SHRINKAGE EFFECT DURING THE DRYING PROCESS OF FRESH PRETREATED TOMATOES (*Lycopersicon esculentum* L.)

Robert Karel Kross, Mario Eduardo Rangel Moreira Cavalcanti Mata, Maria Elita Martins Duarte

**ABSTRACT**

Fresh pretreated tomatoes at 10-0.4% NaCl-Sucrose in a osmotic solution were submitted to a thin layer drying process in a FANEM 330 drier, at the temperatures of 60, 70, 80 and 90°C, to study its drying kinetics. The samples were visually selected by its consistency, ripeness and physical damages and divided in two parts, classified as tomatoes with epidermis and tomatoes without epidermis. Since it is known that drying processes of products with high initial moisture contents involve a significant shrinkage phenomenon, the main objectives of this experiment were to study this phenomenon, by fitting the experimental data of the moisture content against the drying period, using the usual Page’s equation to be compared with Park’s proposed model of. In this case, the phenomenon was included in the non-dimensional moisture rate term by its replacement in a non-dimensional concentration rate. When the shrinkage wasn’t included in the Page’s equation, the coefficient $K$ values of tomatoes with and without epidermis varied from 0.245 to 6.080x10^-3 s^{-1} and from 9.328 to 33.262x10^-3 s^{-1}, respectively. At the other side, when this phenomenon is considered, the values of the coefficient $K$ from the Page equation of tomatoes with and without epidermis, varied from 0.0983 to 54.607x10^-3 s^{-1} and 0.1757 to 513.3892x10^-3 s^{-1}, respectively. The samples without epidermis presented higher coefficients of the Page’s equation, as expected, According to the results it can be concluded that the shrinkage phenomenon needs more attention, because the mathematical model has to represent the real physical mechanisms involved in the drying process.

**Keywords:** dry tomatoes, kinetics, Page’s equation

**EFEITO DO ECOLHIMENTO DURANTE O PROCESSO DE SECAGEM DE TOMATE (*Lycopersicon esculentum* L.) PRÉ-TRATADOS**

**RESUMO**

Tomates pré-tratados em uma solução osmótica de 10-0.4% NaCl-sacarose foram submetidos a um processo de secagem em camada delgada, num secador FANEM 330, às temperaturas de 60, 70, 80 e 90°C, com a intenção de estudar sua cinética. As amostras foram selecionadas visualmente por sua consistência, maturação e danos físicos e em seguida, separados em duas partes, classificadas como tomates com epiderme e tomates sem epiderme. Sabendo-se, que a secagem de produtos com altos teores de umidade envolvem um fenômeno de encolhimento significante, os objetivos principais deste experimento foram de estudar o mesmo, ajustando os dados experimentais da razão de umidade versus o período de secagem, usando a equação de Page e o modelo proposto de Park. Neste caso, o fenômeno foi incluído no termo da razão de umidade adimensional pela sua substituição em uma razão de concentração adimensional. Quando o encolhimento não foi incluído na equação de Page, os valores do coeficiente $K$ de tomates com epiderme e sem epiderme, variaram de 0.245 a 6.080x10^{-3} s^{-1} e de 9.328 a 33.262x10^{-3} s^{-1}, respectivamente. Por outro lado, quando este fenômeno é considerado, os

---

1 Químico Industrial, Mestre em Engenharia Agrícola pela Universidade Federal da Paraíba, e-mail: robkross@ureach.com or robert@feq.unicamp.br
2 Professor (a) Dr(a) do Departamento de Eng. Agrícola, UFPB. Av. Aprígio Veloso 882, Bodocongó, Cep 58109-970, Campina Grande-PB. E-mail: elita@deag.ufpb.br; mmata@deag.ufpb.br e elita@deag.ufpb.br
Shrinkage effect during the drying process of fresh pretreated tomatoes (Lycopersicon esculentum L.), Kross et al.

valores do coeficiente K da equação de Page de tomates com epiderme e tomates sem epiderme, variando de 0,0983 a 54,6072x10^{-3} s^{-1} e de 0,1757 a 513,3892x10^{-3}s^{-1}, respectivamente. Como esperado, as amostras sem epiderme apresentaram coeficientes da equação de Page mais altos. De acordo com os resultados pode ser concluir, que o fenômeno de encolhimento precisa de mais atenção, uma vez que o modelo matemático tem que representar a realidade dos mecanismos físicos envolvidos no processo de secagem.

Palavras-chave: tomates secos, cinética, equação de Page

INTRODUCTION

Drying of agricultural products, with high initial moisture content, such as fruits and vegetables, always produces a considerable shrinkage effect. Shrinkage during drying processes is mostly important in high moisture products such as vegetables, particularly fruits. Its occurrence is essential in the beginning of the drying process, due to the fact that this stage is characterized by a large removal of water from capillary porous, increasing void spaces and causing shrinkage.

Therefore, it is necessary to include the shrinkage phenomenon because it affects the drying rate and diffusion coefficient. Several theoretical and experimental studies have been developed to predict the mass transfer of foods, in particular banana-drying process (Mauro and Menegalli, 1995; Kiranoudis et al. 1997; 1997; Drouzas and Schubert, 1996; Rastogi et al. 1997). However, few works have been done about the moisture diffusion behavior including shrinkage (Queiroz, 1994; Queiroz and Nebra, 1996). We considered a one-dimensional geometry, such as a plate or a cylinder to use the diffusion model, in all the studies that were cited above.

Actually, this phenomenon must be included in the modulation in order to improve the physical representation of the process and to increase the confidence level of the obtained coefficients, such as the diffusion coefficient and the drying rate one, when Page’s equation is applied. Shrinkage has been treated theoretically in several ways in the literature. For some authors, shrinkage could be considered as directly related to the water volume removed during the process (Aregba, et al., 1990; Kechaou and Roques, 1989; Vagenas and Marinos-Kouris, 1991a; Balaban, 1989; Mulet et al., 1989). Other authors have proposed a further component to the shrinkage phenomenon during drying besides the volume reduction due to the loss of moisture: the mechanical forces (Misra and Young, 1980; Ketelaars, et al., 1992). However, the mechanical shrinkage can be neglected if the analyses are focused on drying kinetics (Ketelaars et al., 1992).

Many investigators have successfully used Page's equation (Page 1949) to describe mathematically the thin-layer drying rate of various cereal grains and oil seeds. Nowadays this model is also being used to predict the rate coefficients in dryers for food processing. Page's equation is convenient to use, compared with the theoretical moisture transfer equation, which takes more computing time in setting the data and deep bed simulations.

According to Park (1987), when the shrinkage phenomenon is considered, the non-dimensional term of the moisture rate can be replaced by a non-dimensional concentration rate.

Therefore, the purpose of this work is to determine the Page’s coefficients equation of fresh pretreated tomatoes, submitted to an osmotic solution and dried at the temperatures of 60, 70, 80 and 90°C, with the aim of comparing the results when the shrinkage phenomenon is included in the moisture rate, as proposed by PARK.

MATERIAL AND METHODS

The drying experiments were done in the Agricultural Products Storage and Processing Laboratory at the Agricultural Engineering Department, of the Federal University of Campina Grande.

Fresh tomatoes, obtained from a local market, were selected visually according to their ripeness, size and physical damage. A part of these tomatoes was peeled manually by heating them with the flame of a Bunsen burner To compare the influence of the epidermis. At the other side, since the tomato waxy skin presents a high resistance to mass transfer, the fruits with its epidermis were perforated with needles and immersed in a NaCl-sucrose (10:0,4 %) solution at room temperature, 25°C. An excess of osmosis solution (fruit to solution ratio 1:10) was used to limit the concentration changes due to water uptake from the tomato and loss of solute to the fruit. The time of the osmotic pretreatment was fixed in 5 and 9
hours for samples with and without epidermis, respectively (Kross et al., 2001).

It was used a tray-dryer FANEM330 with a circulating air flow \( (v = 76 \text{m.min}^{-2}) \) at the drying temperatures of 60, 70, 80 and 90°C until the equilibrium moisture content to the drying fresh and osmotic dehydrated samples

The samples moisture loss content was accomplished by periodical weights of the mass. It was used a Mettler PC 440 digital balance. These experimental data were fitted to the Page’s, to describe the thin layer characteristics of the samples under forced convection in a dryer.

\[
RX = \frac{X - X_e}{X_0 - X_e} = \exp(-K.t^n) \quad (1)
\]

where \( RX \) is the moisture ratio; \( X \) the moisture content of sample at any time, % dry-basis (% d.b.); \( X_0 \) the initial moisture content of sample, % d.b.; \( X_e \) the equilibrium moisture content, % d.b.; \( t \) the drying time, min; \( K \) and \( n \) are the drying parameters.

The phenomenon was included in the moisture rate to analyze the shrinkage effect. It was used the modified Page’s equation, presenting a non-dimensional concentration term in its formula, as suggested by Park.

\[
RC = \frac{C - C_e}{C_i - C_e} = \exp(-K.t^n) \quad (2)
\]

where \( RC \) is the concentration ratio; \( C \) is the moisture concentration content in the sample at any time, (gH_2O.g^{-1}.m^{-3}); \( C_i \) is the sample initial moisture content, (gH_2O.g^{-1}.m^{-3}) and \( C_e \) the equilibrium moisture content, (gH_2O.g^{-1}.m^{-3}).

Page’s equation coefficients were determined by fitting the experimental data to the equation by a non-linear regression, using the software Statistica 5.0.

**RESULTS AND DISCUSSION**

**Tomato Characterization**

The results of the physical characterization and classification, of the tomatoes, which are used in the experiments and shown in Table 1, based on the Filgueira (1982) table:

**Page’s Model without the shrinkage phenomenon**

According to Table 2, we can observe the values of the coefficient \( K \) of tomatoes with and without epidermis, varying from 0,245 to 6,080x10^{-3}s^{-1} and 9,328 to 33,262x10^{-3}s^{-1}, respectively, from the Page’s equation.
The tomatoes with epidermis are presenting a mayor resistance to the simultaneous mass and heat transport during the drying process as expected, considering the values of the coefficients $K$. At the other side, when the samples are peeled, the drying rate increases together with an increase of the drying temperature, from 60 to 90°C. The same behavior wasn’t noticed when the tomatoes with epidermis were dried, presenting values with small differences between them.

In Figure 1, we can observe the characteristic drying curve, when the experimental data of the moisture ratio plotted against the drying period and they were was fitted to the Page’s equation, presenting acceptable determination coefficients (>95,0%), except for the samples dried at 60°C. In this case, these deviations could be attributed to the non-homogeneous material, typical for biological products, which, in fact, is practically impossible to control.

In Figure 1, we can observe the characteristic drying curve, when the experimental data of the moisture ratio plotted against the drying period and they were was fitted to the Page’s equation, presenting acceptable determination coefficients (>95,0%), except for the samples dried at 60°C. In this case, these deviations could be attributed to the non-homogeneous material, typical for biological products, which, in fact, is practically impossible to control.

**Page’s Model without Shrinkage effect**

![Graph of Page’s Model without Shrinkage effect](image)

**Figure 1** – Non-linear regression fitted curves of the experimental data, without the shrinkage phenomenon, of tomatoes with and without epidermis, submitted to conventional drying at the temperatures of 60, 70, 80 e 90°C

Conform this figure, it is obvious that the influence of the epidermis on the drying kinetics is significant, and it is already been investigated by Fornell et al. (1980), who studied the tomatoes permeability and concluded that the evaporation moisture rate at the tomatoes superficies without the epidermis presented values 10 times higher than the samples with epidermis.

**Model of Page with the shrinkage phenomenon**

When the shrinkage phenomenon is included in Page’s equation, by replacing the moisture ratio, the following results for the coefficients were obtained, as shown in Table 3. According to this table, the values of the coefficient $K$ from Page’s equation of tomatoes with and without epidermis, varied from 0,0983 to 54,6072x10$^{-3}$s$^{-1}$ and from 0,1757 to 513,3892x10$^{-3}$s$^{-1}$, respectively.

According to these values of the coefficient $K$, when the shrinkage is included in the formula as suggested by Park, it is impossible to establish any commitment, even though obtaining fitted curves with determination coefficients above 92%.
Table 3 – Page’s equation Coefficients, including the shrinkage phenomenon

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>With Epidermis</th>
<th></th>
<th>Without Epidermis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K x10^3 (s^-1)</td>
<td>n</td>
<td>R^2 (%)</td>
<td>K x10^3 (s^-1)</td>
</tr>
<tr>
<td>60</td>
<td>54.6072</td>
<td>1,275</td>
<td>99,9</td>
<td>0,1757</td>
</tr>
<tr>
<td>70</td>
<td>14.6597</td>
<td>1,318</td>
<td>70,9</td>
<td>5.6284</td>
</tr>
<tr>
<td>80</td>
<td>0.0983</td>
<td>2.935</td>
<td>72,8</td>
<td>513.3892</td>
</tr>
<tr>
<td>90</td>
<td>0.2148</td>
<td>3.377</td>
<td>82,1</td>
<td>220.1135</td>
</tr>
</tbody>
</table>

Page’s Model with Shrinkage effect

![Figure 2](image-url) – Non-linear regression fitted curves of the experimental data of tomatoes with and without epidermis, submitted to conventional drying at the temperatures of 60, 70, 80 e 90°C, based on Page’s equation, including the shrinkage phenomenon.

In fact, the proposed model was developed by including the shrinkage phenomenon into the moisture rate term, based on the experimental data obtained when Park indeed succeeded in proving a linear relation between the moisture loss and volume reduction during the drying period with fish cubes experiments, assuming an one-dimensional linear shrinkage. This can also be proved in the experiment with tomatoes, obviously similar results should be expected.

With the intention, these data were plotted against each other. To analyze the non-dimensional volume reduction as a function of the moisture loss content during the drying period, as shown in Figure 3.

It is clear that these two variables, V/V_o and %X_wb, don’t present any linear relation as expected. As a matter of fact, the most probable data fit should be exponential, considering the Figure 4.
However, some researchers also succeeded (Gouveia et al., 1999) in fitting their experimental data to the proposed Park’s model. Another important factor should be mentioned in this specific experiment with tomatoes: Besides the non-linear shrinkage proved by the fitting curve, the samples are also being passed through different phases of their geometrical representation, shown in the Figure above.

In this case, the mathematical modeling to estimate the drying rate coefficients should be reformulated, if it’s possible. It should include the empirical relation, between the moisture loss and the decrease of the volume, in the analytical or numerical solution Fick’s law, once this will be the most accurate form, attempting to represent the physical phenomenon occurring during the drying process of tomatoes.

**Figure 3** – Shrinkage phenomenon expressed by a linear fitted curve: \( \frac{V}{V_0} \) against the moisture content

**Figure 4** – Shrinkage phenomenon expressed by a non-linear fitted curve: \( \frac{V}{V_0} \) against the moisture content
**CONCLUSIONS**

The following conclusions can be established, according to the results of this experiment:

- As expected, tomatoes without epidermis, presented less resistance to the mass and heat transfer mechanisms, during the drying process, which can also be confirmed by observing the coefficients of the Page equation;

- When the shrinkage phenomenon was included in the moisture content ratio, as proposed by Park, the obtained results for this experiment were unsatisfactory, once this model is based on the assumption that the shrinkage phenomenon is related to a linear function.

**Acknowledgements**

The authors gratefully acknowledge to CAPES PEC-PG and FUNAP for the scholarship and financial support.

**BIBLIOGRAPHIC REFERENCES**


Park, K.J. *Estudo comparativo do coeficiente de difusão sem e com encolhimento durante a secagem*. Campinas: Departamento de Engenharia de Alimentos da Faculdade de Engenharia de Alimentos. 54f., 1987 (Tese Livre Docência em Fenômenos de Transporte)


