International Journal of Scientific and Technological Research
ISSN 2422-8702 (Online)
Vol 1, No.1, 2015

Determining the Moisture Transfer Parameters for Regularly Shaped Products

Ahmet Kaya (Corresponding author)
Department of Mechanical Engineering, Kahramanmaras Sutcu Imam University,
46050 Kahramanmaras, TURKEY, ekaya38@gmail.com, kaya38@ksu.edu.tr

Muhammed Safa Kamer
Department of Mechanical Engineering, Kahramanmaras Sutcu Imam University,
46050 Kahramanmaras, TURKEY

Huseyin Emre Sahin
Department of Mechanical Engineering, Kahramanmaras Sutcu Imam University,
46050 Kahramanmaras, TURKEY

Abstract

In this article, an experimental and theoretical investigation of drying of slab, cylinder and spherical products to study dimensionless moisture content distributions and their comparisons have been presented. The measurement of the moisture content distributions of slab, cylindrical and spherical potato slices during drying at various temperatures (e.g., 45°C, 50°C, 55°C and 60°C) and velocities (U=0.5 m/s, 1 m/s, 1.5 m/s and 2.0 m/s) have been determined in the experimental study. Two models are used to determine drying process parameters (e.g., drying coefficient and lag factor) and moisture transfer parameters (e.g., moisture diffusivity and moisture transfer coefficient), and to calculate the dimensionless moisture content distributions in the theoretical analysis. The calculated and experimental results are compared with one another. The calculated results were shown to be consistent with the results obtained experimentally.

Keywords: Convective drying, potato, drying parameters, moisture transfer, moisture distribution.

1. Introduction

Drying process of moist products has complex phenomena with simultaneous heat and mass transfer mechanisms taking place. Understanding its physical mechanisms and phenomena is of great practical importance. In particular, accurate determination of moisture transport parameters (moisture diffusivities, moisture transfer coefficients) is essential for an accurate mass transfer analysis (Dincer, 1998; Mcminn, 2004). When a drying model is developed, the mechanism of water removing and controlling resistance must be specified firstly (Mulet et al., 1999). In drying fruits and vegetables, diffusion is the main mechanism of moisture removing (Saravaco and Maroulis, 2001). Dincer and Dost (1995,1996) developed and confirmed analytical models to describe the mass transfer during drying of regular geometry solid objects (slab, cylinder and sphere) in the case of constant diffusion (Dincer et al. 2002; Dincer and Hussain 2002; Dincer and Hussain 2004). These models were obtained and validated on the data found in literature for different types of food. Mrkic et al. (2007) verified the simple model between Biot and Dincer numbers in order to describe broccoli drying kinetics at different drying air conditions. Corzo et al. (2008) investigated for application of the correlation between Biot (Bi) and Dincer numbers for determining the moisture transfer parameters during the air-drying of mango slices at different ripeness stages. Liu et al. (2013) studied in the literature regarding the applicability of the Bi–G correlation for determining transport parameters in the process of convective drying, several values of moisture diffusivity and convective moisture transfer coefficient. Sadeghi et al. (2013) investigated drying kinetics and mass transfer phenomena for selecting optimum operating conditions, and obtaining a high quality dried product. Two analytical models, conventional solution of the diffusion equation and the Dincer and Dost model, were used to investigate mass transfer characteristics during combined microwave-convective drying of lemon slices.

In this study, the mass transfer parameters (moisture diffusivity and moisture transfer coefficient) of slab, cylindrical and spherical products (i.e., potato) investigated and compared under convective drying of using two different correlations proposed by Dincer and Hussain (2004).

2. Materials and Methods

Experiments were conducted in a lab-scale convective air-dryer as shown in Fig. 1. The experimental setup consists of fan, heater, air conditioner, fresh air damper, air exit damper, mixing damper, test section, precision balance, velocity and temperature meters, flow regulator, data acquisition and computer. Drying air velocity and temperature are kept constant during the process in the test section. For this purpose, the convective dryer insulated is equipped with controllers for controlling the temperature and airflow velocity. The precision balance arranged to not disturb the flow and sealing well provided has been located in the test section. Instantaneous mass changes in precision balance with speed and temperature changes in the test region, in the specified period can be saved directly to the computer via a software program. Additionally, these values can be followed by PLC screen on convective dryer.

At the PLC screen on convective dryer, the desired speed and temperature values are entered in the test section and these values are kept constant during the drying process. Drying process has been monitored with velocity and temperature sensors located five different sections on convective dryer and the values can be saved directly to the computer. These values can also be monitored from the PLC screen. Before starting the drying process, the system was run for about 30 minutes and reached to equilibrium. Experiments, three different drying air velocity (0.5 m/s, 1.0 m/s and 1.5 m/s) and three different temperatures (40, 50 and 60°C) were performed. Drying was continued until the equilibrium moisture content is reached. The test samples of the slab potato (2 cm x 2 cm 2 cm), cylindrical potato (R=2 cm, L=6 cm) and spherical potato (R=2 mm), weighing about 500 g are placed in precision balance. The initial moisture contents of products are determined using the OHAUS MB45 infrared moisture analyzer.

3. Modeling

Here, two different drying models are considered to assess drying process parameters (e.g., drying coefficient and lag factor), moisture transfer parameters (e.g., moisture diffusivity and moisture transfer coefficient), and to compute moisture content distributions at different velocities and drying air temperatures.

3.1 Model I

The transient moisture diffusion process while drying of a moist solid occurs similar to the heat conduction process in such a moist solid. The governing Fickian equation for different geometric shaped moist objects is given by Dincer and Dost (1995). In one-dimensional rectangular, spherical and cylindrical coordinates for an infinite slab, an infinite a sphere and cylinder, the time-dependent moisture diffusivity equation can be written in the following form:

$$\left(\frac{1}{y^m}\right)\left(\frac{\partial}{\partial y}\right)\left(y^m\frac{\partial M}{\partial y}\right)=\left(\frac{1}{D}\right)\left(\frac{\partial M}{\partial t}\right) \tag{1}$$

where m=0, 1 and 2 for infinite slab, infinite cylinder and sphere, respectively. In addition, y=z for slab, and y=r for infinite cylinder and sphere.

The following boundary and initial conditions:

$$\phi(y,0)=\phi_i=(M_i-M_e)\,;\quad \left(\frac{\partial}{\partial z}\phi(0,t)\right)=0\,;\quad -D\left(\frac{\partial}{\partial z}\phi(Y,t)\right)=k\left(\phi(Y,t)-\phi_0\right) \tag{2}$$

where Y is the characteristic dimension (half thickness for slab (Y=L/2), radius for cylinder and sphere (Y=r)) and $\phi=\left(M-M_e\right)$.

The dimensionless Biot and Fourier numbers are:

$$Bi = kL/D \tag{3}$$

$$Fo = Dt/L^2 \tag{4}$$

The moisture content at any point of the moist solid is non-dimensionalized by:

$$\emptyset = (M - M_e)/(M_i - M_e) \tag{5}$$

The solution of the governing Eq. (1) with the boundary conditions yields dimensionless center moisture distribution for the objects:

$$\phi = \sum_{n=1}^{\infty} A_n B_n \tag{6}$$

The above solution can be simplified if the values of Fo>0.2 are negligibly small. Thus, the infinite sum in Eq. (6) is well approximated by the first term only, i.e. (for details, see Dincer and Dost, 1995):

$$\phi \cong A_1 B_1 \tag{7}$$

where for infinite slab object

$$A_1 = G = \exp[0.2533Bi/(1.3 + Bi)] \tag{8}$$

for infinite cylindrical object

$$A_1 = G = \exp\left[0.5066Bi/\left(1.7 + Bi\right)\right] \tag{9}$$

for spherical object

$$A_1 = G = \exp[0.7599Bi/(2.1 + Bi)] \tag{10}$$

and for all objects

$$B_1 = \exp\left(-\mu_1^2 Fo\right) \tag{11}$$

The characteristic equation in Eq.(11) is given by Dincer and Dost (1995) as follows;

For infinite slab object,

$$\mu_1 = a\tan(0.640443Bi + 0.380397) \quad \text{for } 0.1<Bi<100 \tag{12}$$

For infinite cylindrical object,

$$\mu_1 = \left(\left(3/4.188\right)\ln\left(6.796\,Bi + 1\right)\right)^{1/1.4} \quad \text{for } 0.1<Bi<10 \tag{13}$$

For spherical object,

$$\mu_1 = \left((1.1223)In(4.9Bi + 1)\right)^{1/1.4} \text{ for } 0.1<Bi<100 \tag{14}$$

The following exponential form can express dimensionless moisture distribution (Dincer and Dost, 1995);

$$\emptyset = G\exp(-St) \tag{15}$$

where G represents lag factor (dimensionless) and S represents drying coefficient (1/s). The drying capability of an object or product per unit time is defined as the drying coefficient. Lag factor is an indication of internal resistance of an object to the heat and/or moisture transfer during drying. These parameters are beneficial in evaluating and representing a drying process. The value of the dimensionless moisture content can be acquired using the experimental moisture content measurements from Eq. (5). There are same forms both Eqs (7) and (15). Having G=A_1 can equate to each other. So, the moisture diffusivity for an infinite slab, spherical or cylinder products is shown by the following equation:

$$D = SY^2/\mu_1^2 \tag{16}$$

The expression for the moisture transfer coefficients results in

$$k = (DBi/Y) \tag{17}$$

Also, the following is used for determining the moisture transfer coefficient (Dincer and Dost, 1995):

For infinite slab object

$$k = \left({}^{D}/_{L}\right)[(1 - 3.94813 \text{ In } G)/(5.1325 \text{ In } G)] \tag{18}$$

For infinite cylindrical object

$$k = \left({}^{D}/_{Y}\right)[(1 - 1.974 \text{ In } G)/(3.3559 \text{ In } G)] \tag{19}$$

For spherical object

$$k = \left({}^{D}/_{Y}\right)[(1 - 1.316 \text{ In } G)/(2.76369 \text{ In } G)] \tag{20}$$

The process of using the above modeling technique for predicting the drying parameters and process parameters is as follows:

1. The values of experimental moisture contents are non-dimensionalized using Eq. (5).
2. The drying time and measured dimensionless moisture content values are declined in the exponential form of Eq. (15) with the least square curve-fitting method. Therefore, drying coefficient (S) and lag factor (G) are acquired accordingly.
3. The Biot number is ccomputed through Eq. (8), (9) or (10) as regards proper geometric shaped product since $G=A_1$.
4. μ_1 value is computed from Eq. (12) to (14) as regards proper geometric shaped product.
5. The moisture diffusivity is computed from using Eq. (16).
6. The moisture transfer coefficient is computed from using Eq. (18), (19) or (20) as regards proper geometric shaped product.
7. At last, A_1 is computed from using Eq. (8), (9) or (10) as regards proper geometric and B_1 is computed from using Eq.(11). And, the dimensionless moisture distribution is acquired from using Eq. (7).

3.2 Model II: Bi-G correlation

In this part, the mass transfer parameters are determined using the Biot number–lag factor (Bi–G) correlation. Dincer and Hussain (2002, 2004) propose the Biot number-lag factor correlation and given as below;

$$Bi = 0.0576\,G^{26.7} \tag{21}$$

The process of using the above modeling technique for predicting the drying parameters and process parameters is as follows:

1. The values of experimental moisture contents are non-dimensionalized using Eq. (5).
2. The drying time and dimensionless moisture content values are declined in the exponential form of Eq. (15) using the least square curve-fitting method. Therefore, the values of G and S are determined.
3. The characteristic root μ_1 in Eq. (11) is determined using the following expression (Dincer and Hussain (2002, 2004));

   for infinite slab object

   $$\mu_1 = -419.24G^4 + 2013.8G^3 - 3615.8G^2 + 2880.3G - 858.94 \tag{22}$$

   for infinite cylindrical object

   $$\mu_1 = -3.4775G^4 + 25.285G^3 - 68.43G^2 + 82.468G - 35.638 \tag{23}$$

   for spherical object

$$\mu_1 = -8.3256G^4 + 54.842G^3 - 134.01G^2 + 145.83G - 58.124 \tag{24}$$

4. The values of moisture diffusivity are then computed from using Eq. (16).
5. Biot number (Bi) is computed, using the Biot number-drying coefficient correlation (Eq. (21)).
6. The moisture transfer coefficient is computed from using Eqs. (17).
7. At last, A_1 is computed from using Eq. (8), (9) or (10) as regards proper geometric and B_1 is computed from using Eq.(11). And, the dimensionless moisture distribution is acquired from using Eq. (7).

4. Results and Discussion

When surrounding air is brought to set conditions, drying process started. The beginning moisture contents of potato was measured. And the beginning moisture contents of potato found to be around 77.88% w.m. (3.52kg H_2O/kg d.m.). Drying experiments were carried out at various temperatures (30, 40, 50 and 60°C) and velocity (0.5 m/s, 1.0 m/s, 1.5 m/s and 2.0 m/s). Drying was carried on until reaching the equilibrium moisture content. Experiments were performed at least three times for each studying range in order to confirm the results obtained.

After non-dimensionalizing the experimental moisture contents, these were declined towards time with the exponential function (Eq. (1)) by using the least-square method, and the model parameters (drying coefficient, S (1/h) and lag factor, G (dimensionless)) were acquired for slab, cylindrical and spherical products and these results are tabulated at Table 1.

Table 1. Effect of Drying Air Temperature on Lag Factor (G) and Drying Coefficient (S), $\phi = G\exp(-St)$

				U=1 m/s					
Parameter	Slab Potato			Cylindrical Potato			Spherical Potato		
T (°C)	G	S (1/h)	R^2	G	S (1/h)	R^2	G	S (1/h)	R^2
45	1.1010	0.2031	0.9977	1.0586	0.1961	0.9963	1.0732	0.2043	0.9923
50	1.0402	0.2284	0.9946	1.0439	0.2258	0.9955	1.0647	0.2310	0.9968
55	1.0362	0.2884	0.9985	1.0384	0.2367	0.9948	1.0578	0.2692	0.9982
60	1.0232	0.3404	0.9975	1.0304	0.2880	0.9931	1.0398	0.3279	0.9972
U (m/s)				T=50°C					
0.5	1.0557	0.1943	0.9947	1.1044	0.2213	0.9928	1.0741	0.2249	0.9978
1.0	1.0402	0.2284	0.9946	1.0439	0.2258	0.9955	1.0647	0.2310	0.9968
1.5	1.0348	0.2482	0.9953	1.0321	0.2888	0.9971	1.0459	0.2665	0.9955
2.0	1.0258	0.2701	0.9948	1.0286	0.3398	0.9985	1.0355	0.2998	0.9950

G, is an indicator of magnitude of both external and internal resistance of a product to the heat and/or moisture transfer during drying time. *S* is drying coefficient which shows the drying capability of a solid product per unit time and lag factor. The effect of drying air velocity and temperature on coefficients *S* and *G* were analyzed. Drying coefficient (*S*) increase thanks to rising the drying air temperature and drying air velocity. The relative magnitude of *S*, in the range 0.1961 - 0.3404 1/h for drying air temperatures and 0.1943-0.3398 for drying air velocity, supplies an proper indication of the drying behavior. The lag factors are greater than 1, confirming the presence of internal resistance to moisture diffusion within the all geometric shaped products. Rising the air temperature and velocity reduce the lag factor *G*. The variation in computed values, between 1.0232 and 1.1044, reflects system specific mass transfer properties.

The moisture diffusivity (*D*) for each experimental condition was determined using Eq. (16). In table 2, the calculated diffusivities for infinitive slab, infinitive cylindrical and spherical products are showed. Rising the drying air temperature and velocity increase the value for D_{eff} at Model-I and Model-II. The effective diffusivity values were assessed between 3.8377x10^{-5} - 18.085x10^{-5} m^2/h for slab products, 2.3476x10^{-5} - 13.977x10^{-5} m^2/h for cylindrical products and 2.7682x10^{-5} - 9.3397x10^{-5} m^2/h spherical products using the Model-I and 2.9192x10^{-5} - 23.503x10^{-5} m^2/h for slab products, 2.9734x10^{-5} - 19.977x10^{-5} m^2/h for cylindrical products and 3.3760x10^{-5} - 11.154x10^{-5} m^2/h spherical products using the Model-II.

Table 2. Computed Values of Mass Transfer Parameters for Different Velocities At T=50^{o}C

Parameter	Model-I U=0.5 m/s	Model-I U=1.0 m/s	Model-I U=1.5 m/s	Model-I U=2.0 m/s	Model-II U=0.5 m/s	Model-II U=1.0 m/s	Model-II U=1.5 m/s	Model-II U=2.0 m/s
Slab Potato, T=50^{o}C								
Bi	0.3539	0.2396	0.2030	0.1450	0.2449	0.1650	0.1436	0.1136
Dx10^5(m^2/h)	6.5272	9.4998	11.144	13.822	4.9370	8.3237	10.681	16.520
μ_1	0.5456	0.4903	0.4719	0.4420	0.6273	0.5238	0.4821	0.4044
k x10^3 (m/h)	18.441	39.654	54.901	95.295	1.2090	1.3733	1.5336	1.8760
Cylindrical Potato								
Bi	0.4145	0.1575	0.1131	0.1002	0.8166	0.1814	0.1339	0.1223
Dx10^5(m^2/h)	2.3476	6.2501	10.366	13.977	2.9774	9.3257	15.138	19.977
μ_1	0.9709	0.6280	0.5275	0.4935	0.8621	0.5141	0.4365	0.4128
k x10^3 (m/h)	0.9667	2.5737	4.2684	5.7555	2.4313	1.6916	2.0271	2.4431
Spherical Potato								
Bi	0.2181	0.1888	0.1318	0.1010	0.3884	0.3072	0.1909	0.1462
Dx10^5(m^2/h)	3.0086	3.5849	6.1140	9.3397	3.6629	4.4413	7.7044	11.154
μ_1	0.8646	0.8027	0.6608	0.5666	0.7836	0.7212	0.5881	0.5095
k x10^3 (m/h)	1.5760	1.8778	3.2027	4.8924	1.4228	1.3643	1.4708	1.6881

The Biot numbers were expected to be in the range of $0.1 < Bi < 100$, under the experimental drying conditions of which products were dried. This is fundemantally indicative of the presence of both finite internal and external (surface) resistances to moisture transfer. Also in practical applications, this is considered the most realistic case (Dincer and Dost, 1995). The variation in computed Bi numbers, between the range of 0.1010 - 0.7963 for Model-I and 0.1063 - 0.8166 for Model-II, indicates that it is dependent upon the product properties and drying air temperatures.

Based on the *D, Bi* and μ_1 values, the moisture transfer coefficient (*k*) was computed from the Biot number definition Eq.(17) for Model-II and Eq.(18), (19) and (20) infinite slab, infinite cylindrical and spherical products for Model-I, respectively. And values are determined in Table 2. This is an important drying parameter that depends on mass diffusivity, viscosity, velocity of the fluid, and geometry of the transfer system (Saravacos and Maroulis, 2001). The values of k ranged between 4.8190x10^{-3} - 139.73x10^{-3} m/h for slab product, 0.9667x10^{-3} - 5.7555x10^{-3} m/h for cylindrical product and 1.4501x10^{-3} - 4.8924x10^{-3} m/h spherical product using the Model-I and 1.2090x10^{-3} - 2.4974x10^{-3} m/h for slab product, 1.4061x10^{-3} - 2.4431x10^{-3} m/h for cylindrical product and 1.2833x10^{-3} - 1.8195x10^{-3} m/h spherical product using the Model-II.

Using the acquired data from Table 2, dimensionless moisture content profiles were computed for all drying air temperatures and velocities. Dimensionless moisture content profiles were compared with experimental data in order to confirm the applicability of Model-I and Model-II. The estimated dimensionless moisture distribution was acquired using Eq. (7), with A_1 being computed from Eq. (8), (9) or (10) according to suitable geometrical shaped products and B_1 determined from Eq. (11) for all object. Fig. 2, Fig. 3 and Fig. 4 for slab, cylindrical and spherical products, respectively, presents experimental and computed profiles for exemplary. As indicated, the results of the Model-I and Model-II agreed with the experimental moisture content data with reasonable accuracy. McMinn (2004), Dincer and Hussain (2004), Mrkic et al. (2007), Corzo et al. (2008), Liu et al. (2013) reported similar results.

Table 3. Computed Values of Mass Transfer Parameters for Different Temperatures At U=1 m/s

Slab Potato, U=1 m/s								
	Model-I				Model-II			
Parameter	T=45 °C	T=50 °C	T=55 °C	T=60 °C	T=45 °C	T=50 °C	T=55 °C	T=60 °C
Bi	0.7963	0.2396	0.2124	0.1294	0.7519	0.1650	0.1489	0.1063
Dx10^5(m^2/h)	3.8377	9.4998	12.692	18.085	2.9192	8.3237	11.853	23.503
μ_1	0.7275	0.4903	0.4767	0.4338	0.8341	0.5238	0.4933	0.3806
k x10^3 (m/h)	4.8190	39.654	59.757	139.73	2.1949	1.3733	1.7648	2.4974
Cylindrical Potato								
	Model-I				Model-II			
Bi	0.2153	0.1575	0.1366	0.1068	0.2635	0.1814	0.1575	0.1281
Dx10^5(m^2/h)	3.6629	5.7253	6.9518	11.018	5.3363	8.5425	10344	15.944
μ_1	0.7317	0.6280	0.5835	0.5113	0.6062	0.5141	0.4784	0.4250
k x10^3 (m/h)	1.5083	2.3576	2.8626	4.5372	1.4061	1.5495	1.6295	2.0430
Spherical Potato								
	Model-I				Model-II			
Bi	0.2153	0.1888	0.1667	0.1137	0.3801	0.3072	0.2582	0.1633
Dx10^5(m^2/h)	2.7682	3.5849	4.7388	8.9030	3.3760	4.4413	5.9317	11.142
μ_1	0.8591	0.8027	0.7537	06069	0.7779	0.7212	0.6737	0.5425
k x10^3 (m/h)	1.4501	1.8778	2.4824	4.6631	1.2833	1.3643	1.5317	1.8195

5. Conclusions

The paper has presented a theoretical and experimental investigation of drying of moist cylinder, slab and spherical products. The following conclusions can be summarized from the study:

- Rising the drying air temperature and the drying air velocity increase the mass transfer parameters (mass diffusion coefficient and moisture transfer coefficient).
- Model-I and Model-II were able to determine the values of mass transfer coefficient and moisture diffusivity for various geometrical shaped in a simple and quite precise manner.

Figure Captions

Figure 1. The Schematic of The Experimental Setup

Figure 2a. Computed and Measured Dimensionless Moisture Content for Slab Potato for Different T at U=1 m/s

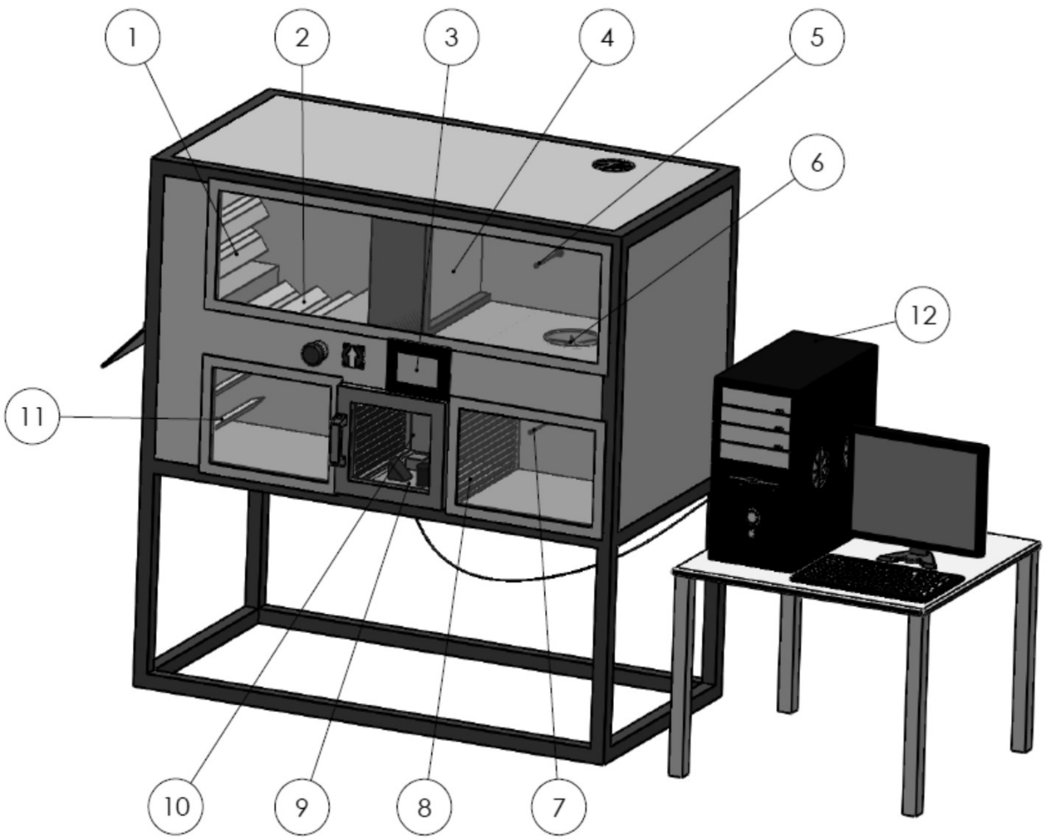
Figure 2b. Computed and Measured Dimensionless Moisture Content for Slab Potato for Different U at T=50ºC

Figure 3a. Computed and Measured Dimensionless Moisture Content for Cylindrical Potato for Different T at U=1 m/s

Figure 3b. Computed and Measured Dimensionless Moisture Content for Cylindrical Potato for Different U at T=50ºC

Figure 4a. Computed and Measured Dimensionless Moisture Content for Spherical Potato for Different T at U=1 m/s

Figure 4b. Computed and Measured Dimensionless Moisture Content for Spherical Potato for Different U at T=50ºC



1) Fresh Air Damper, 2) Mixing Damper, 3) Plc Monitor, 4) Heater,

(5-7) Temperature And Humidity Meters And Velocity Sensor, 6) Fan, 8) Flow Regulator,

9) Precision Balance, 10) Test Section, 11) Exhausting Damper, 12) Computer.

Figure 1. The Schematic of The Experimental Setup

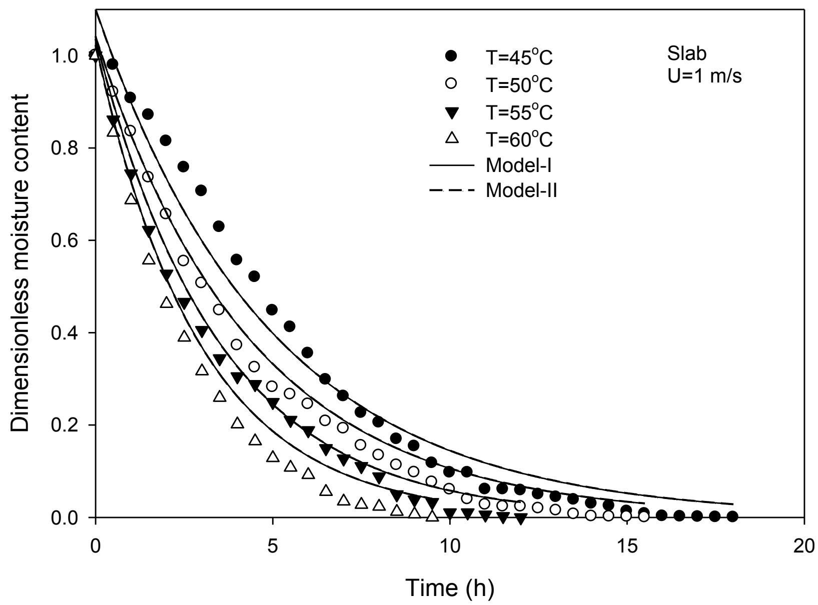


Figure 2a. Computed and Measured Dimensionless Moisture Content for Slab Potato for Different T At U=1 m/s

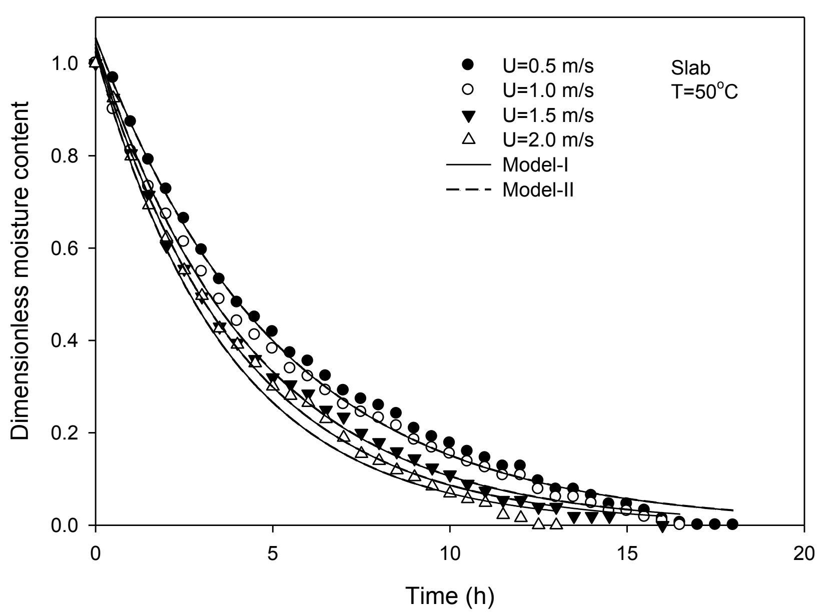


Figure 2b. Computed and Measured Dimensionless Moisture Content for Slab Potato for Different U At T=50°C

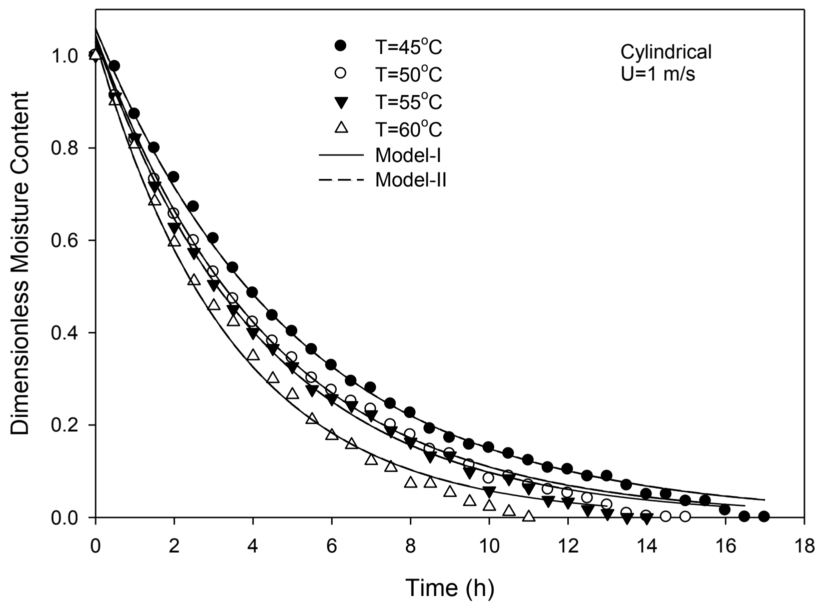


Figure 3a. Computed and Measured Dimensionless Moisture Content for Cylindrical Potato for Different T At U=1 m/s

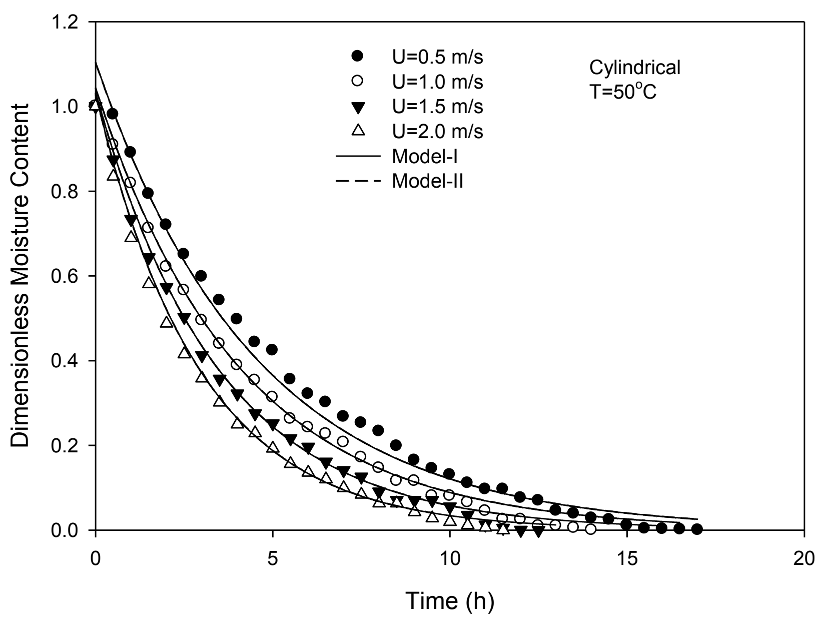


Figure 3b. Computed and Measured Dimensionless Moisture Content for Cylindrical Potato for Different U At T=50°C

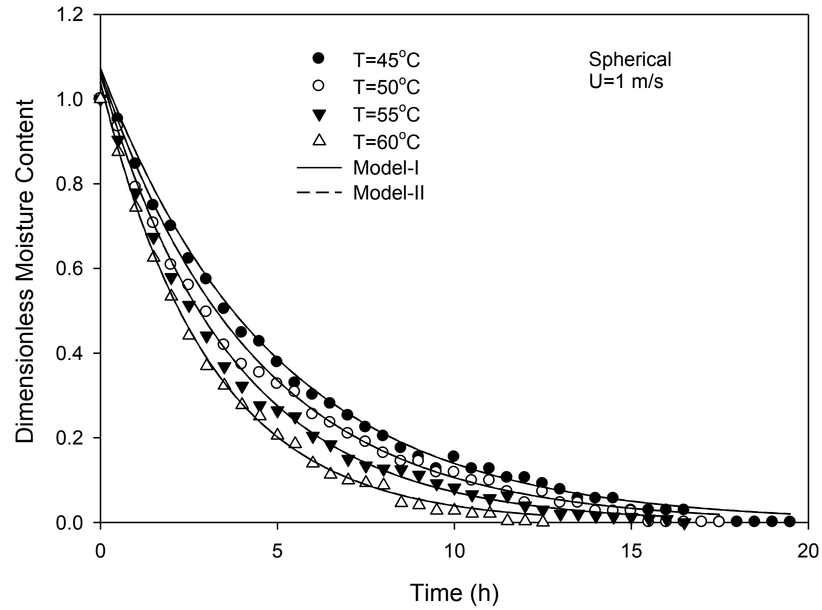


Figure 4a. Computed and Measured Dimensionless Moisture Content for Spherical Potato for Different T At U=1 m/s

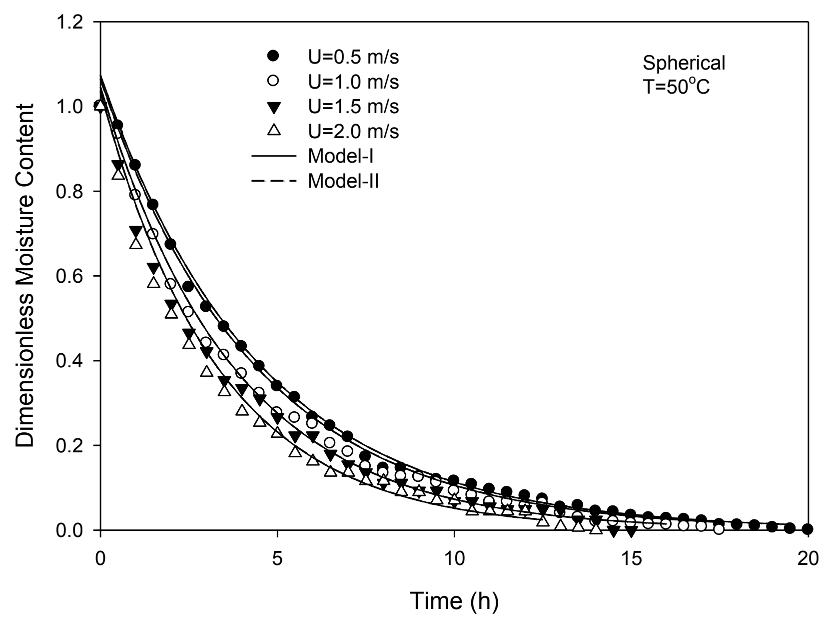


Figure 4b. Computed and Measured Dimensionless Moisture Content for Spherical Potato for Different U At T=50^{o}C

Nomenclature

A_1 constant

B_1 constant

Bi Biot number (dimensionless)

D moisture diffusivity (m^2/h)

Fo Fourier number (dimensionless)

G Lag factor (dimensionless)

k moisture transfer coefficient (m/h)

M moisture content (kg H_2O/kg d.m.)

M_e equilibrium moisture content (kg H_2O/kg d.m.)

M_i initial moisture content (kg H_2O/kg d.m.)

μ_1 root of the transcendental characteristic equation

R^2 correlation coefficient

S drying coefficient (1/h)

t drying time (h)

T air temperature (°C)

U air velocity (m/s)

Y characteristic dimension (m) (half thickness for slab, radius for sphere and cylinder)

ϕ dimensionless moisture content

φ relative humidity

Acknowledgements

The authors acknowledge the financial support provided by Kahramanmaras Sutcu Imam University Scientific Research Fund under Grant No 2013/3-38M.

References

Corzo, O., Bracho, N., Alvarez, C., Rivas, V., Rojas, Y. (2008), "Determining The Moisture Transfer Parameters During The Air-Drying of Mango Slices Using Biot–Dincer Numbers Correlation", J. Food Pro. Engin. 31, 853–873.

Dincer, I., Dost, S. (1995), "An Analytical Model for Moisture Diffusion in Solid Objects During Drying", Drying Technol. 13(1-2), 425–435.

Dincer, I., Dost, S. (1996), "A Modeling Study for Moisture Diffusivities and Moisture Transfer Coefficients in Drying of Solid Objects", Int. J. Energy Res. 20, 531–539.

Dincer, I. (1998), "Moisture Loss from Wood Products During Drying–Part II: Surface Moisture Content Distributions", Energy Source 20(1), 77–83.

Dincer, I., Hussain, M.M. (2002), "Development of A New Bi–Di Correlation for Solids Drying", Int. J. Heat Mass Transfer 45, 3065–3069.

Dincer, I., Hussain, M.M., Sahin, A.Z., Yilbas, B.S. (2002), "Development of A New Moisture Transfer (Bi–

Re) Correlation for Food Drying Applications", Int. J. Heat Mass Transfer 45, 1749–1755.

Dincer, I., Hussain, M.M. (2004), "Development of A New Biot Number and Lag Factor Correlation for Drying Applications", Int. J. Heat Mass Transfer 47, 653–658.

Mcminn, W.A.M. (2004), "Prediction of Moisture Transfer Parameters for Microwave Drying of Lactose Powder Using Bi–G Drying Correlation", Food Res. Int. 37, 1041–1047.

Mrkic, V., Ukrainczyk, M., Tripalo, B. (2007), "Applicability of Moisture Transfer Bi–Di Correlation for Convective Drying of Broccoli", J. Food Engin. 79, 640–646.

Mulet, A., Sanjuan, N., Bon, J., Simal, S. (1999), "Drying Model for Highly Porous Hemisperical Bodies", Europ. Food Res. Tech. 210, 80–83.

Saravacos, G.S., Maroulis, Z.B. (2001), "Transport Properties of Food", Marcel Dekker Press, New York.

Ahmet KAYA was born in Kayseri, 1978. He received the B.S. and M.Sc. degree from Mechanical Engineering, Nigde University, in 1999 and 2002, respectively. He received Ph. D. degree in Mechanical Engineering, Karadeniz Technical University, 2008. Major Field: Fluid Flow, Convective drying, Heat Transfer, external flow, similarity solution. Professor Dr. Kaya has 35 papers published at International journals, 3 International conferences and 4 National conferences.

E-mail address: ekaya38@gmail.com, kaya38@ksu.edu.tr

Muhammed Safa KAMER was born in Kahramanmaras, 1982. He received the B.S. degree from Mechanical Engineering, Selcuk University, in 2004. He received M.Sc. degree in Mechanical Engineering, Kahramanmaras Sutcu Imam University, in 2014. Major Field: Fluid Flow, drying, numerical study.

E-mail address: msafakamer@hotmail.com

Hüseyin Emre ŞAHİN was born in Mugla, 1989. He received the B.S. degree from Mechanical Engineering, Selcuk University, in 2012. Major Field: Fluid Flow, drying, numerical study.

E-mail address: hemreshn@gmail.com