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Research Article

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Experimental investigating and thermodynamic modeling of drying a single body

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ABSTRACT

In this study drying process of a single body in a dryer has been modeled. The proposed model was validated with the experimental data obtained from drying the spherical potatoes. Samples of spherical potatoes at temperatures of 40, 50 and 60°C were dried in a pilot scale dryer and moisture content, surface temperature data was extracted. The proposed model by applying mass and heat balance equations based on thermodynamic equations predicted changes of sample temperature, samples moisture and also entropy generation and exergy. The results show that the moisture content of the samples has a downward and change of air velocity has little effect on drying, but increases the diameter longer drying time. Entropy generation increased rapidly at first and then will deteriorate. Exergy as energy increased during the drying time. Comparison of model results with experimental data approved the proposed model

Keywords: Drying, Thermodynamic, Modeling, Moisture, Exergy, Entropy

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INTRODUCTION

Drying process is one of the main methods of maintaining materials which are perishable, degradable or reactive due to high humidity. Drying process involves a complex process of heat, mass and momentum transfer. The process causes non-destructive and destructive irreversible changes in the physical, chemical and material appearance, such as color, viscosity and in some cases the failure of Hydrocarbons. These changes may result in a drop in product quality. For this reason, drying of each product needs the selection of the best method in optimal condition in order to minimal loss of quality in product and operations performed in the shortest possible time. Drying solid materials is necessary for the following reasons: Convenient use of solids in the later stages of the process, storage and proper maintenance, increase maintenance time, reduce the cost of transportation and achieve optimal quality. In many processes, improper drying may destroy and reduce the quality of the product.

Significant researches have been done in the field of modeling of heat and mass transfer in fixed bed dryer. Here is a brief overview have already been discussed in the form of empirical research and mathematical modeling on drying. Understanding the previous works will help in better understanding this type of dryers. Scientifically, the first drying was about eight thousand years ago in northern France that the smooth rock surface was used for drying materials. They have been dried their crops by using moderate breeze or winds blew in these areas as well as the simultaneous use of sun. Elkann et al. in 1986 studied the effects of temperature and air velocity on the process of drying grain dryer and proposed a model based on the diffusion phenomenon. [4] Chandram et al 1990 proposed a model for drying kinetics of particles in a fluid bed dryer, which included two constant rate and dropping rate of drying. [5] Obeid et al 1990 investigating the theory of heat and mass transfer mechanism in a fluid bed dryer containing inert particles in the laboratory and in this field work on the drying of grain. [6] Jin et al. 2011 studied spray dryer and milk production by the second law of entropy. [7] Jenna et al 2013 provided a model for the penetration of a fluid bed dryer. By studying on mushrooms and vegetable plants, they acquire effective diffusion coefficient and mass transfer coefficient. They provided examples of correction coefficients for permeability samples. Relations obtained compared with neural network showed good agreement that had the ability to use these relationships in the industry

[8]. In this study, firstly in the process of drying, a single body is released freely inside the dryer and at different intervals; mass and surface temperature is checked. After conducting experiments with the establishment of the relevant equations, numerical simulation of drying was done and compared by using MATLAB software and the accuracy of the model was also evaluated. This study investigated the mechanism of simultaneous heat and mass transfer in the process of drying of a single body, mathematical modeling of heat and mass transfer processes in a sample by using mass energy balance, obtaining effective diffusion coefficient by solving Fick's second law, and also obtaining the function of this coefficient in terms of presented variables, predicting variations for samples' average moisture, surface temperature of samples, moisture by using mathematical models and comparing the results obtained from mentioned modeling by using analytical solving of partial differential equations and also compared with experimental results obtained from drying samples.

EXPERIMENTAL SECTION

A single body material dries in air with temperature T_∞ and absolute humidity Y_∞ (Figure 1). By assuming of negligible volume change during the drying, we consider the material as a control volume that the moisture penetrates from Pores on the surface of the water, and exits. Thermodynamic modeling of single body drying is obtained by Establishing of mass, energy and entropy on the materials.

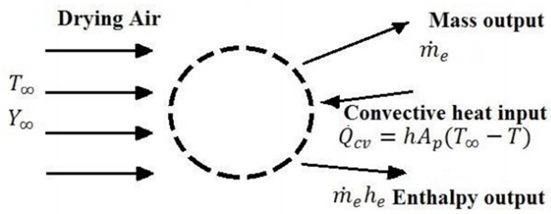

Fig.1: Schematic view of the sample (dotted lines are boundary of control volumes)

2.1 Mass balance

The overall mass balance on a control volume can be expressed as follows [9]:

Accumulation= input – output (1)

$$\frac{dm_{cv}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e \quad (2)$$

If the output mass flow rate of vapor expressed as $\dot{m}_e$, we have:

$$\frac{dm_{cv}}{dt} = -\dot{m}_e \quad (3)$$

Where mass flow rate of the exhaust gas are obtained from mass diffusion equation as follows:

$$\dot{m}_e = k_y A_p \rho_{air}(Y_e - Y_\infty) \quad (4)$$

Where k_y mass transfer coefficient ($\frac{m}{s}$) and Y_e و Y_∞ are the absolute humidity of vapor on the surface of sample and in drying air respectively. If represent mass variation of the average humidity on dry basis:

$$m_s \frac{d\bar{X}}{dt} = -k_y A_p \rho_{air}(Y_e - Y_\infty) \quad (5)$$

Y_e in equation (5) is the equilibrium absolute humidity of the gas phase on the surface of the sample that can be calculated directly by empirical relationships or by relative humidity of drying sample surface as follows [10].

$$Y_e = \frac{M_{water}}{M_{air}} \frac{a_w(X,T)P_{sat}(T)}{P_t - a_w(X,T)P_{sat}(T)} \quad (6)$$

Where a_w is the water activity or relative humidity (RH) of water vapor on the surface of the drying at temperature and humidity levels of sample surface that calculated from the empirical formula. The average moisture content in a sphere of radius R is obtained as follows [11]:

$$\frac{\bar{X}(t) - X_e}{X_0 - X_e} = \frac{6}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{n^2} \exp\left(-n^2 \pi^2 \frac{D_e t}{R^2}\right) \quad (7)$$

2.2 Energy balance

The first law of thermodynamics for a control volume can be written as follows [9]:

$$\frac{dE_{cv}}{dt}=\frac{dU_{cv}}{dt}=\dot{Q}_{cv}-\dot{W}_{cv}+\sum\dot{m}_i\left(h_i+\frac{1}{2}v_i^2+gz_i\right)-\sum\dot{m}_e\left(h_e+\frac{1}{2}v_e^2+gz_e\right) \quad (8)$$

The term of the above equation by eliminating the work and energy input with input mass and potential and kinetic energy can be summarized as follows:

$$\frac{dU_{cv}}{dt}=\frac{d(mu)_{cv}}{dt}=\dot{Q}_{cv}-\dot{m}_e h_e \quad (9)$$

For solids and liquids [9]:

$$dh\approx du\approx CdT \quad (10)$$

$$h_2-h_1\approx u_2-u_1\approx C(T_2-T_1) \quad (11)$$

As a result, the internal energy of the reference temperature is the following:

$$u\approx h\approx C(T-T_0) \quad (12)$$

Where by considering the reference temperature $T_0=0$ or ignoring $\frac{d(mCT_0)}{dt}$ we have:

$$\frac{d[mC(T-T_0)]_{cv}}{dt}=\frac{d(mCT)_{cv}}{dt}=\dot{Q}_{cv}-\dot{m}_e h_e \quad (13)$$

Sample input heats consist of convective heat transfer from drying air temperature T_∞ to sample by temperature variation of T:

$$\dot{Q}_{cv}=hA_p(T_\infty-T) \quad (14)$$

Outlet enthalpy is the enthalpy of the output vapor, which lead to:

$$h_e=\lambda_0+c_v(T-T_0)\approx\lambda(T) \quad (15)$$

As a result:

$$\dot{m}_e h_e=m_s\frac{d\bar{X}}{dt}\lambda \quad (16)$$

And the definition of average moisture content in dry basis:

$$\bar{X}=\frac{m-m_s}{m_s} \quad (17)$$

$$m=m_s(1+\bar{X}) \quad (18)$$

And definition of heat capacity of wet material according to heat capacity of water and dry material concluded [10]:

$$C\approx C_P^S+\bar{X}C_P^W \quad (19)$$

By replacing equation (14), (15), (16), (18) and (19) in equation (13) we have:

$$\frac{d(m_sC_P^ST+\bar{X}m_sC_P^WT)}{dt}=hA_p(T_\infty-T)+m_s\frac{d\bar{X}}{dt}\lambda \quad (20)$$

$$m_sC_P^S\frac{dT}{dt}+m_sC_P^W\frac{d(\bar{X}T)}{dt}=hA_p(T_\infty-T)+m_s\frac{d\bar{X}}{dt}\lambda \quad (21)$$

$$m_sC_P^S\frac{dT}{dt}+m_sC_P^W\left(T\frac{d\bar{X}}{dt}+\frac{\bar{X}dT}{dt}\right)=hA_p(T_\infty-T)+m_s\frac{d\bar{X}}{dt}\lambda \quad (22)$$

$$m_s(C_P^S+\bar{X}C_P^W)\frac{dT}{dt}=-T\left(m_sC_P^W\frac{d\bar{X}}{dt}\right)+m_s\frac{d\bar{X}}{dt}\lambda+hA_pT_\infty \quad (23)$$

$$\frac{dT}{dt}=\frac{m_s\frac{d\bar{X}}{dt}\lambda+hA_pT_\infty}{m_s(C_P^S+\bar{X}C_P^W)}-T\frac{m_sC_P^W\frac{d\bar{X}}{dt}}{m_s(C_P^S+\bar{X}C_P^W)} \quad (24)$$

This equation is differential equation of surface temperature of sample during drying. It is assumed that the above relationships sample temperature is uniform everywhere as a function of time.

2.3 Entropy balance (second law of thermodynamic)

Second law of thermodynamics for a control volume is defined as follows [9]:

$$\frac{dS_{cv}}{dt} = \sum \dot{m}_i\, s_i - \sum \dot{m}_e\, s_e + \frac{\dot{Q}_{cv}}{T} + \dot{S}_{gen} \tag{25}$$

That it simplify for single body as follows:

$$\frac{dS_{cv}}{dt} = -\dot{m}_e s_e + \frac{\dot{Q}_{cv}}{T} + \dot{S}_{gen} \tag{26}$$

Because output entropy is equal to output entropy of the water evaporated during drying, s_e is written as follows [15]:

$$s_e = \frac{\dot{Q}_{cv}}{T} \approx \frac{\Delta H_{ev}}{T} = \frac{\lambda}{T} \tag{27}$$

According to $\dot{Q}_{cv}$ where is equivalent to convective heat received by the sample we have:

$$\frac{dS_{cv}}{dt} = \frac{d(ms)_{cv}}{dt} = -\dot{m}_e \frac{\lambda}{T} + \frac{hA_p(T_\infty - T)}{T} + \dot{S}_{gen} \tag{28}$$

The amount of entropy generated by integrating both sides of equation (37) at time interval from zero to t is obtained as follows:

$$S_{12\,gen} = \int_0^t \frac{d(ms)_{cv}}{dt} d + \int_0^t \dot{m}_e \frac{\lambda}{T} dt - \int_0^t \frac{hA_p(T_\infty - T)}{T} dt \tag{29}$$

2.4 Exergy

Accumulation of exergy in a control volume without shaft and boundary work was determined as [9]:

$$\frac{d(Ex)_{cv}}{dt} = \frac{dE_{cv}}{dt} - T_0 \frac{dS_{cv}}{dt} - (h_0 - T_0 s_0) \frac{dm_{cv}}{dt} \tag{30}$$

Apart from the variation of mass in the control volume at a small time interval dt for obtain exergy, multiply parties of equation (26) to the basis temperature T_0 and subtract the result from energy equation (13) therefore exergy equation can be obtained as follows [12]:

$$\frac{d(Ex)_{cv}}{dt} = \dot{Q}_{cv} - \dot{m}_e h_e + \dot{m}_e s_e T_0 - \frac{\dot{Q}_{cv}}{T} T_0 - \dot{S}_{gen} T_0 \tag{31}$$

According to definition $\dot{Q}_{cv}$ ، h_e ands_e from equations (14), (15) and (27) we have:

$$\frac{d(Ex)_{cv}}{dt} = hA_p(T_\infty - T)\left[1 - \frac{T_0}{T}\right] - \dot{m}_e\left[h_e - \lambda \frac{T_0}{T}\right] - \dot{S}_{gen} T_0 \tag{32}$$

2.5 Solving method

The average humidity in an explicit form is obtained from equation (5) or (7). Surface temperature is obtained by solving the differential equation (24) by a finite difference method. By writing central difference of temperature and moisture, around the point i, n +1 / 2 as follows:

$$\left.\frac{dT}{dt}\right|_{n+1/2} = \frac{T_{n+1} - T_n}{\Delta t} \tag{33}$$

$$\left.\frac{d\bar{X}}{dt}\right|_{n+1/2} = \frac{\bar{X}_{n+1} - \bar{X}_n}{\Delta t} \tag{34}$$

$$T_{n+1/2} = \frac{T_{n+1} + T_n}{2} \tag{35}$$

$$\bar{X}_{n+1/2} = \frac{\bar{X}_{n+1} + \bar{X}_n}{2} \tag{36}$$

And replacing them in equation (24), we obtain the following equation of temperature:

$$T_{n+1} = T_n \frac{\left[1 - \frac{1}{2}\frac{dt\left(m_s C_P^W \frac{\bar{X}_{n+1} - \bar{X}_n}{\Delta t} + A_p h\right)}{m_s\left(C_P^S + C_P^W \frac{\bar{X}_{n+1} + \bar{X}_n}{2}\right)}\right]}{\left[1 + \frac{1}{2}\frac{dt\left(m_s C_P^W \frac{\bar{X}_{n+1} - \bar{X}_n}{\Delta t} + A_p h\right)}{m_s\left(C_P^S + C_P^W \frac{\bar{X}_{n+1} + \bar{X}_n}{2}\right)}\right]} + \frac{\left[\frac{dt\left(m_s \lambda \frac{\bar{X}_{n+1} - \bar{X}_n}{\Delta t} + A_p h T_a\right)}{m_s\left(C_P^S + C_P^W \frac{\bar{X}_{n+1} + \bar{X}_n}{2}\right)}\right]}{\left[1 + \frac{1}{2}\frac{dt\left(m_s C_P^W \frac{\bar{X}_{n+1} - \bar{X}_n}{\Delta t} + A_p h\right)}{m_s\left(C_P^S + C_P^W \frac{\bar{X}_{n+1} + \bar{X}_n}{2}\right)}\right]} \tag{37}$$

To calculate the entropy generated during the drying process. If be considered average quantity $m^{-}$and^{-}T in a small time interval Δt for the mass m and temperature T, Equation (29) can be simplified as follows:

$$S_{12\,gen} = \bar{m}\int ds + \dot{m}_e \frac{\lambda}{\bar{\bar{T}}}\Delta t - \frac{hA_p(T_\infty - \bar{T})}{\bar{T}}\Delta t \quad (38)$$

And in liquids and solids [9]:

$$ds \approx \frac{du}{T} \approx \frac{C}{T}dT \quad (39)$$

$$S_{12\,gen} = \bar{m}\bar{c}ln\frac{T_2}{T_1} + \dot{m}_e \frac{\lambda}{\bar{\bar{T}}}\Delta t - \frac{hA_p(T_\infty - \bar{T})}{\bar{T}}\Delta t \quad (40)$$

That:

$$\bar{m} = \frac{m_{n+1} + m_n}{2} = m_{n+1/2} \quad (41)$$

$$\bar{T} = \frac{T_{n+1} + T_n}{2} = T_{n+1/2} \quad (42)$$

To calculate exergy increase in the control volume by omission $\frac{dm}{dt}$ at short time intervals Δt and thus multiply both sides of equation (32) at dt and integrating we have:

$$Ex_{12} = \Delta Ex_{cv} = hA_p(T_\infty - \bar{T})\left[1 - \frac{T_0}{\bar{\bar{T}}}\right]\Delta t - \dot{m}_e\left[h_e - \lambda\frac{T_0}{\bar{\bar{T}}}\right]\Delta t - S_{12\,gen}T_0 \quad (43)$$

At first to solve the model by knowing initial temperature and moisture, these variables obtained at the period of time n +1. The moisture content can be achieved in two ways. 1- Using the empirical relationship of equation (6), which this is function of temperature and moisture content and then calculating Y_e of gas and finally moisture content at time n +1 by equation (5). 2- Using Fick's law and obtain effective diffusivity coefficient D_e and equilibrium moisture content $\bar{X}_e$ and using equations (7) to obtain the moisture content at the time n +1. After obtaining moisture content for calculation of sample temperature at time n +1 where is function of T_n ,$\bar{X}_n$and $\bar{X}_{n+1}$ equation of (39) was used. To calculate the entropy production and exergy the amount of mass was calculated in time n +1 by the equation $m_{n+1} = m_s(1 + \bar{X}_e)$. Now, with T_{n+1} and $\bar{X}_{n+1}$ again to calculate $\bar{X}_{n+2}$ and the calculation of the loop continued until the equilibrium moisture content of sample reached the equilibrium moisture content at that gas temperature and sample temperature reached input gas temperature. After determining theses variable, entropy production and exergy was obtained by equation (40) and (43) respectively.

2.6 Method of preparing sample and experiment

Potato samples were purchased from a store in the city of Rasht and after peeling prepared in form of spheres with 2 and 3 cm diameters, then placed into plastic packages and was maintained for 24 hours in the refrigerator at 4 ° C, because moisture content in the samples to be homogeneous. Average mass of each sample with 2 and 3 cm diameters were 5.5±0.1 and 17±0.1 respectively; and the average moisture of selected samples were 4.2±0.05 at dry basis.

Experimental data of drying were extracted from a pilot dryer that designed for this purpose. Schematic view and photograph of the dryer is shown in figure 2 and consists of four main parts:

1 - Blower that blow gas with a maximum velocity of 3.5 into the heater.
2– Heater that was including heating elements with power 3000 watts.
3 – Main part of this dryer was temperature controller and hold inlet air temperature with accuracy of 0.1 Celsius degrees at desired value.
4 – Drying column that was made from cylindrical glass with a diameter of 7.8 cm and materials placed to dry in this section. Air velocity were measured by the tachometer (Anemometer, Model: AM-4200, Taiwan) with an accuracy of 0.1 that represent velocity in meters per seconds.

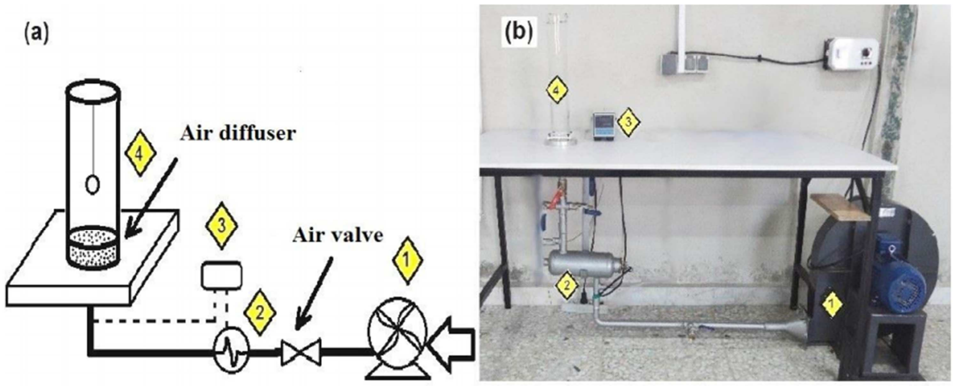

Fig.2: Schematic view (a) and photograph (b) pilot dryer designed for experiment (1 - Blower 2 –Heater 3 - Temperature controller 4 – Drying column)

2.7 Thermodynamic equations
Some physical properties of samples and input gas are provided in table 1.

Table 1: Physical and thermal properties of experimental samples and air

Property	Equation	Reference
Latent heat	$\lambda = 2501.3 - 2.301T(℃) - 0.00142T^2(℃)^2$	[13]
j/(kg.k) The specific heat capacity of water	$C_V=1.883*10^3 - 1.6763*10^{-1}\ T + 8.4386*10^{-4}T^2-2.6966*10^{-7}\ T^3$	[14]
j/(kg.k)The specified heat capacity of potato	$Ca=1009.26-0.0040403\ T+6.1756*10^{-4}T^2-4.097*10^{-7}T^3$	[15]
Volatility factor of water in the potato	$C_p=\frac{4.19\ P}{100}+\frac{0.84\ (100-P)}{100}$, $\frac{p}{100}=Xwet$	[16]
Saturation pressure	$\lambda = 2501.3 - 2.301T(℃) - 0.00142T^2(℃)^2$	[17]
$(\frac{kg}{m^3})$Air density	$\rho_{air} = \frac{101.325}{(0.287\ T_{abs})}$	[18]

2.8 Error Estimation in Modeling Process
In order to investigate the simple and interactive effects of process in different thermal conditions and speed and processing curves, various statistical parameters such as the correlation coefficient (R^2) and root mean square error (RMSE) were used as follows:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=0}^{N}(\overline{C}(i)_{Exp} - \overline{C}(i)_{predicted})^2} \tag{44}$$

$$R^2 = 1 - \sqrt{\frac{\sum_{i=1}^{N}(\overline{C}(i)_{Exp} - \overline{C}(i)predicted)^2}{\sum_{i=1}^{N}(\overline{C}(i)_{Exp} - \overline{C}_m)^2}} \tag{45}$$

In order to evaluate the deviation of the results of the proposed model to experimental data, percent relative error between the predictions of polynomial approximation method and experimental data and also accurate analytical predictions and experimental data, the following equation were used:

$$E(t) = 100 \times \left|\frac{\overline{C}(t)_{Exp} - \overline{C}(t)_{predicted}}{\overline{C}(t)_{Exp}}\right| \tag{46}$$

That mean relative error in total operating range is as follows:

$$MRE = \overline{E} = \frac{1}{N}\sum_{i=0}^{N} E_i \tag{47}$$

Where N is the number of time slots during the entire process over time. Software used for data analysis was MATLAB and Cftool toolbox.

RESULTS AND DISCUSSION

At first heat transfer coefficient obtained for different geometric shapes, and after calculating D_e , investigating the model and its experimental data have been done.

3.1 Calculation of heat transfer coefficient (h)

Heat transfer coefficient obtained by measuring temperature variation of metals and plotted $\ln(\frac{T-T_\infty}{T_0-T_\infty})$ versus time, according to the following equation.

$$ln(\frac{T-T_\infty}{T_0-T_\infty}) = -(\frac{hA}{mc_p})t \tag{48}$$

figure shows the changes $\ln\left(\frac{T-T_\infty}{T_0-T_\infty}\right)$ versus time for heat transfer coefficient of sphere with a diameter of 2 cm at temperature of 50 Celsius degrees and a velocity of 1 m / s. Calculation of biot number has confirmed assuming of compact heat capacity of (Bi <0.1) and show the accuracy of the calculations biot number for sphere obtained 0.032. Heat transfer coefficient for sphere with 2 diameters and the air velocity of 1 and 2 m/s were obtained 98.6 and 181.1, respectively, and for sphere with 3 diameters were 53.5 and 129.5. The values of h with errors for sphere and slab are shown in table, respectively.

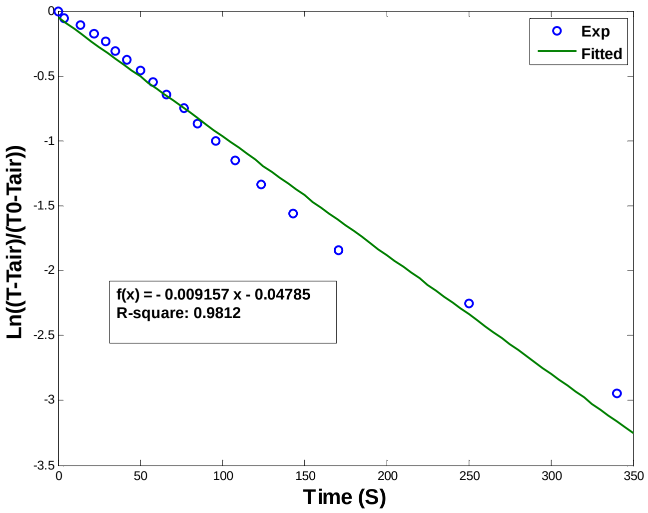

Fig.2: Plot of log dimensionless temperature versus time for the heat transfer coefficient of sphere with diameter of 2 cm and at velocity 1 m/s (h= 98/6 $\frac{w}{m^2k}$)

Table 2: The values of heat transfer coefficient at different conditions for the slab

$v_{air}(\frac{m}{s})$	1m/s		2m/s	
D (cm)	2 Cm	3 Cm	2 Cm	3 Cm
h $(\frac{w}{m^2k})$	98.6	53.5	181.1	129.5
R^2	0.981	0.978	0.976	0.969
RMSE	0.11	0.15	0.16	0.18

3.2 Calculation of effective diffusion coefficient of moisture in potato

To obtain D_e it was used the second law of Fick's equation at infinite sphere equation (7). Therefore, using the first Series of equations (7) the amount of D_e was calculated. If the variation of $Ln\frac{\bar{X}-X_e}{X_0-X_e}$ versus time be plotted, obtained slope for sphere with diameter of 2 cm equals $-\frac{542.79}{R^2}D_e$. Figure shows the variation of $Ln\frac{\bar{X}-X_e}{X_0-X_e}$ with time for drying potato at 50 Celsius degrees temperature.

Table 3: Values of D_e for potato at three input gas temperature with unit m^2/min.

T(°C)		40	50	60
$D_e(\frac{m^2}{min})$ $\times10^{-9}$	D=2Cm	1.1	1.36	1.76
	D=3Cm	1.81	1.79	2.63
RMSE	D=2Cm	0.042	0.057	0.054
	D=3Cm	0.046	0.033	0.028

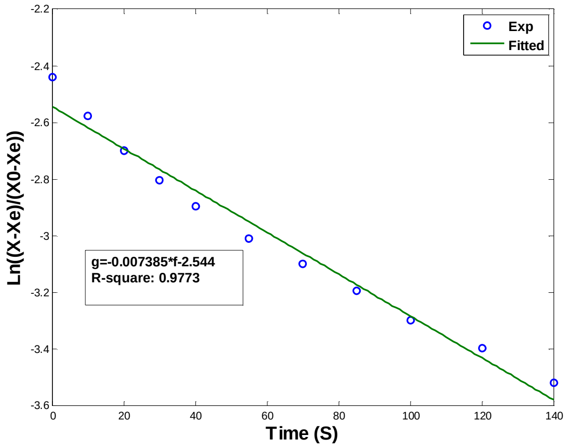

Fig.4: calculating D_e for potato at 50 degrees Celsius temperature and 1 m/s velocity by plotting the logarithm of the dimensionless moisture ratio versus time.

3.3 Moisture Investigation

After calculating the heat and mass transfer coefficients and effective diffusion coefficient of moisture in potato, the values were used in the model and the results of the model were compared with experimental data. Figure shows variation of moisture content versus time for potato. The results indicated an acceptable fit with the experimental values of moisture and model, thus validated the proposed model. Figures show that potato drying in all period of the drying was performed at falling rate zone where indicates the internal moisture diffusion of sample controls the drying. The mean relative error (MRE) between experimental data and model for potato with 2 diameters at air temperatures of 40, 50 and 60 ° C was 2.6, 2.8 and 3.5. for potato with 3 diameter at given temperature was 3.03, 4.2, and 2.86. Low and acceptable levels of errors indicate reliability and validity of the proposed model. Error rate increased that with increasing diameter of the model prediction accuracy will be reduced thus the proposed model is accurate for objects with small diameter or thickness.

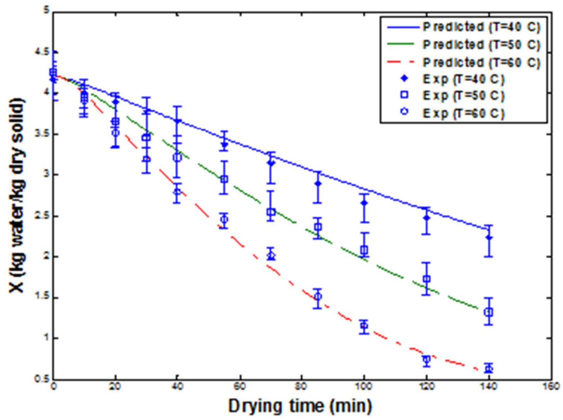

Fig.5: variation of moisture content for spherical potato with diameter of 2 cm at 1 m/s velocity and at different temperatures

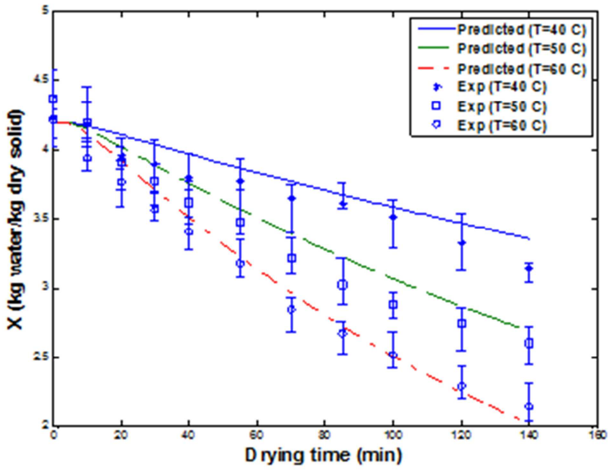

Fig.6: variation of moisture content for spherical potato with diameter of 3 cm at 1 m/s velocity and at different temperatures

Figure shows the effect of velocity (flow) of drying on the drying rate and drying curve. Figures show that although increased air velocity resulting in increased heat and mass transfer coefficients, but the velocity increase did not noticeable effect on the drying. This was confirmed the fact that controlling mechanisms of drying foods such as tea and potato related the moisture within the samples.

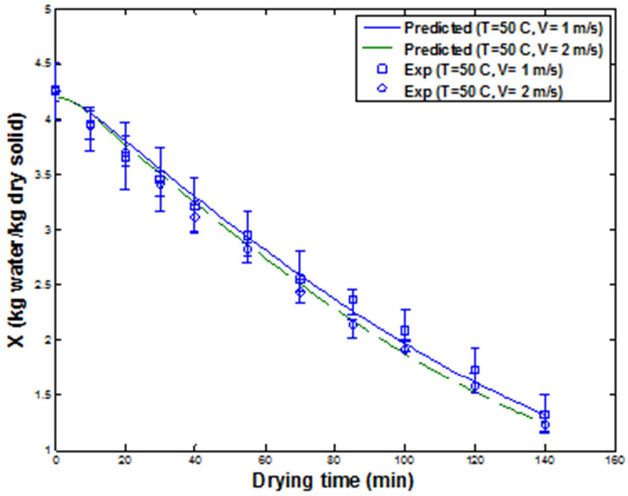

Fig. 7: The effect of velocity on the drying curve of potato with diameter of 2 cm at 50 ° C

3.4 Surface temperature investigation

The values of samples surface temperature are shown at three temperatures. Figure shows the temperature variations of potato with 2 and 3 diameters with time. Figures show the temperature predicted by the model matched the experimental temperature measured at the surface of the material. The mean relative error (MRE) between the experimental data and the results predicted by the model for potato with 2 diameter at temperatures of 40, 50 and 60 degrees Celsius was equal to 5.5, 3.3 and 3.1, and for potato with 3 diameter at given temperatures was 7.4, 4.2, 3.8. Figures show that round potato according to the thickness of the sample rapidly reached up gas temperature. Result show that this model is more accurate for objects with small diameter and by increasing the thickness and diameter of the sample temperature profile is created which leads to errors.

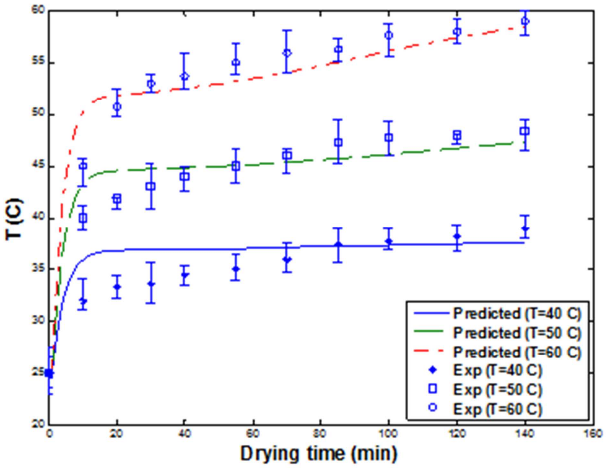

Fig.8: Comparison between predicted temperatures by the model with experimental data for potato drying with diameter of 2 cm and with a velocity of 1 m/s and different temperatures

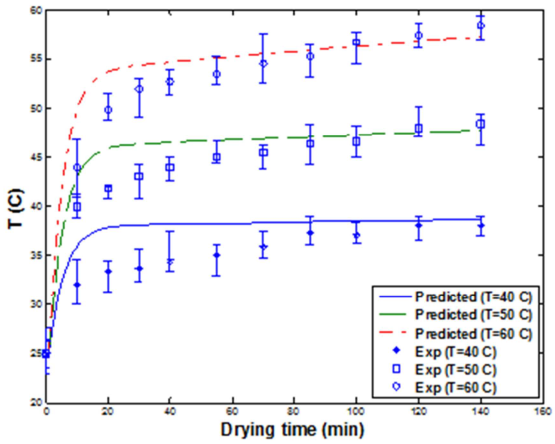

Fig.9: Comparison between predicted temperatures by the model with experimental data for potato drying with diameter of 3 cm and with a velocity of 1 m/s and different temperatures

3.5 Entropy and Exergy Investigation

Figure 16, shows the variation of entropy production for spherical potato at different drying gas temperature. Figures show that at first entropy production significantly increases due to the increase in the sample temperature. But gradually be low, with drying and diminishing sample temperature variance. Also at higher temperature of input gas due to dry, entropy production more quickly reached to zero. [20]

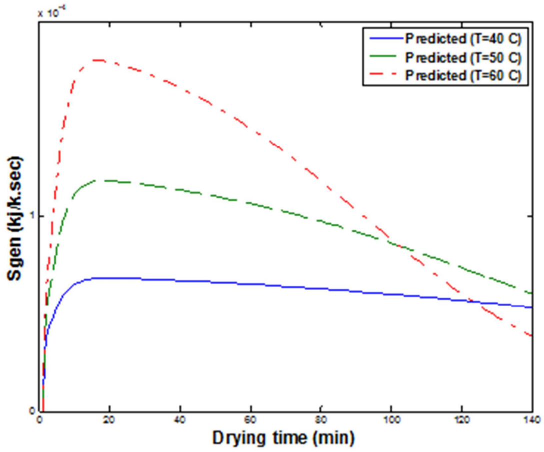

Fig.10: Entropy production variation for potato with diameter of 2 cm and at 1 m/s velocity and different temperatures

Figure shows the increase in the exergy of potato (D= 2cm) during drying at different temperatures. Exergy increases rapidly at first, but after a while it will reach a constant value. According to equation 43, entropy production and steam output of the material lead to zero over time. On the other hand, surface temperature is constant so exergy difference in two time periods is zero. [12,21]

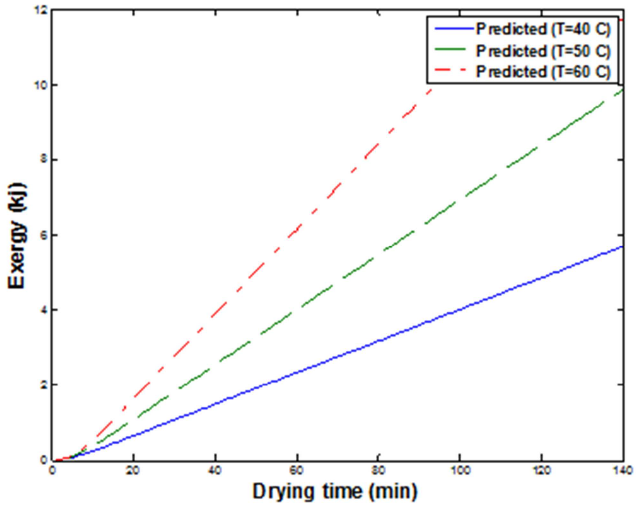

Fig.11: Increase in exergy for potato with diameter of 2 cm during drying at 1 m/s velocity and different temperatures

CONCLUSION

Laboratory data shows that during the drying process, drying rate is not constant and drying has been dropping from the beginning. It means that immediately after the particles are exposed to the dryer's air, due to the low external resistance against heat and mass transfer, surface moisture will be disposed too fast. After the passage of time and progress the process of drying, moisture excretion is significantly reduced. Because the moisture inside the particle encounters with the internal diffusion resistance and gradually penetrates the surface of the particle. This process suggests that for this type of material, the initial rate of drying is high. And after a while, due to the emergence of a dry layer (decrease of outside moisture), drying rate reduced very fast. According to the curves, it was observed that the thermodynamic model for thin objects both in temperature and humidity will be very close but in the case of thick objects the maximum difference between the predicted and experimental moisture is available. According to the observations, the rate of drying is not much dependence to the speed and flow rate of drying air, because by changing the speed, the amount of h increases that doesn't have so much effect in the equation. Entropy production is increased in the beginning with increasing inlet air temperature but after the drying it has been falling. The increase of exergy in the case of dryer shows rising rate that after a while reaching to a fixed amount. Exergy indicates increase during drying and finally it is close to a constant value.

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