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The Modeling of Mass and Heat Transfer of Dryers during the Drying Process

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ABSTRACT

In this research has been studied the modeling of mass and heat transfer in dryers. Initially the attend to study of accomplished things on the various geometry of materials that must have been dry ;then is proposed an modeling for a spherical shell that is the dominant form in drying fruits .Provided model due to the heat and mass profiles ,can predict the moisture content during the drying process. In the end provided a numerical method for solving the dryer equation.

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INTRODUCTION

Drying is one of most important operation units in the industry such as food production , pharmacy , sewage filtration ,etc [1] . this operation is involve several mechanisms of mass and heat transfer .However, the water transfer in the under survey product generally to be consider as a controller factor; and usually this transfer based on diffusion mechanism and study according to the second law of fick [2-6].In addition heat transfer within solids generally take place by conduction mechanism [7-8] . Mass and heat transfer equation at unsteady state for moisture diffusion and energy conduction within homogeny and convergent material (being shown by V_β) is provided by Ruiz Lopez etal [8] .

$$\frac{\partial(\rho_{d\beta}X_\beta)}{\partial t}=\nabla.[D_{eff}\nabla(\rho_{d\beta}X_\beta)] \quad in \quad V_\beta \tag{1}$$

$$\frac{\partial(\rho_\beta C_p T_\beta)}{\partial t}=\nabla.[k_{eff}\nabla(T_\beta)] \quad in \quad V_\beta \tag{2}$$

In addition, mass and heat transfer at product level ($A_{\beta\gamma}$) is expressed by boundary condition. Here the mechanism is considered for mass and heat transfer from product level to air mass [8] .

$$h_{m\infty}\rho_{d\gamma}(X_{\gamma i}-X_\gamma)=-n.D_{eff}\nabla(\rho_{d\beta}X_{\beta i}) \; on \quad A_{\beta\gamma} \tag{3}$$

$$h_{C\infty}(T_{\gamma i}-T_\gamma)=-n.k_{eff}\nabla(T_{\beta i})+n.Q.D_{eff}\nabla(\rho_{d\beta}X_{\beta i}) \quad on \quad A_{\beta\gamma} \tag{4}$$

In addition, the moisture content of the air and temperature at level between air and solid can be represented by the following equilibrium relations [8] .

$$X\gamma i=f(X_{\beta i},T_{\beta i}) \quad on \quad A_{\beta\gamma} \tag{5}$$

$$T_{\gamma i}=T_{\beta i} \quad on \quad A_{\beta\gamma} \tag{6}$$

Several researcher use from equation 1-6 for the production behavior study from flat surface, parallel tubular, circular cylinder or sphere forms, that by these equation they can examine the drying mechanism during the process [2, 9-11]. However, in some cases these geometries of simple, may not reflect the exactly the result shape. The importance of taking into account the actual shape of solids that must to be dry, is expressed in some of the references. Though a inadequate assumption or simplifier in the shape may lead to the excess or less

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estimation in mass transfer. Therefore, many researchers focus on the geometries of that are not such as traditional geometries. For example, Dolyma and nebra examined the drying process of like-circular solids that were generally like-banana [6]. Di Matteo et al presented an analytical solution for mass transfer equation in drying fruits that have shapes of like curve spherical [7]. Analysis on a similar geometry as well as was studied by Diane flash and salty to study of mass and heat transfer during the drying process of porous rocks for compressed air energy storage[5]. Dokarmo and Dolyma predicted the lentil dried behavior using a system that is fit with it shape [6].

Most of the references that mentioned, were based on traditional shapes and did not focus on incomplete shapes, information is very low about incomplete shapes. Among of the above tasks, ben *et al* presented a semi-analytical solution for mass transfer equation with a hemispherical shape that predicted the moisture behavior in fungu, apricot leaf, coffee grain and semi-cantaloupe[3]. In addition, in recent works, researchers examined the same geometry shape for mass transfer in apricot leaf were lost water the take place only from hemisphere outer portion recently, Hernandez Diaz *et al* using spherical drawn geometry the proposed a model of mass and heat transfer for coffee green bean drying. In addition, he using the geometry and simulated behavior with an average dried kinetic and diffusion length due to the flat shape of the product, proposed a simple expression for dried time prediction of product [11]. Shape that selected in this research for study is a hemisphere that part of it in fruits is empty due to core existence. The geometry is an complex geometry and give a more accurate approximation of mass and heat transfer in dryers, because it is not based on traditional geometries that behave a simplification and affect the results.
In total, this shape is very closer to existence reality.

2-Modeling theory:

Equation 1-4 can be rewritten again dimensionless. Equation as well as rewritten in spherical coordinate and gradient and divergence as well as are open the corresponding results for a product with a hemispherical geometry as figure 1 is obtained by the following relation[12].

$$\frac{\partial \Upsilon_j}{\partial \tau}=\frac{1}{\xi^2}\frac{\partial}{\partial \xi}\left[\alpha_j \xi^2 \frac{\partial H_j}{\partial \xi}\right]+\frac{1}{\xi^2 \sin\theta}\frac{\partial}{\partial \theta}\left[\alpha_j \sin\theta \frac{\partial H_j}{\partial \theta}\right]+\frac{1}{\xi^2 \sin^2\theta}\frac{\partial}{\partial \varphi}\left[\alpha_j \frac{\partial H_j}{\partial \varphi}\right] \tag{7}$$

$$\xi_{\min}\le \xi \le 1, -\frac{\pi}{2}\le \theta \le \frac{\pi}{2}, 0\le \varphi \le \pi$$

$$n.\beta_{jk}\frac{\partial H_{ki}}{\partial \xi}e_R=-\delta_j \psi_{ji} \qquad for \qquad \xi=\xi_{\min},1 \tag{8}$$

$$n.\frac{\beta_{jk}}{\xi}\frac{\partial H_{ki}}{\partial \theta}e_\theta=-\delta_j \psi_{ji} \qquad for \qquad \theta=-\frac{\pi}{2},+\frac{\pi}{2} \tag{9}$$

$$n.\frac{\beta_{jk}}{\xi \sin\theta}\frac{\partial H_{ki}}{\partial \varphi}e_\phi=0 \qquad for \qquad 0\le \varphi \le 2\pi \tag{10}$$

Obtained in the following, groups and dimensionless variable

$$\psi_1=\frac{X_\beta - X_{\beta e}}{X_{\beta 0}-X_{\beta e}} \qquad \psi_2=\frac{T_\beta - T_\gamma}{T_{\beta 0}-T_\gamma} \qquad \tau=\frac{D^o_{eff}t}{R^2} \qquad \xi=\frac{r}{R} \tag{11}$$

$$\Upsilon_1=\eta_1\psi_1+\nu_1\eta_1 \qquad \Upsilon_2=\eta_2\psi_2+\nu_2\eta_2 \qquad H_1=\Upsilon_1 \qquad H_2=\psi_2 \tag{12}$$

$$\eta_1=\frac{\rho_{d\beta}}{\rho^o_{d\beta}} \qquad \eta_1=\frac{\rho_\beta C_p}{\rho^o_\beta C^o_p} \qquad \nu_1=\frac{X_{\beta e}}{X_{\beta 0}-X_{\beta e}} \qquad \nu_2=\frac{T_\gamma}{T_{\beta 0}-T_\gamma} \tag{13}$$

$$\alpha_1=\frac{D_{eff}}{D^o_{eff}} \qquad \alpha_2=\frac{k}{Lu} \qquad \delta_1=\frac{2Bi_m}{1-\xi_{\min}} \tag{14}$$

$$\beta_{11}=\alpha_1 \qquad \beta_{12}=0 \qquad \beta_{21}=\alpha_1 \nu\sigma Ko Lu \qquad \beta_{22}=\kappa \tag{15}$$

$$\xi_{\min}=\frac{\varepsilon}{R} \qquad \kappa=\frac{k_{eff}}{k^o_{eff}} \qquad \nu=\frac{Q}{Q^o} \qquad \sigma=\frac{\rho^o_{d\beta}}{\rho^o_\beta}=\frac{1}{1+X^o_\beta} \tag{16}$$

$$Bi_m=\frac{K_{eq}\rho_{d\gamma}h_{m\infty}}{\rho^o_{d\beta}(D^o_{eff}/L_r)} \qquad Bi=\frac{h_{c\infty}}{k^o_{eff}/L_r} \qquad L_r=\frac{R-\varepsilon}{2} \tag{17}$$

$$Lu=\frac{D^o_{eff}}{k^o_{eff}/\rho^o_\beta Cp^o} \qquad Ko=\frac{Q^o(X_{\beta 0}-X_{\beta e})}{Cp^o(T\gamma - T_{\beta 0})} \tag{18}$$

In these equation is considered the equilibrium distribution coefficient of $\mathbf{K}_{eq}$ to relate the amount of water between solid and gas phases of $Y_i=K_{eq}X_i$ and $X_{\beta e}$

As constant that are equal with $X_{\beta e}$ [13]. In is important that note the numbers of Bi_m and Bi are not based on the outer diameter of *R* but is according to the characteristic length for diffusion that is defined as half the thickness spherical shell (External length as the characteristic length for diffusion is not with a physical

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meaning, there for is not valid for incomplete geometry). However, hemispherical shell with the same outer diameter of R that share the same characteristic length for diffusion (as well as in Bayot number), for any amount $\xi_{\min}$ is physically unstable. A form of symmetrical, therefore is heat transfer in spherical coordinate and in the direction of φ , and cannot be of related expression in modeling (This assumption is closer to reality).

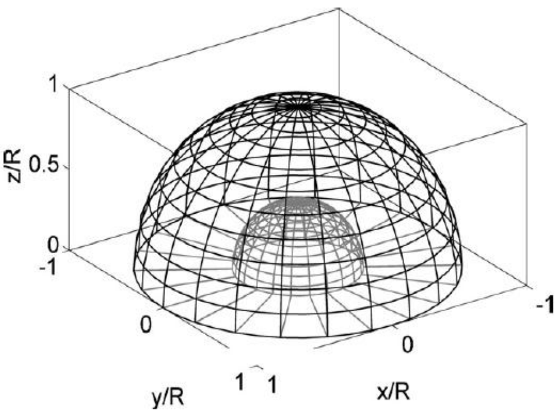

Fig. 1: out of spherical shell in use for modeling.

3- Modeling solution:

The governing equation can solve with different method and achieve it outcomes. A highly efficient and common method for this action is line method. The performance of this method is so that unchanged remain the time – dependent part and the other parts be placement as central derivative, then obtained equation that are in form a series of first order equation, solution using common method such as runge kata, ovlyr Etc. Outline of problem geometry two-dimensional is shown in figure 2 with respect to the dimensions of dimensionless. After applying the line method, the following equation that time is as the independent variable, can be obtained.

$$\frac{\partial \psi_j^{p,q,m}}{\partial \tau} = \frac{\alpha_j}{(\xi^2)^{p,q,m}}\left[\frac{\zeta^{(p+1/2)}(\psi_j^{p+1,q,m}-\psi_j^{p,q,m})-\zeta^{(p-1/2)}(\psi_j^{p,q,m}-\psi_j^{p-1,q.m})}{\Delta\xi}\right]$$
$$+\frac{\alpha_j}{(\xi^2\sin\theta)^{p,q,m}}\times\left[\frac{\zeta^{(q+1/2)}(\psi_j^{p,q+1,m}-\psi_j^{p,q,m})-\zeta^{(q-1/2)}(\psi_j^{p,q,m}-\psi_j^{p,q-1,m})}{\Delta\theta}\right]$$
$$+\frac{\alpha_j}{(\xi^2\sin^2\theta)^{p,q,m}}\times\left[\frac{\zeta^{(q+1/2)}(\psi_j^{p,q,m+1}-\psi_j^{p,q,m})-\zeta^{(q-1/2)}(\psi_j^{p,q,m}-\psi_j^{p,q,m-1})}{\Delta\psi}\right] \tag{19}$$

$$\zeta^{(p\pm1/2)} = (\xi^2)^{p\pm1/2,q,m} = \frac{1}{2}\left[(\xi^2)^{p\pm1,q,m} + (\xi^2)^{p,q,m}\right] \tag{20}$$

$$\zeta^{(q\pm1/2)} = (\sin\theta)^{p,q\pm1/2,m} = \frac{1}{2}\left[(\sin\theta^2)^{p,q\pm1,m} + (\sin\theta^2)^{p,q.m}\right] \tag{21}$$

$$\zeta^{(m\pm1/2)} = (\sin^2\theta)^{p,q,m\pm1/2} = \frac{1}{2}\left[(\sin^2\theta^2)^{p,q,m\pm1} + (\sin^2\theta^2)^{p,q.m}\right] \tag{22}$$

$$\psi_j^{p\pm1,q,m} = \psi_j^{p\mp1,q,m} - \frac{\beta_{jk}}{\beta_{jj}}(\psi_k^{p\pm1,q,m} - \psi_k^{p\mp1,q,m}) - \frac{2\Delta\xi\delta_j}{\beta_{jj}}\psi_j^{p,q,m} \tag{23}$$

$$for\ p = 1, n_\xi;\ j,k = 1,2;\ j \neq k \tag{24}$$

$$\psi_j^{p,q+1,m} = \psi_j^{p,q-1,m} - \frac{\beta_{jk}}{\beta_{jj}}(\psi_k^{p+1,q,m} - \psi_k^{p-1,q,m}) - \frac{2\Delta\theta\delta_j}{\beta_{jj}}\xi^{p,q}\psi_j^{p,q,m} \tag{25}$$

$$For\ q = n_\theta;\ j,k = 1,2;\ j \neq k \tag{26}$$

$$\psi_j^{p,q,m+1} = \psi_j^{p,q,m-1} - \frac{\beta_{jk}}{\beta_{jj}}(\psi_k^{p+1,q,m} - \psi_k^{p-1,q,m}) - \frac{2\Delta\theta\delta_j}{\beta_{jj}}\xi^{p,q}\psi_j^{p,q,m} \tag{27}$$

$$m = n_\varphi;\ j,k = 1,2;\ j \neq k \tag{28}$$

$$\psi_j^{p,q-1} = \psi_j^{p,q+1} \qquad for \qquad q = 1, j = 1,2 \tag{29}$$

After the above changes, should be classified these first order differential equation of occurred this figure in the direction of θ , radius and φ . Finally, for each solve a first order equation in the direction of time. As a result , with convergence of these equation is obtained after a certain time, temperature distribution and stable concentration for each these parts.

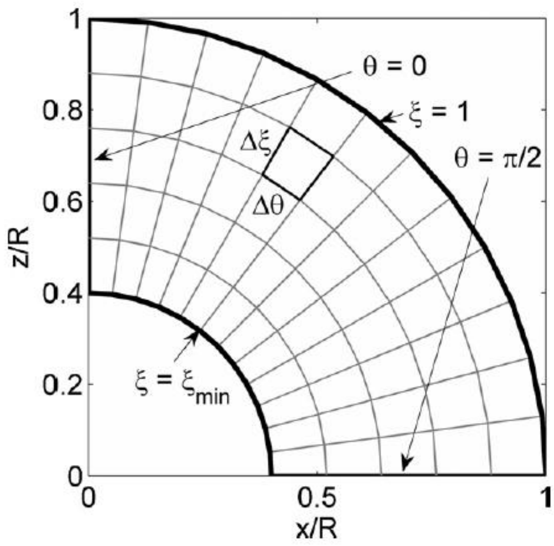

Fig. 2: landscape of geometry shape in two dimensions, in dimensionless scale for solving the governing equation.

Discussion and conclusion:

The results obtained for this geometry in two dimensional mode that provided by Roze Lopez and their colleagues showed that modeling used compared with in vitro condition with good accuracy[14]. But they did not consider changes in the direction of φ in spherical coordinate. If we consider these change, certainly will improve the results, because respect to drier conditions and it temperature asymmetry, the amount of mass and heat transfer is related to φ . However, may be small this dependence but is impressive and it considering cause modeling improve.

Conclusion:

In this research, is provided a modeling of mass and heat transfer in tree-dimensional for an spherical shell that is common geometry in drying industrial, then proposed a numerical method for solve of governing equation it

Seem to be due to non-traditional geometry and consider of more dimensional in modeling, with more accuracy and therefore more practical.

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