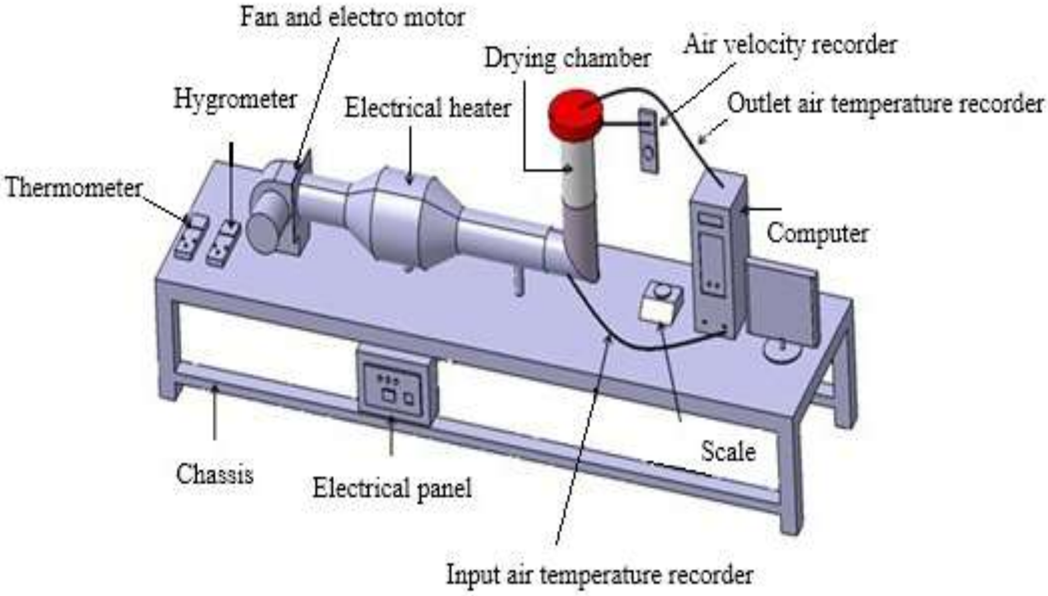


Fig. 2. Laboratory Scale Schematic Diagram of the Fluidized Bed Dryer (Golpour et al, 2021)

Modeling

Partial differential equations that govern the forced convection motion of a fluid bed drying in a two-dimensional geometry are included in the energy, mass and momentum conservation equations. In some cases that are not complex, physical and thermal properties are considered constant. For a two-dimensional cylindrical problem, considering the flow incompressible, the Navier-Stokes equations are described in their most general form:

The equation of mass conservation (i.e. continuity) is (Norton and Sun, 2006):

$$\frac{1}{r}\frac{\partial}{\partial r}(ru_r)+\frac{\partial u_z}{\partial z}=0 \qquad (1)$$

where the radial coordinate is r and the axial coordinate is z.

The momentum equations are (Norton and Sun, 2007):

$$\rho(u_r\frac{\partial u_r}{\partial r}+u_z\frac{\partial u_r}{\partial r})=-\frac{\partial p}{\partial r}+\mu\left[\frac{1}{r}(\frac{\partial}{\partial r}(r\frac{\partial u_r}{\partial r})+\frac{\partial^2 u_r}{\partial z^2}-\frac{u_r}{r^2}\right] \qquad (2)$$

$$\rho(u_r\frac{\partial u_r}{\partial r}+u_z\frac{\partial u_z}{\partial r})=-\frac{\partial p}{\partial r}+\mu\left[\frac{1}{r}(\frac{\partial}{\partial r}(r\frac{\partial u_z}{\partial r})+\frac{\partial^2 u_z}{\partial z^2}\right] \qquad (3)$$

where ρ represents density (kg/m^3), μ denotes the dynamic viscosity (Pa.s), p is the pressure (Pa) and u shows the velocity in x-direction (m/s).

The energy equation is (Ferziger and Peric, 20002):

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial r}+v\frac{\partial T}{\partial z}=\alpha\left[\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial T}{\partial r})+\frac{\partial}{\partial z}(\frac{\partial T}{\partial z})\right] \quad (5)$$

which T shows the air temperature (K), t is the drying time (h), v represents the velocity in y-direction (m/s) and α denotes the thermal diffusivity (m^2/s).

The Fluent V6.3.26 CFD package based on the finite volume method has been used for transforming and solving these equations. The boundary conditions assumed are as follows:

1) For velocity, no-slip conditions
2) The constant surface temperature of the drying material.

The following governing equations related to two-dimensional heat and moisture transfer can be written as follows, taking into account the above assumptions (Anderson, 1992):

$$\rho C_p\frac{\partial T}{\partial t}=\frac{1}{r}\frac{\partial}{\partial r}(kr\frac{\partial T}{\partial r})+\frac{\partial}{\partial z}(k\frac{\partial T}{\partial z}) \quad (6)$$

$$\frac{\partial W}{\partial t}=\frac{1}{r}\frac{\partial}{\partial r}(Dr\frac{\partial W}{\partial r})+\frac{\partial}{\partial z}(D\frac{\partial W}{\partial z}) \quad (7)$$

where C_p represents the constant pressure specific heat (J/kg K), k stands for the thermal conductivity (W/m K), D is the moisture diffusivity (m^2/s) and W denotes the moisture content (kg/kg, d.b.).

In both instances, the following initial and boundary conditions were used (Anderson, 1992):

$T(r,z,0)=T_i$ and $M(r,z,0)=M_i$

Where M_i is the initial moisture content (kg/kg, d.b.), n is normal to surface, s represents the surface coordinate, h denotes the heat transfer coefficient (W/m^2 K) and h_m shows the mass transfer coefficient (m/s).

The spectrum of coefficients associated with convective heat and mass transfer (h and h_m) on the surface of the material was assumed. For

$$\frac{\Delta T}{\Delta t}=\alpha\nabla^2 T \quad (4)$$

Or:

solving the mass transfer equations under the initial and boundary conditions of interest, the finite difference method was applied.

$$\begin{aligned}
&k\frac{\partial T}{\partial r}\Big|_{r=R}=h(T_s-T_\infty)\\
&k\frac{\partial T}{\partial z}\Big|_{z=0}=h(T_s-T_\infty)\\
&k\frac{\partial T}{\partial z}\Big|_{z=1}=h(T_s-T_\infty)\\
&k\frac{\partial T}{\partial r}\Big|_{r=0}=0\\
&D\frac{\partial M}{\partial r}\Big|_{r=R}=h_m(M_s-M_\infty)\\
&D\frac{\partial M}{\partial r}\Big|_{r=0}=0\\
&D\frac{\partial M}{\partial z}\Big|_{z=0}=h_m(M_s-M_\infty)\\
&D\frac{\partial M}{\partial z}\Big|_{z=1}=h_m(M_s-M_\infty)
\end{aligned} \quad (8)$$

Various researchers have used the following correlations for calculating parameters for the pistachio, as follows:

For bulk density (Hsu *et al.*, 1991); $\rho=439+5.003M$ $(R^2=0.959)$

For thermal diffusivity (Hsu *et al.*, 1991); $\alpha=51.1\times10^{-9}-0.568\times10^{-9}M$ $(R^2=0.983)$

For thermal conductivity (Hsu *et al.*, 1991); $k=0.0866+0.2817\times10^{-3}M$ $(R^2=0.963)$

For constant-pressure specific heat (Hsu *et al.*, 1991); $C_p=1074+27.79M$ $(R^2=0.920)$

For moisture diffusivity (AmiriChayjan *et al.*, 2012); $D_{eff}=4\times10^{-9}m^2/s$

Finally, Four indices such as correlation coefficient (R^2), absolute error (E_{abs}), mean squared error (*MSE*) and chi-square (χ^2) were used as the goodness of fit and agreement between experimental results and numerical solutions. These indices are as follow (AmiriChayjan *et al*., 2012):

$$R^2 = 1 - \frac{\sum_{i=1}^{N}\left[M_{\exp,i} - M_{num,i}\right]}{\sum_{k=1}^{N}\left[M_{num,i} - \frac{\sum_{k=1}^{n} M_{num,i}}{N}\right]} \quad (9)$$

$$E_{abs} = \left[\frac{1}{N}\sum_{i=1}^{N}\left|\frac{M_{\exp.i} - M_{num,i}}{M_{\exp,i}}\right|\right] \quad (10)$$

which $M_{\exp.i}$ represents the experimental moisture ratio of i^{th} data, $M_{num,i}$ denotes the numerical moisture ratio of i^{th} data and N shows the number of observations.

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(f_i - y_i)^2$$

where N stands for the number of observations, f_i represents the numerical value of i^{th} data and y_i shows the experimental value of i^{th} data.

$$\chi 2 = \sum_{i=1}^{N}\frac{(O_i - E_i)^2}{E_i}$$

In which N denotes the number of observations, O_i is the experimental value of i^{th} data and E_i is the numerical value of i^{th} data.

Results and discussion

Comparison of experimental and numerical results

Drying curves of pistachio nuts in all the three bed conditions and temperature conditions using both experimental and numerical methods are presented in Figs. 3-5.

After drying the pistachio nuts to nearly 9% (d.b.), the simulated moisture contents at 45°C were found to be higher compared to the measured values (Fig. 3A). Results related to the simulated moisture curve and to the experimental variation of moisture at an air temperature of 60°C are shown (Figure 3B). Based on this result, the simulated values within the range of 6000 and 10000 seconds were slightly higher than the measured values. Because the properties of the product are expressed as averages, so for half of the conditions, the forecast is done properly (Makarichian *et al.*, 2021; Rashidi *et al*., 2021).

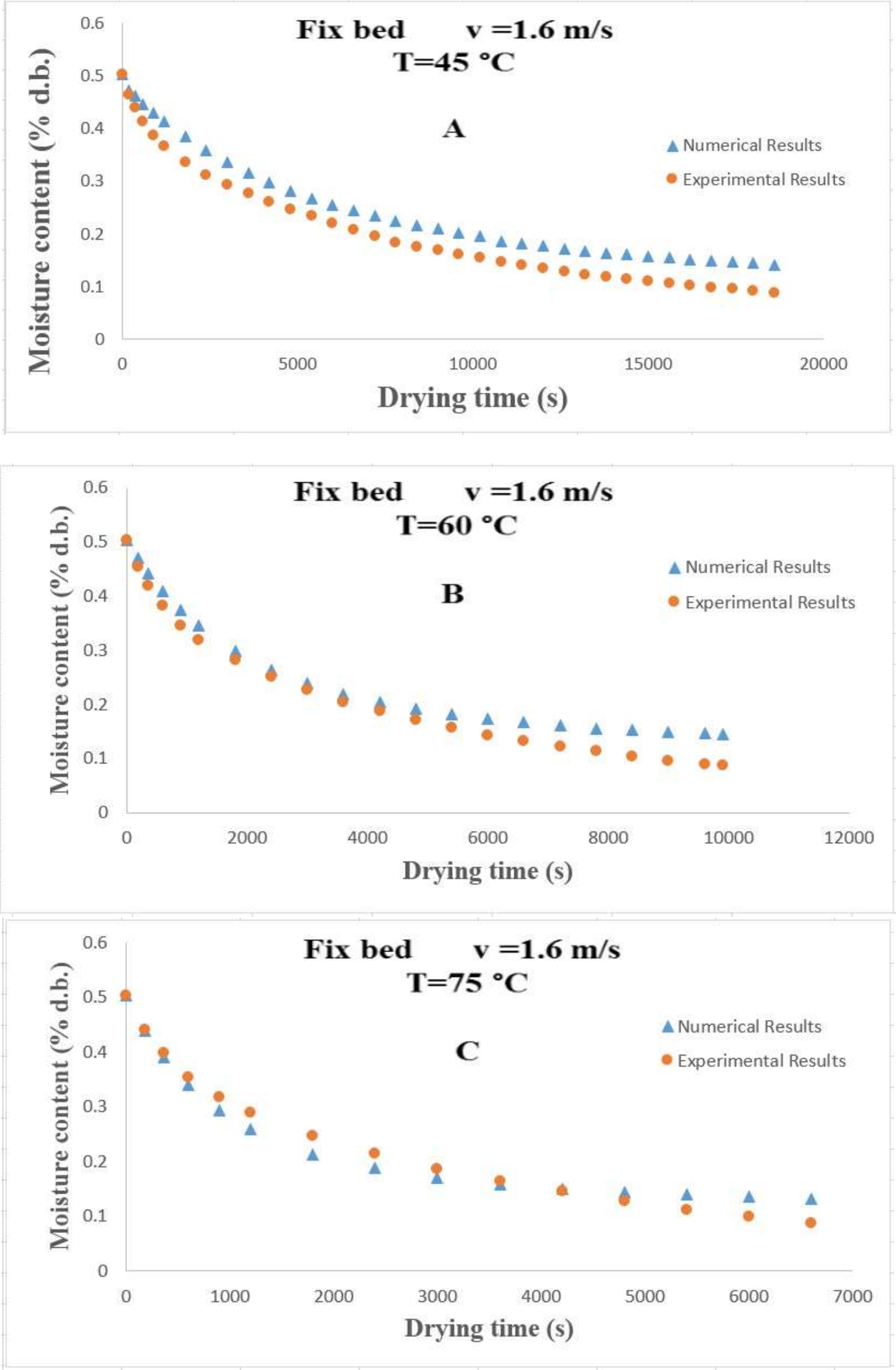
At 75°C the simulated values between 8500 and 30000 seconds were slightly lower and those between 47000 and 66000 seconds were higher compared to the measured values (Fig. 3C) and at 90°C the values simulated were lower than the values measured (Fig. 3D).

Fig. 4A till Fig. 4D show the simulated moisture contents for semi fluid bed at 45°C and 90°C, respectively. They had the same trend in contrast with fix bed. The reason for this condition can be the average amount of physical and thermal properties

At 60°C the simulated values between 60000 and 10800 seconds were slightly higher than the measured values (Fig. 4B). Fig. 4C showed that the simulated values from 48000 to 66000 seconds were slightly higher than the measured values (at 75°C).

The same trends were found for fluid, fix and semi fluid bed at 45°C and 90°C (Fig. 5A and Fig. 5D), also the curve trends for fluid bed was the same against semi fluid bed at 60°C and 75°C (Fig. 5B and Fig. 5C).

According to Figs. 3- 5, following an increase in air temperature, drying time decreased.



Fix bed v =1.6 m/s
T=45 °C
A
Numerical Results
Experimental Results
Moisture content (% d.b.)
Drying time (s)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
5000
10000
15000
20000
Fix bed v =1.6 m/s
T=60 °C
B
Numerical Results
Experimental Results
Moisture content (% d.b.)
Drying time (s)
0
2000
4000
6000
8000
10000
12000
Fix bed v =1.6 m/s
T=75 °C
C
Numerical Results
Experimental Results
Moisture content (% d.b.)
Drying time (s)
0
1000
2000
3000
4000
5000
6000
7000

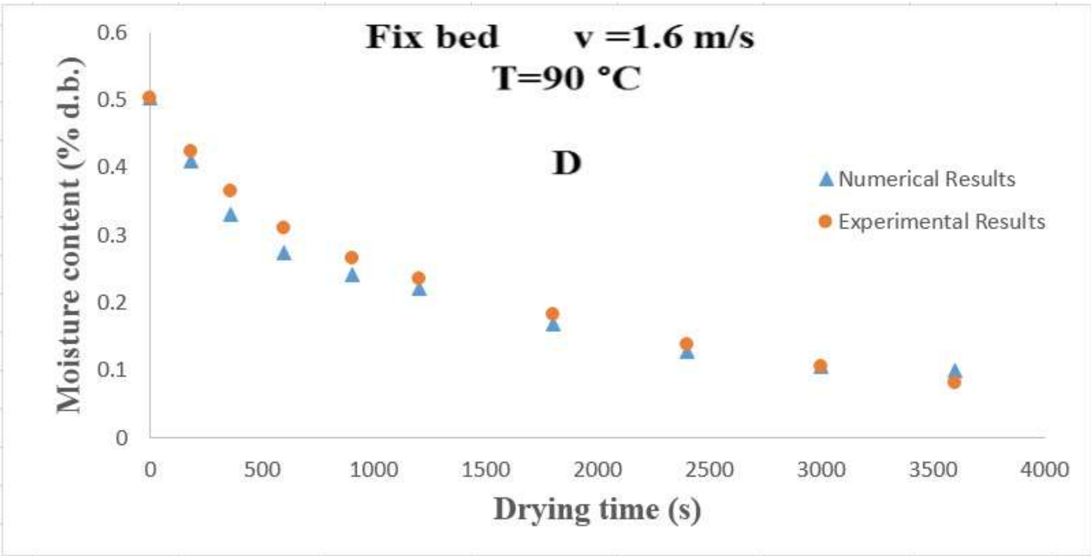
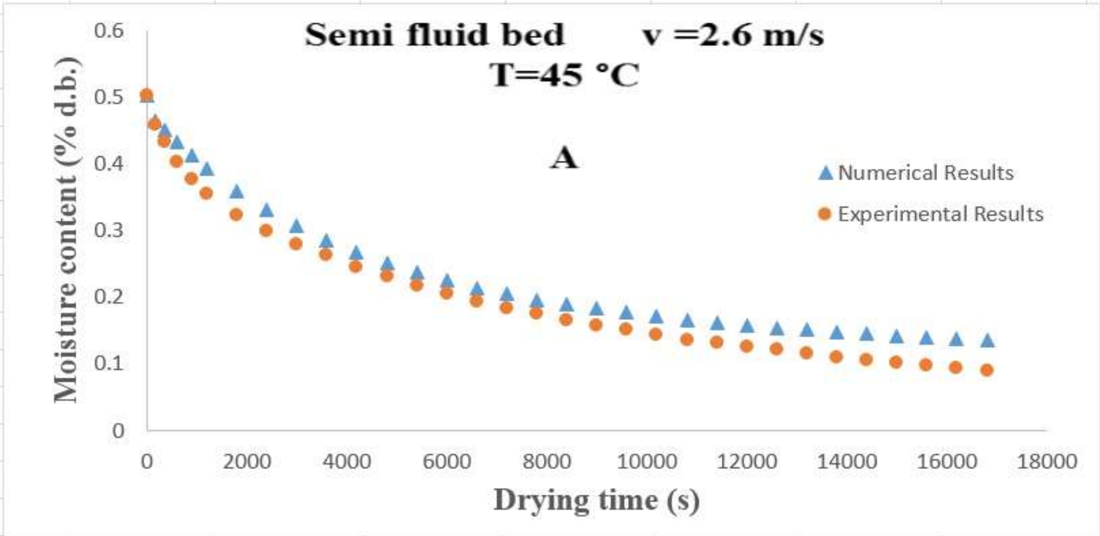
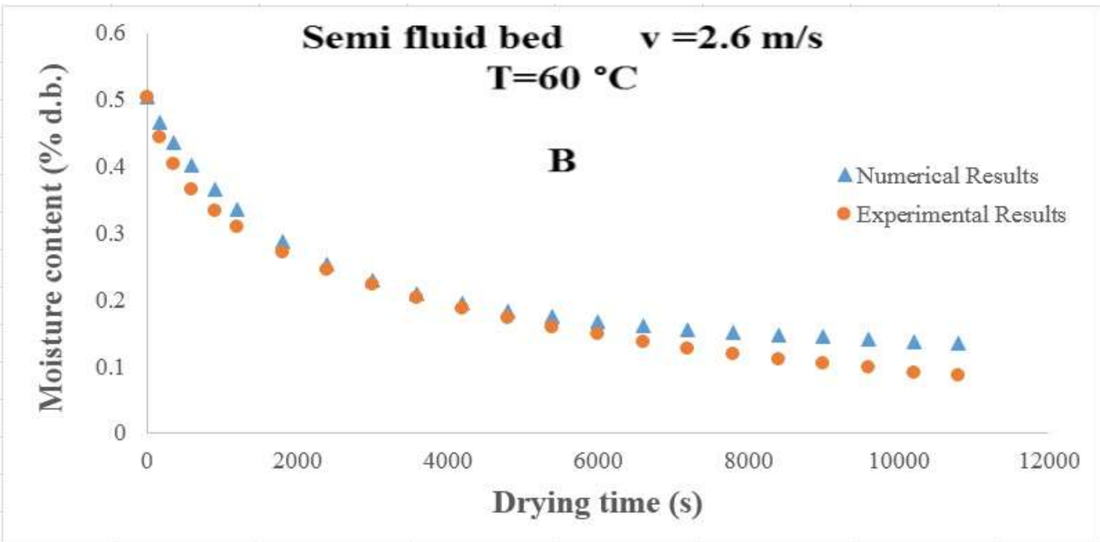
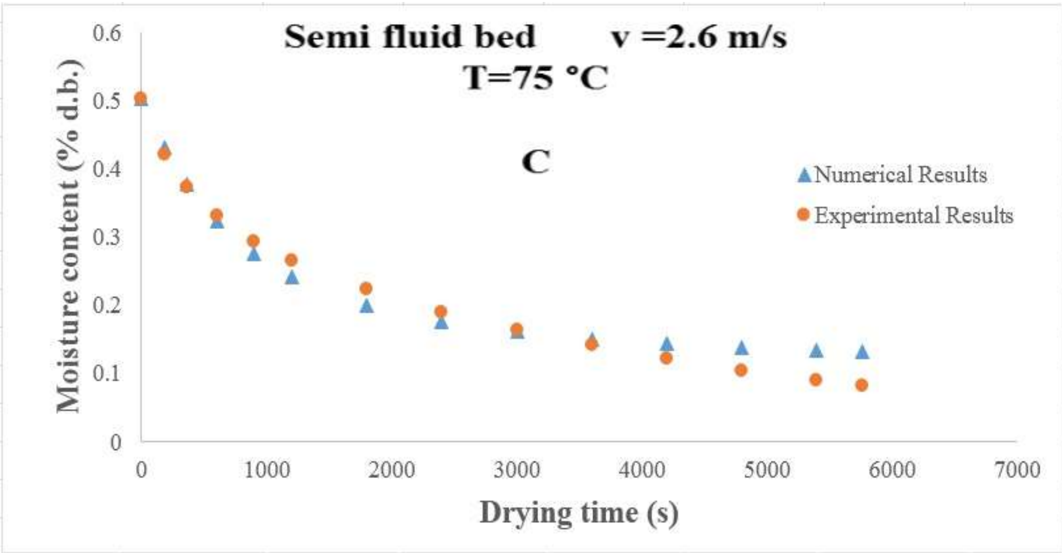


Fig. 3: Measured and simulated moisture contents at fix bed (velocity=1.6 m/s).







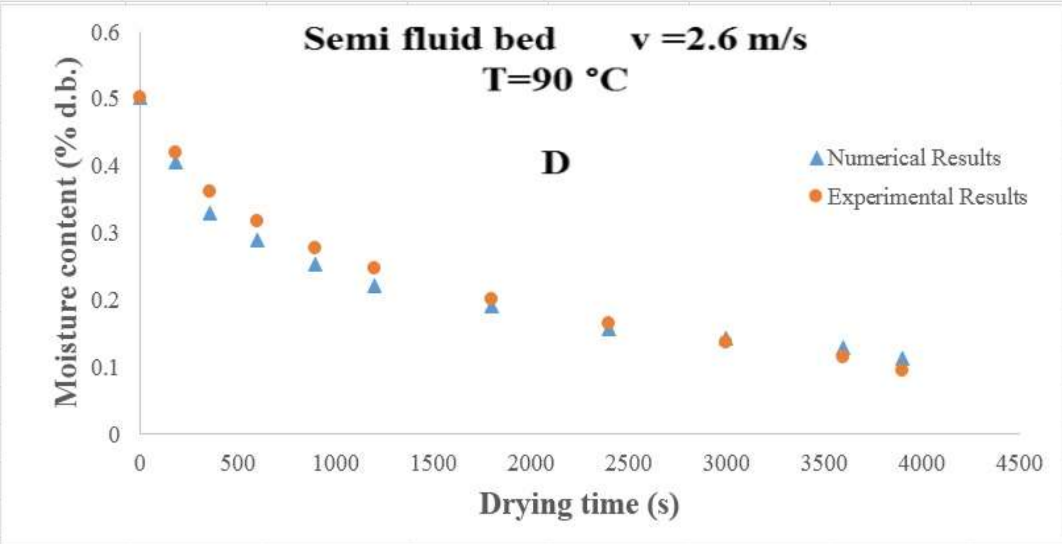
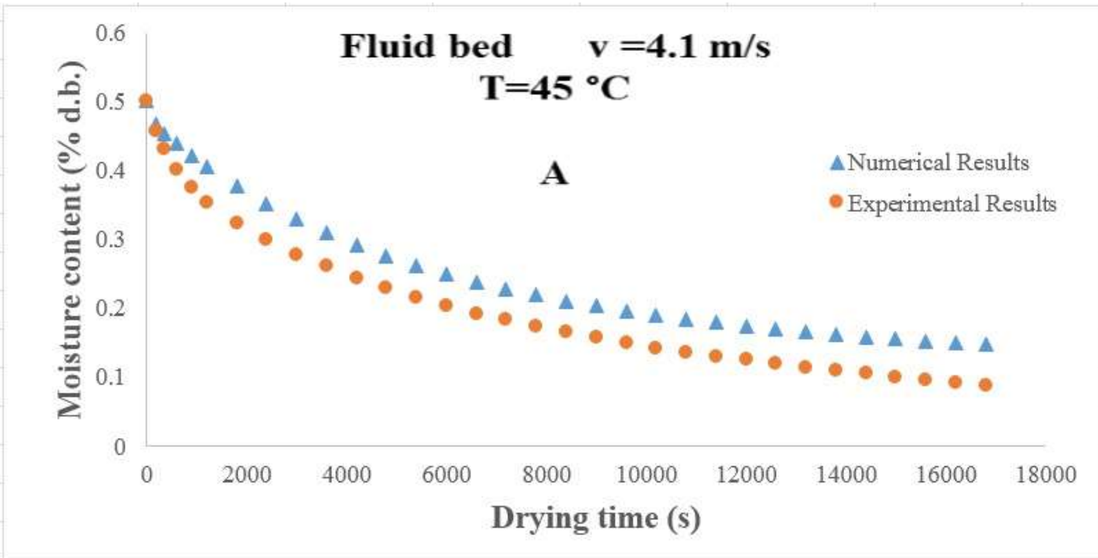


Fig. 4. Measured and simulated moisture contents at semi fluid bed (velocity=2.6 m/s).



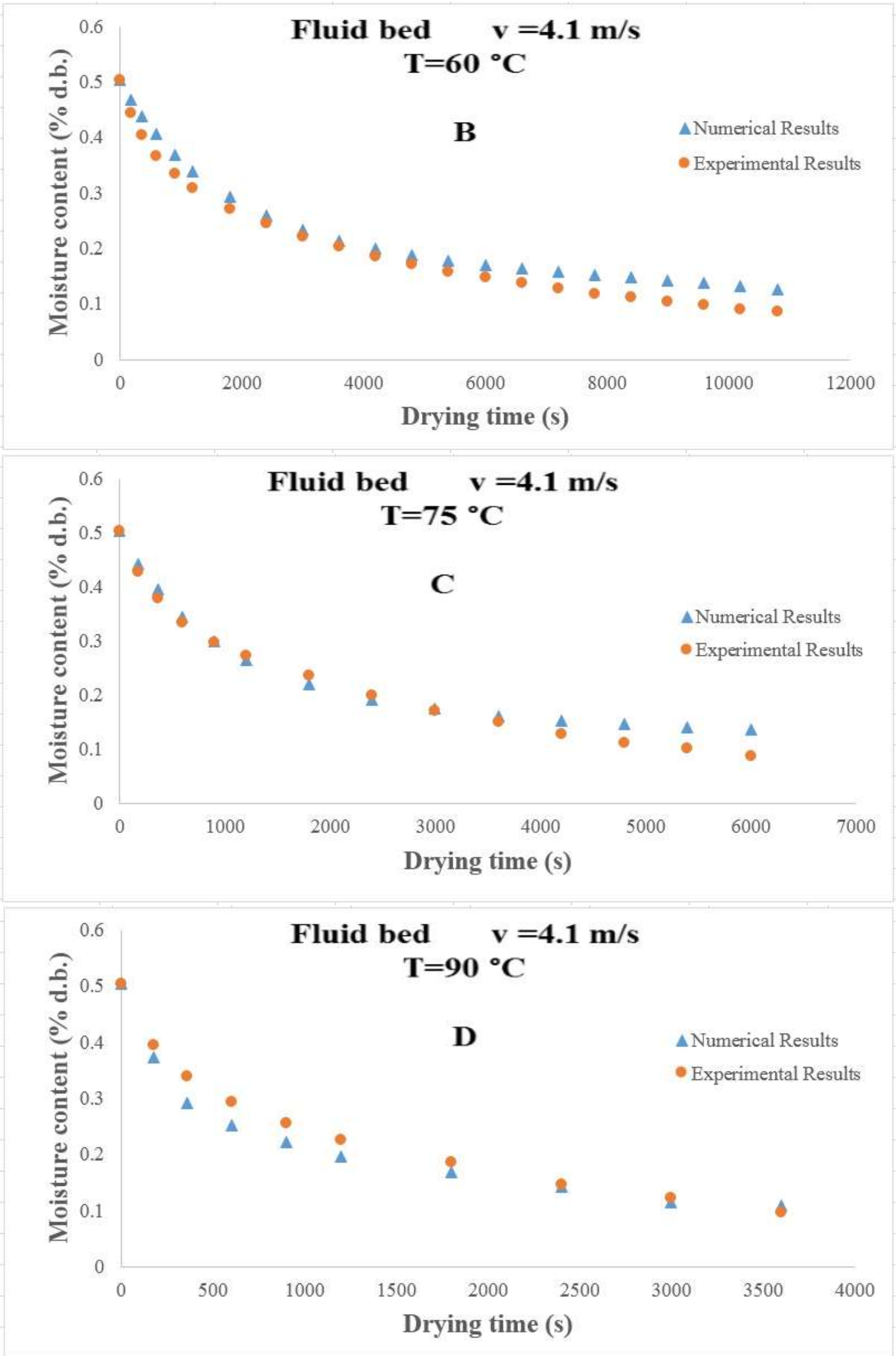


Fig. 5. Measured and simulated moisture contents at fluid bed (velocity=4.1 m/s).

The rate of energy exerted to the pistachio sample bed and then the drying rate increased following increased the temperature being applied to the pistachio bed. Increased temperature allows the rate of transfer of heat to the product to be increased. Air velocity also has no major effect on the rate of drying. An increase in the coefficients of convective heat and mass transfer between the drying air and the pistachio nuts caused an increase in the rate of drying and decreased the drying time.

Similar results were reported by other studies on drying other products including hazelnuts (Topuz *et al.*, 2004), eggplant (Akpinar and Bicer, 2005), peach (Kingsly *et al*., 2007), plum (Goyal *et al*., 2007), berberis fruit (Aghbashlo *et al*., 2007), corn (Vukić *et al*., 2015), ginger (Parlak, 2015), chilean berry (Quispe-Fuentes *et al*., 2016) and turnip (Kaveh and AmiriChayjan, 2016).

Table 1 shows the values related to R^2, E_{abs}, MSE and $\chi 2$, which were calculated for all examined bed conditions. The highest and the lowest values of R^2 and E_{abs}, confirm the highest agreement between experimental results and numerical solutions.

Figure 6 A-C shows the comparison between the numerical solution and experimental results on each bed condition.

According to Fig 6, it seems that the numerical solution result at 60, 75 and 90°C were so close to experimental results except for air temperature of 45°C. The values of each parameter in Table 1 proved this result. In fix bed, the value of E_{abs} at 60, 75 and 90°C were 0.2123, 0.1257 and 0.0337 that were lower than the air temperature of 45°C (0.2595) and R^2 values for these temperatures were 0.9903, 0.9705 and 0.9807. These trends were repeated for the bed conditions of semi fluid and fluid bed with different values.

The average values of R^2 for all applied bed conditions was calculated 0.9850. This value showed the high agreement between experimental results and numerical solutions.

According to the values of statistical indices for different conditions, the errors created by using the model type and fixed numbers of physical and thermal properties are not significant and the results of this study can be used to predict the kinetics of dried pistachios at any temperature and used air velocity in the study area. The advantage of this numerical method is its accuracy and comprehensiveness. However, to predict the drying kinetics of pistachios with the help of experimental and semi experimental models, it will be necessary to adjust the model coefficients (Azharul Karim and Hawlader, 2005; Shahbazi and Rahmati, 2013; Castro *et al*., 2018; Nguyen *et al*., 2021).

Table 1- Values of R^2, E_{abs}, MSE and X^2 for all applied bed conditions

Bed condition	Temperature (°C)	R^2	E_{abs}	MSE	X^2
Fix bed (1.6 m/s)	45	0.9955	0.2595	0.0017	0.3
	60	0.9903	0.2123	0.0010	0.13
	75	0.9705	0.1257	0.0005	0.059
	90	0.9807	0.0337	0.0004	0.018
Semi fluid bed (2.6 m/s)	45	0.9944	0.1850	0.0008	0.15
	60	0.9879	0.1706	0.0007	0.098
	75	0.9715	0.1475	0.0005	0.053
	90	0.9856	0.0120	0.0003	0.017
Fluid bed (4.1 m/s)	45	0.9942	0.2908	0.0022	0.34
	60	0.9911	0.1746	0.0008	0.098
	75	0.9808	0.1278	0.0004	0.045
	90	0.9782	0.0662	0.0007	0.029

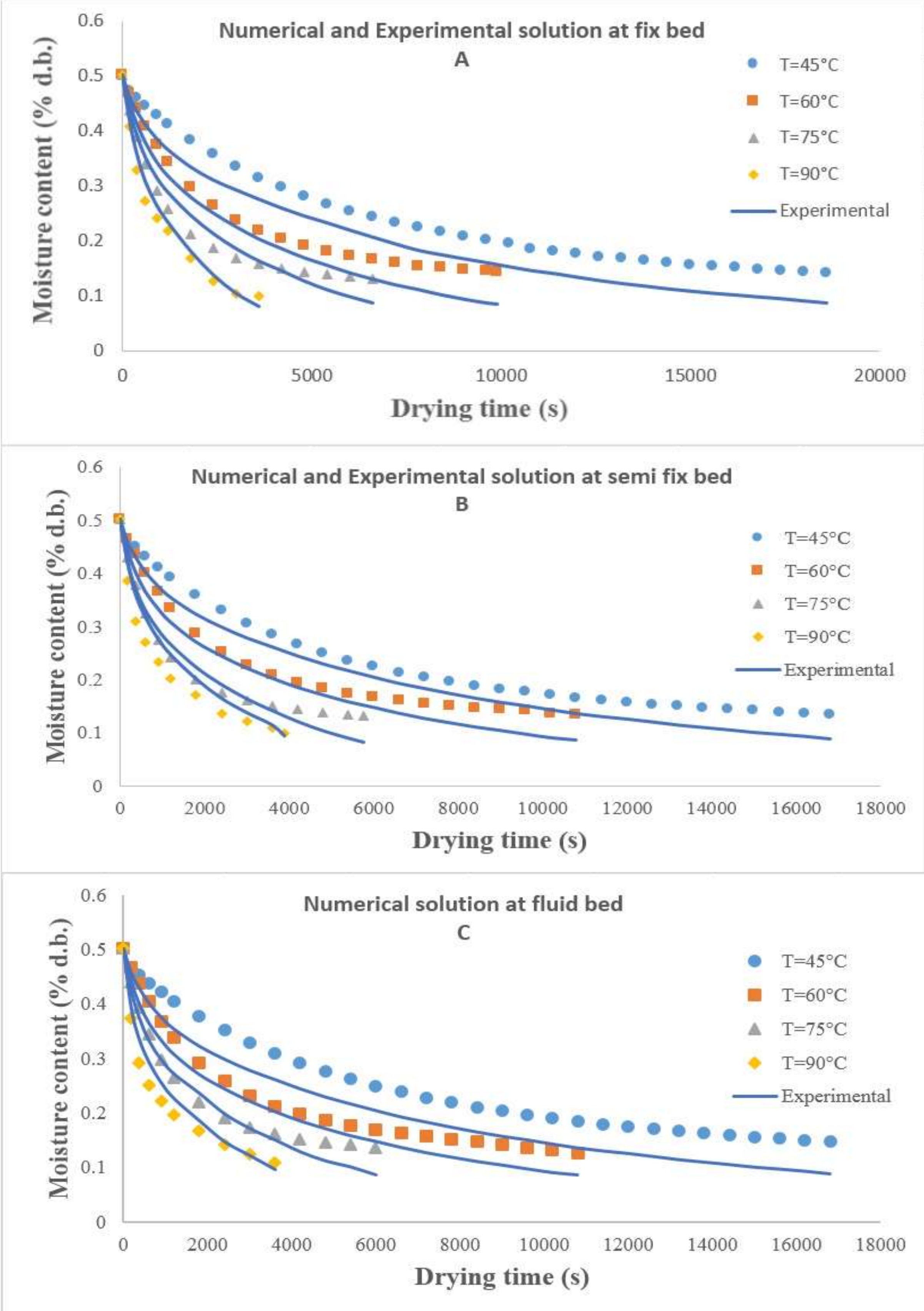


Fig. 6. Experimental results and the numerical solution of drying kinetic of pistachio nuts in bed conditions

Conclusions

The results of this research work are as follows:

1) Comparison between the experimental data with the results obtained in the numerical solution with Fluent CFD code showed that there is a high agreement between them.

2) In fix bed (1.6 ms^{-1}), the lowest values of E_{abs} (0.0337) and $\chi 2$ (0.0004) were related to the temperature of 90°C. The R^2 value of this temperature was 0.9807, which shows the highest agreement between experimental data and numerical solution compared to other examined temperatures.

3) The lowest values of $\chi 2$ and E_{abs} in the semi fluid bed (2.6 ms^{-1}) were 0.017 and 0.0120 and belong to the temperature of 90°C with R^2= 0.9856. In semi fluid bed, the highest agreement was obtained between experimental data and numerical solution for 90°C. After 90°C, temperatures of 75, 60 and 45°C showed the greatest agreement between experimental and numerical results, respectively.

4) The temperature of 90°C showed the highest agreement in the fluid bed (4.1 m s-1). The values of R^2, $\chi 2$ and E_{abs} for this temperature were 0.9782, 0.029 and 0.0662, respectively.

5) The average value of R^2 for all applied bed conditions was calculated 0.9850. This value showed the high agreement between experimental results and numerical solutions.

6) The highest agreement in all bed conditions was related to temperature of 90°C.

7) As the temperature decreased, the values of E_{abs} and $\chi 2$ increased in all bed conditions.

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Nomenclatures

a	thermal diffusivity (m^2/s)	p	pressure (Pa)
C_p	constant pressure specific heat (J/kg K)	r	radial coordinate
D	moisture diffusivity (m^2/s)	s	surface coordinate
E_{abs}	absolute error	T	air temperature (K)
h	heat transfer coefficient (W/m^2 K)	t	Drying time
h_m	mass transfer coefficient (m/s)	u	velocity in x direction (m/s)
k	thermal conductivity (W/m K)	v	velocity in y direction (m/s)
$M_{\exp,i}$	experimental moisture ratio	W	moisture content (kg/kg, db)
$M_{num,i}$	numerical moisture ratio	z	axial coordinate
M_i	initial moisture content (kg/kg, db)	ρ	density (kg/m^3)
N	number of observations	μ	dynamic viscosity (Pa.s)
n	normal to surface		
R^2	correlation coefficient		

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شبیه‌سازی انتقال جرم مغزهای پسته با استفاده از دینامیک سیالات محاسباتی (CFD) در حین خشک کردن بسترسیال

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چکیده

خشک کردن مواد غذایی می‌تواند ماندگاری آن را افزایش داده و موجب کاهش هزینه حمل و نقل و نگهداری آن شود. قانون دوم فیک معمولاً برای ارزیابی فرآیندهای انتقال جرم در فرآیند خشک کردن به روش استاندارد مورد استفاده قرار می‌گیرد و بر اساس بسیاری از فرضیات است. درک معنای انتقال جرم در محصولات می‌تواند روند خشک شدن و کیفیت محصول را بهبود بخشد. دینامیک سیالات محاسباتی (CFD) با استفاده از ریاضیات قدرتمند رایانه‌ای و کاربردی به‌منظور پیش‌بینی انتقال جرم در فرآیندهای صنعتی، شرایط جریان سیال را مدل می‌کند. هدف از این تحقیق بررسی عددی رفتار خشک شدن مغز پسته با استفاده از روش CFD و ارزیابی نتایج عددی در شرایط بستر سیال، نیمه سیال و بستر ثابت و همچنین دمای هوا ۴۵ ، ۶۰ ، ۷۵ و ۹۰ درجه بود. در حین خشک کردن با استفاده از دینامیک سیال محاسباتی و کد CFD Fluent، جریان‌های خارجی و زمینه‌های دما در اطراف جسم استوانه‌ای (۱۰ ×۷/۵ میلی‌متر) در تجزیه و تحلیل عددی پیش بینی می‌شود. برای آزمایشات خشک کردن از خشک‌کن بستر سیال آزمایشگاهی استفاده شد. قسمت‌های اصلی خشک‌کن فن شعاعی جلو، محفظه خشک‌کن، بخاری برقی، اینورتر و کنترل‌کننده دما است. اتصالات خشک‌کن سنسورهای دمای ورودی و خروجی، بادسنج و کامپیوتر هستند. بخش عددی انجام و با داده‌های تجربی کنار هم قرار گرفت. نتیجه حل عددی در دمای ۶۰ درجه سانتی‌گراد، ۷۵ درجه سانتی‌گراد و ۹۰ درجه سانتی‌گراد به جز در دمای هوا ۴۵ درجه سانتی‌گراد ، بسیار نزدیک به نتایج تجربی بود. میانگین خطای مطلق در بستر ثابت، در دمای ۶۰ ، ۷۵ و ۹۰ درجه سانتیگراد به‌ترتیب ۰/۲۱۲۳، ۰/۱۲۵۷ و ۰/۰۳۳۷ بود که کمتر از دمای ۴۵ درجه سانتی‌گراد و مقادیر R^2 برای این دماها به‌ترتیب ۰/۹۹۰۳، ۰/۹۷۰۵ و ۰/۹۸۰۷ بود. با کاهش دما، مقادیر E_{abs} و $\chi 2$ در تمام شرایط بستر افزایش می‌یابد. مقادیر متوسط R^2 برای تمام شرایط بستر اعمال شده ۰/۹۸۵۰ محاسبه شد. این مقدار نشان داد که توافق زیاد بین نتایج تجربی و راه حل‌های عددی وجود دارد.

واژه‌های کلیدی: خشک‌کن بستر سیال، خشک‌کن بستر نیمه سیال، خشک‌کن بستر ثابت، نتایج تجربی، مدل‌سازی، حل عددی.

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