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# Variação da Densidade e Porosidade Durante a Secagem de Peras Inteiras e em Metades

# Variation of Density and Porosity During the Drying of Pears and Pear Halves

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## RESUMO

Neste trabalho a umidade e a densidade de pêras da variedade D. Joaquina foram avaliadas ao longo da secagem, para pêras inteiras e em metades, e os dados experimentais recolhidos foram ajustados a um modelo teórico de previsão da porosidade. Dos resultados obtidos foi possível verificar que a porosidade das pêras estava muito próxima de zero para umidades elevadas e aumentava com a perda de água até porosidades da ordem de 11 %, quando o teor de umidade era nulo. Do estudo efetuado foi possível ainda comprovar a relação de linearidade entre o volume específico e o conteúdo de umidade, e também o aumento exponencial da porosidade das pêras ao longo do processo de secagem.

## ABSTRACT

In the present work the moisture content and density of pears of the variety D. Joaquina were evaluated throughout the drying process, for both whole pears and pear halves, and the experimental data fitted to a theoretical model for the prediction of bulk porosity. From the results obtained, it was possible to conclude that the porosity of the pears was very close to zero at high moisture contents and increased as the moisture was removed from the pears until it reached about 11%, for totally dry samples. It was also possible to verify a strong linearity between the specific volume and the moisture content, and also an exponential increase in porosity throughout the drying process.

**PALAVRAS-CHAVE**
KEY WORDS

pêra, secagem, densidade, porosidade, volume específico, modelo de porosidade.
pear, drying, density, porosity, specific volume, porosity model.

## 1. INTRODUCTION

Drying processes involve simultaneous heat and mass transfer, as well as thermodynamic phenomena and instantaneous modifications of the physical properties of the food products. The modifications that occur to properties such as density and porosity as a result of shrinking are of extreme importance for the characterization of the transfer phenomena and the texture and quality of the foods, when these are submitted to a drying operation, KROKIDA & MAROULIS (1997), LANG et al (1994).

The porosity of foods suffers changes during drying, which depend on their composition, in particular their initial moisture content, and also on product size and the drying conditions used. The development of models describing the drying processes should inevitably include a parameter accounting for shrinkage, which seems to be strongly related to the moisture content, although this relation still needs to be further studied from the experimental point of view, ZOGZAS, MAROULIS & MARINOS-KOURIS (1994), RAHMAN (2001).

ZOGZAS, MAROULIS & MARINOS-KOURIS (1994) developed a quite simple mathematical model to correlate the density, porosity and shrinkage with the water content, which was tested for the drying of apples, carrots and potatoes. KROKIDA & MAROULIS (1997) studied the effect of the drying method on the properties mentioned above for the same food products and also for bananas.

## 2. MATHEMATICAL MODELLING

The variables dry basis specific volume, v (defined as the total volume per unit mass of dry solids), particle density, $_p$, bulk density, $_b$, and porosity, , expressed as functions of the dry basis moisture content, W, can be predicted using the model proposed by ZOGZAS, MAROULIS & MARINOS-KOURIS (1994), which is summarised in the following four equations:

**1.** $$v = v_0 (1 + \ W)$$

where $v_0$ is the specific volume of the dry solids,

**2.** $$\rho_p = \frac{1 + W}{\frac{1}{\rho} + \frac{W}{\rho}}$$

**3.** $$\rho_p = \frac{1 + W}{\frac{1}{\rho\ +}}$$

**4.** $$\varepsilon = 1 - \frac{\rho_b}{\rho_p}$$

This model requires four parameters, which must be estimated from experimental data, namely: enclosed water density ($\rho_w$), solids density ($\rho_s$), bulk density of dry solids ($\rho_{b0}$) and the volumetric shrinkage coefficient ( ).

## 3. EXPERIMENTAL METHODOLOGY

For the present study, the pears used were of the local variety known as D. Joaquina, which were dried in a ventilated drying chamber at a constant temperature of 30 ºC up to a moisture content very close to zero.

The pears were analysed throughout the drying process in terms of their moisture content (with a Halogen Moisture Analyser Mettler Toledo HG53) and their apparent density (by picnometry at 20 ºC). All analysis was performed in duplicate and the apparent density was determined for the uncut pears (including the central structure with the seeds) and also for pears cut in half (only the pulp without the central part and seeds).

The dry basis specific volume as defined by ZOGZAS, MAROULIS & MARINOS-KOURIS (1994), was determined using the experimental values obtained for the apparent density as $v = (W+1)/\rho_b$.

## 4. RESULTS AND DISCUSSION

In Figures 1 and 2 the variations in relative density and specific volume with moisture content are represented throughout the drying process both for the uncut pears and for the pear halves. By observing the graphs it is possible to verify that the data relative to both types of sample are very consistent, and that the density increases exponentially as the pears lose moisture, undoubtedly as a result of the shrinkage that takes place throughout drying. As for the relation between the dry basis specific volume and the dry basis moisture content, this is strongly linear, as could be predicted according to Equation (1).

Applying a linear regression of the form $y = a + bx$ to the plotted data of the specific volume against moisture content, a straight line was obtained where $a = v_0 = 1/_{\rho b0}$ (since $W_0 = 0$) and the slope $b = \ .v_0 = /_{\rho b0}$. The fitting to the experimental values was done with the software Sigma Plot, v 8.0 (SPSS, Inc.) and the results of the fitting as well as the estimated parameters are presented in Table 1. Apart from the parameters $_{\rho b0}$ and calculated from the above relations, the value of the enclosed water density, $_{\rho w}$, is also presented in Table 1, and was determined taking into consideration that $_{\rho w} = \ _{\rho b0}/\ $.

The values for $_{\rho p}$, $_{\rho b}$ and were determined from Equations (2) to (4) using the values for the three model parameters presented in Table 1. The value used for the dry solids density was $_{\rho s} = 1506$ kg/m$^3$, and was determined experimentally for the pear solids triturated after total water removal. The value found for the enclosed water density, $_{\rho w} = 1007$ kg/m$^3$, was calculated as stated before, using the relation $= \ _{\rho b0}/_{\rho w}$, which can be

**Table 1** Results of the fitting and estimated parameters for the drying of pears at 30 °C.

| Fitting | Estimated parameters |
|---|---|
| a = 7.4905x10$^{-4}$ | $\rho_{bo}$ = 1/a = 1 335 kg/m$^3$ |
| b = 9.9266x10$^{-4}$ | = b/a = 1.325 |
| $R^2$ = 0.9969 | $\rho_w$ = 1/b =1 007 kg/m$^3$ |

deduced easily from the definitions of each quantity. It is however important to notice that this value is slightly higher when compared to the density of pure water, since the water in foods is a combination of free water and bound water. In fact, the latter develops strong bonding with the solids, thus increasing its density. This effect is accentuated when in the presence of foods containing a considerable amount of sugars, ZOGZAS, MAROULIS & MARINOS-KOURIS (1994), as in the case of pears, with total sugar contents in the range between 60 and 70 %, GUINÉ & CASTRO (2002).

Figure 3 shows the variations in density (bulk and particle densities) with moisture content, as predicted by the model. It can be seen that both $\rho_b$ and $\rho_p$ increased exponentially as the water was removed from the pears, tending respectively to the values of $\rho_{bo}$ and $\rho_s$ as the moisture content approached zero. For dry basis moisture contents higher than 3, $\rho_b$ and $\rho_p$ varied very slightly and tended to approach each other, evidencing a very low porosity in that range of moisture contents. In fact, as confirmed in Figure 4, which shows the variation of porosity with moisture content, the porosity of the pears was very close to zero for high moisture contents and increased with the loss of water until it reached a final value of around 11 %, when the material was completely dry. The reason why the pears developed relatively low porosities during the drying process, in spite of the high degree of moisture loss, was related to the fact that very significant shrinkage took place throughout drying, thus compensating for the pores left free due to water lost by evaporation.

## 5. CONCLUSIONS

From the present study it was possible to prove a linear behaviour of the dry basis specific volume in relation to the dry basis moisture content, and also an exponential increase in the porosity of the pears during the drying process.

It was also concluded that the model selected seems to be adequate for this particular type of fruit, and that the pears developed porosities that varied from 1 % to 11 % as the process of water removal proceeded throughout the drying process.

## 6. REFERENCES

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**Figure 1** Variation of relative density with moisture content of pear and pear halves during drying at 30 °C.

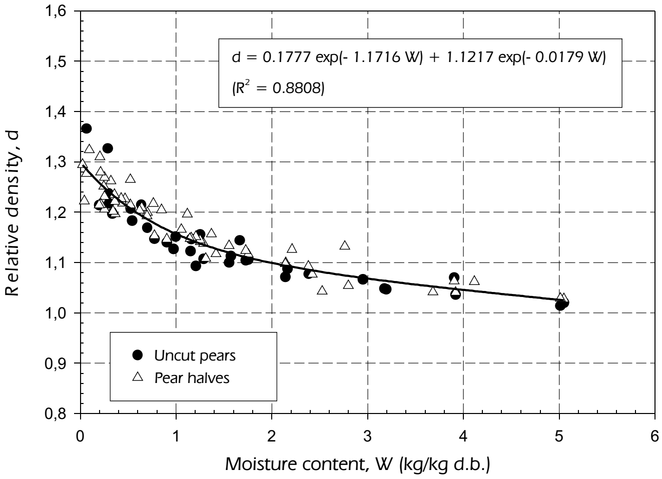



**Figure 2** Variation of specific volume with moisture content of pear and pear halves during drying at 30 °C.

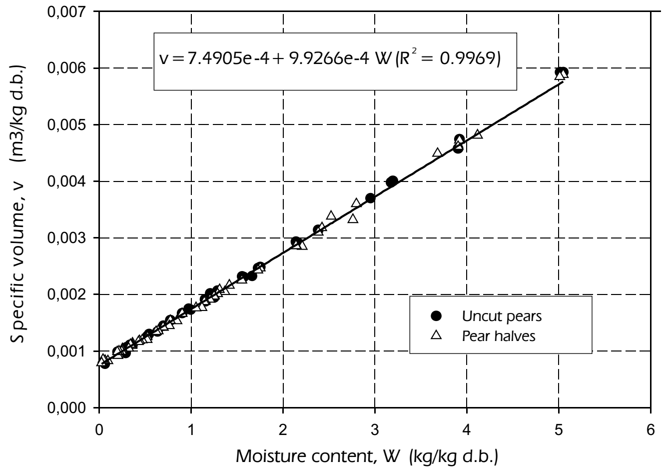



**Figure 3** Variation of densities with moisture content, as predicted by the model, for the drying of pears at 30 °C.

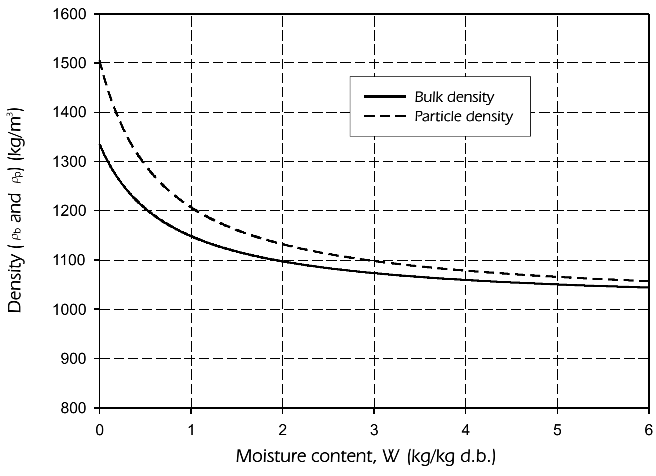
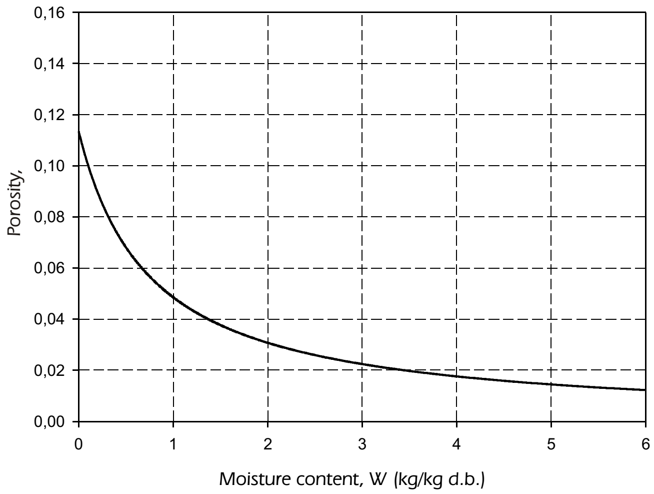


**Figure 4** Variation of porosity with moisture content, as predicted by the model, for the drying of pears at 30 ºC.

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## 6. NOMENCLATURE

d = relative apparent density

m = mass [kg]

v = dry basis specific volume [$m^3$/kg d.b.] = $(v_s + v_w + v_a)/m_s$ = $(W+1)/\rho_b$

$v_0$ = specific volume of dry solids [$m^3$/kg d.b.]

v = volume [$m^3$]

W = dry basis moisture content [kg/kg b.d.] = $m_w/m_s$

## 7. GREEK SYMBOLS

= volumetric shrinkage coefficient = $\rho_{bo}/\rho_w$

= porosity = $v_a/(v_s + v_w + v_a)$

$\rho_b$ = bulk density of moist material [kg/$m^3$] = $(m_s + m_w)$ / $(v_s + v_w + v_a)$

$\rho_{bo}$ = bulk density of dry solids [kg/$m^3$] = $m_s$ / $(v_s + v_a)$

$\rho_p$ = particle density [kg/$m^3$] = $(m_s + m_w)/(v_s + v_w)$

$\rho_s$ = dry solids density [kg/$m^3$] = $m_s$ / $v_s$

$\rho_w$ = enclosed water density [kg/$m^3$] = $m_w$ / $v_w$

## 8. SUBSCRIPTS

a = air
s = solids
w = water