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SHRINKAGE OF APPLE SLICES DURING DRYING BY WARM AIR CONVECTION AND FREEZE DRYING

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ABSTRACT

Volumetric and thickness shrinkage evaluated by direct measurement and n-heptane displacement were determined during convective and freeze drying of *Golden delicious* apples For convective-drying, the influence of blanching and thickness/diameter ratio of the apple disks used were analysed at different levels of moisture content under constant conditions. Freeze drying experiments were carried out to remove all moisture present of the sample, also, under constant drying conditions. It was found that shrinkage of samples dried by convection is significantly anisotropic while less damage to the solid structure during freeze-drying leads to a more isotropic deformation. Blanching did not affect shrinkage results

INTRODUCTION

Drying of porous solids is a process which involves simultaneous heat and mass transfer. Mathematical models of drying involve heat and mass transfer equations with suitable initial and boundary conditions. In many of these models, one of the important assumptions is that shrinkage is negligible. In the case of foods, shrinkage is seldom negligible. Several authors have proposed models for such deformation (Misra and Young, 1980; Roman et al., 1982; Lozano, 1983; Balaban and Pigott, 1986; Sjoholm and Gekas, 1995) and some of these models have even been incorporated in the drying model (Medeiros and Sereno, 1994)

Shrinkage during drying takes place simultaneously with moisture diffusion and thus may affect the moisture removal rate. Volume changes and deformation depend on several factors like sample geometry, dehydration method and drying conditions. The objective of this study was to correlate shrinkage with moisture content of apples and asses its dependence with the other mentioned factors.

THEORY

Shrinking affects many properties of the material and, particularly in drying processes it is important to determine its influence on diffusion coefficient governing the drying kinetics. Among the methods in the literature to describe shrinkage of foods, Gekas and Lamberg (1991) propose to take into account shrinkage effect on moisture diffusion by incorporating volume change into the effective diffusion coefficient, leading to:

$$\frac{D_{eff}}{D_{eff,ref}} = \left(\frac{V}{V_{ref}}\right)^{\frac{2}{d}} \tag{1}$$

where exponent d takes value of one in the case of unidimensional and the value of three for isotropic three-dimensional shrinkage (Sjöholm and Gekas, 1995). Thus this parameter may be viewed as a measure of the degree of isotropicity of the deformation and is related to linear and volume shrinkage by:

$$S_v = S_l^d \tag{2}$$

where S_v and S_l are defined as:

$$S_v = \frac{V}{V_{ref}} = \frac{V}{V_0} \tag{3}$$

$$S_l = \frac{l}{l_{ref}} = \frac{l}{l_0} \tag{4}$$

EXPERIMENTAL

Apple (*Golden delicious* variety) with an initial water content between 0.85 and 0.89 (w/w) on wet basis are used in this study. Disks with 26 ± 0.1 mm diameter and 3.0 ± 0.2 mm, 3.5 ± 0.2 mm thick were prepared by slicing the apples by means of an electric slicing machine. The samples were dehydrated at 70 °C, relative air humidity 12 % and air speed 3.5 $m \cdot s^{-1}$ up to different moisture contents (as determined at 70 °C under 100 mm Hg). Part of the samples were blanched at 85 °C during 60 s before drying.

Disk dimensions were determined by two different techniques: direct measurement (3 thickness and 2 diameter measurement with a calliper) and by displacement after immersion in n-heptane.

Freeze dryer equipment was a Telabe LF-10 model. Operation variables (temperature, vacuum pressure, weight measurement) were monitored during experiments. Initial disk dimension was 59.5 ± 0.1 mm diameter and 15 ± 0.1 mm thick. Dimension changes were in this case measured by direct method only. Freeze drying experiments were conducted at 0.20 mbar during sublimation and 0.05 mbar during desorption; sublimation temperature was -25 °C; this temperature was gradually increased up to 40 °C during desorption phase. Freeze drying samples were dried up to remove virtually all moisture present

RESULTS

Figure 1 presents how volumetric shrinkage depends on moisture content of the samples. A larger shrinkage effect is observed when moisture content is above 0.4 (wet basis), then remaining essentially constant with moisture content. In the same figure the two methods used to evaluate shrinkage are compared, and a good agreement between them was found.

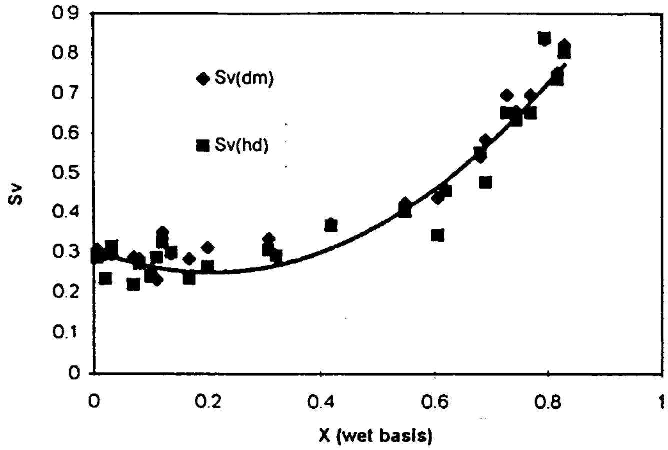

Figure 1. Volumetric shrinkage vs. moisture content. Comparison between heptane-displacement ($S_{v(hd)}$) and direct measurement method ($S_{v(dm)}$)

Analysis of the change of the thickness and the diameter of the samples during drying shows a maximum ratio diameter/thickness ratio at moisture content 0.25 (w/w) wet basis. This behaviour suggests that material thickness decreases faster than diameter at high moisture contents (>0.25) while the reverse is observed for the low moisture zone. One example of this effect is presented in Figure 2.

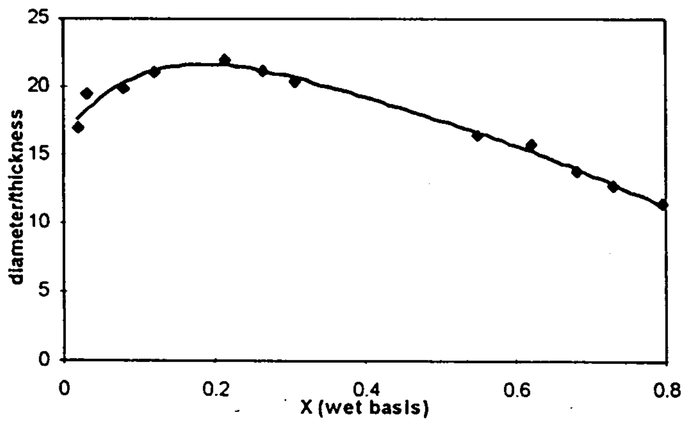

Figure 2. Ratio diameter/thickness at different moisture content

Change of volumetric and thickness shrinkage with sample moisture content is presented in Figures 3 and 4, with and without blanching. It was observed that in this case shrinkage behaviour was not affected by blanching, which differs from the results obtained by Vázquez et al., (1997) with raisins..

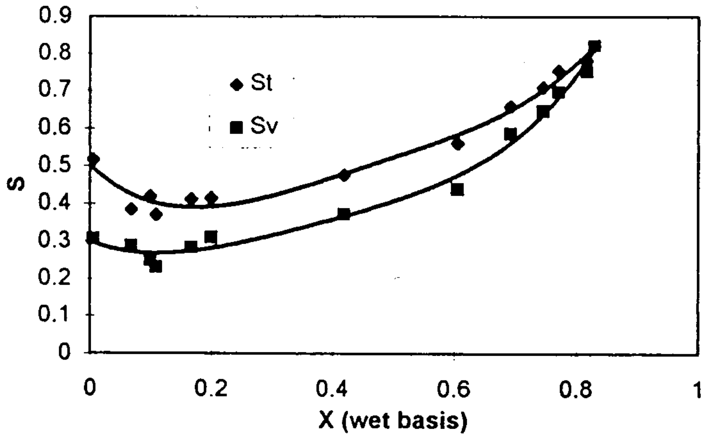

Figure 3. Volumetric and thickness shrinkage vs. moisture content. (Blanched samples).

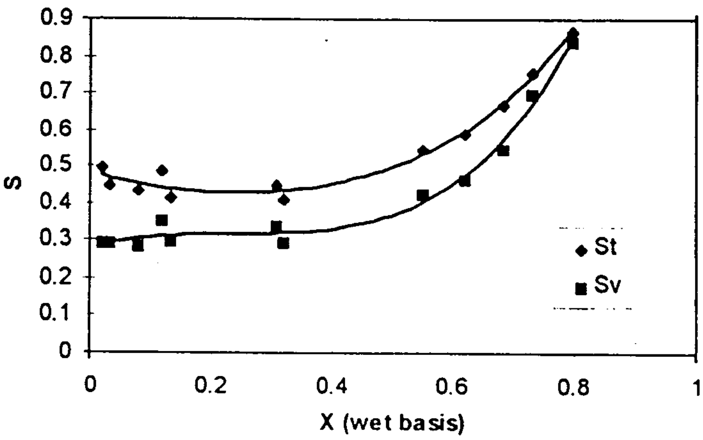

Figure 4. Volumetric and thickness shrinkage vs. moisture content. (No blanching).

Analysing the relationship between S_v and S_t obtained, exponent d is easily calculated by linear regression of ln (S_v) vs. ln (S_t). A typical plot of such results is shown in Figure 5. A good fit was obtained as represented by a correlation coefficient of 0.998 (for all experiments)

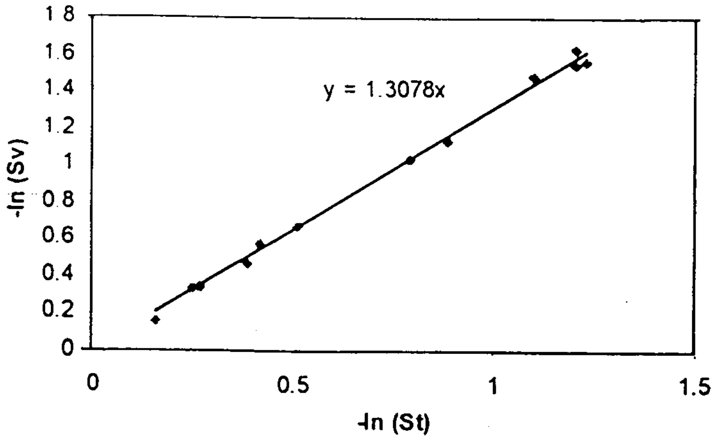

Figure 5. Relation between S_t and S_v (convective drying). Example for blanched samples.

Table 1 shows the values of this parameter as a function of the experimental conditions. These *d* values agree with data reported by Sjöholm and Gekas (1995) for *Mutsu* apples.These values were found independent of blanching pre-treatment, depending only on diameter/thickness ratio, decreasing *d* when the ratio increases. These results obtained suggest an anisotropic behaviour (related with the change of food structure during convective drying) which agrees with an initial diameter/thickness ratio of 7.4 to 8.7. These results confirm that an unidimensional moisture transport can be considered for high diameter/thickness ratio while this assumption is less valid such relationship is lower.

Table 1. Values of *d* as a function of experimental conditions

Thickness (mm)	Diameter (mm)	Blanching	d_{hd}	d_{dm}
		Convective drying		
3.00	26	no	1.30	1.46
3.50		no	1.41	1.52
3.01		yes	1.33	1.43
3.50		yes	1.39	1.49
		Freeze drying		
15.0	59.5	yes		1.91
14.9	59.5			1.93
15.0	59.6			1.88
15.1	59.5			1.90

Lower shrinkage during freeze drying was observed as found by Bellows and King, (1974). Again a linear regression between volumetric and thickness shrinkage was obtained as shown in Figure 6. Value of d_{dm} is larger using freeze drying than convective drying. This larger value for parameter d_{dm} obtained for freeze drying indicate in this case a more isotropic behaviour.

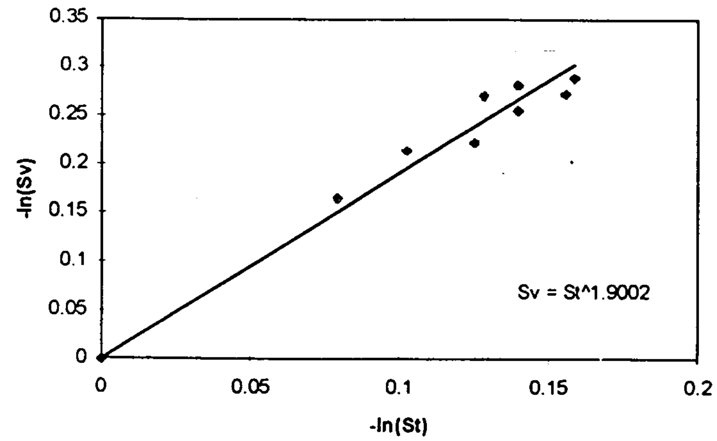

Figure 6. Relation between S_t and S_v (freeze drying)

CONCLUSIONS

Apple shrinkage during drying is important and must be taken account to model drying process. Two different experimental methods were employed to measure this effect with similar results. Relationship between thickness and volumetric shrinkage of disk samples shows that neither an one-dimensional deformation nor an isotropic deformation is taken place. In fact, different types of deformation are produced according to geometry and the diameter/thickness ratio. Freeze drying leads to a more isotropic behaviour. This can be explained by a less intense modification of the cellular structure of the apple, but, further research is considered necessary to confirm this result.

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NOTATION

d	Exponent of eqs	
D	Diffusion coefficient	$m^2 \cdot s^{-1}$
S	Shrinkage	-
V	Volume	m^3

Subscripts

dm	Direct measurement.
eff	Effective.
hd	Heptane displacement.
o	Initial.
ref	Reference.
t	Thickness
v	Volume

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