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Shrinkage, porosity and density behaviour during convective drying of bio-porous material

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Abstract

Drying is a main process of conservation used for agricultural products and it is so essential to control its drying parameters.Bio-material will shrink during the drying process.In this study, the characteristics of drying were investigated through slices shrinkage behaviour at 40, 50 and 60 ℃. Results showed that shinkage was anisotropic and best fitted by the linear model of volume. The apparent density was strongly effected by volume shrinkage , its value decreased from 1035 kg/m^3 at the initial stage of the drying to about 885 kg/m^3 at the end of the drying process.The porosity has a large value approaching 80% and most of the evaporated water during drying was replaced by gas . Drying rates were underestimated and diffusivities overesimated when drying data are not corrected for shrinkage.

Keywords :Shrinkage; Porosity; Density; Isotropicity

1. Introduction

Drying is a most widely used primary method of food preservation. The aim is the removal of water to the level at which microbial spoilage and deterioration reactions are greatly minimized[1]. It can also prolong shelf-life and ruduce the cost of transportation with a smaller space and lighter weight . The drying of the biological materials such as fruits and vegetables usually have high initial moisture , it always shows a shrinkage in volume. Shrinkage of biological materials takes place simultaneously with moisture diffusion during drying and thus may affect the drying rate, so it is important to study the shrinkage phenomena for better understanding of the drying process.

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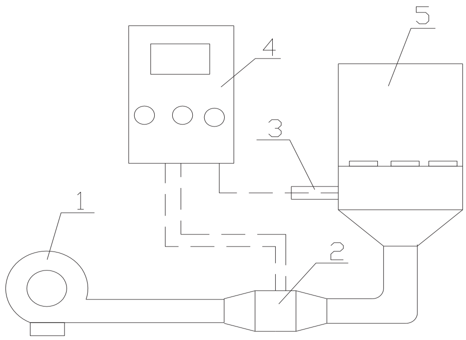
Most mathematical drying models[2-5] in the literatures involve heat and mass transfer equations with perfect initial and boundary conditions. During the models, there have been an important assumption is that shrinkage is megligible, it is useful to slove the models but it is not suitable for all biological materials. Hatamipour and Mowla[6] studied the changes of density, shrinkage and mass diffusivity of green peas and maize in a fluidized bed with and without inert particles. E.L.Schultz, M.M.Mazzuco and R.A.F. Machado[7] observed the influence of different operational conditions on the shrinkage of apple slices. Xu Wei, Ding Jing and Zhao Yi[8] investigated the volume shrinkage characteristics of fresh ginger, carrot, potato and banana in the drying process based on the definitions of volume shrinkage coefficient and shrinkage isotropicity. There is little study on carrot's volomn shrikage. Therefore, the aim of the current work was to observe the effect of drying temperature on drying characteristics of carrot and establish a suitable shrinkage model. Apparent desity and porosity were analyzed. The shrinkage isotropicity between thickness and length was studied. The shrinkage influences on the drying rates of carrot were investigated. This study contributed to a better comprehension of the carrot's drying process.

2. Materials and methods

2.1. *Drying experiments*

The carrots used in this investigation were purchased from a local vegetable market of Kun Ming University of Science and Technology, these carrots [9]had a initial moisture content of about 8.2 kg water /kg dry basis and stored in a fridge at 5℃. Before starting an experiment the carrots were exposed at laboratory temperature for 24 h to equilibrate with the laboratory temperature. Samples were cut into slices of approximately 30×30×5 mm and then immersed in 90℃ boiling water for 5～6 min.

These experiments carrided out in an experimental drier system composed of a fan, a heater, a control cabinet and a drying chamber was shown in Fig 1. During the drying the samples maintained their shape, but the size decreased(shrinkage) as a result of great water loss during the process. In order to observe the shrinkage, the experiments were carried out at 40, 50 and 60℃ and the dimensions were measured at three places of the slices(the middle and the two edges), these measurements taked each 30 min until the dimentions have no change.



1—fan; 2—heaters; 3—thermocouples; 4—control cabinet; 5—drying chamber;
Fig 1 Schematic diagram of the experimental apparatus

2.2. *Shrinkage curves*

In the recent literatures, several shrinkage models were developed by some investigators[10-12]. The influence of temperature on carrot shrinkage was studied. The following definitions are based on the research of Banu Koc, ismail Eren and Figen Kaymak Ertekin[13](2008).

$$V = l^2 h \tag{1}$$

$$A = 2l^2 + 4lh \tag{2}$$

$$B = \frac{V(t)}{V_0} \tag{3}$$

$$S_B = (1 - \frac{V(t)}{V_0}) \tag{4}$$

Where V is the volume of the sample, l the side, h the thickness, A the area, B the volume ratio, V(t) the volume at instant t and V_0 the initial volume.

2.3. Drying rates

The drying rate was expressed as the the mass of moisture removed to air per unit of area and per unit of time, its formula was based on the following definition:

$$C_{v0} = -(\frac{M_s}{A_0})\frac{dM}{dt} \tag{5}$$

Where C_{v0} is the drying rate, M_s the dry mass, A_0 the initial exchange surface area and M the initial moisture content in dry basis.

For a shrinking slice sample the exchange surface varies as the volume shrinkage in this study, and in the drying rates curves it must be taken into account. The drying rate was corrected for exchange suface shrinkage can be expressed as the following formula:

$$C_{vm} = -(\frac{M_s}{A(t)})\frac{dM}{dt}$$

Where C_{vm} is the drying rate corrected for area shrinkage, and A(t) the exchang surface at each time.

2.4. Shrinkage isotropicity

The thickness and length also shrinked during the drying process. In order to better comprehend the drying characteristic of the slice carrots, the shrinkage isotropicity between the direction of side and thickness was expressed as formula(6):

$$S_h = \frac{\frac{l_0 - l(t)}{l_0}}{\frac{h_0 - h(t)}{h_0}} \tag{6}$$

Where l_0, l (t) are respectively the initial and the current values of the sample side and h_0, h(t) respectively the initial and the current values of the sample thickness.

2.5. Apparent density and porisity

Apparent density(ρ(t)) of the sample is the ratio between the current mass of the sample and its total volume and is expressed as:

$$\rho(t)=\frac{m(t)}{V(t)} \tag{7}$$

The sample porosity during the drying at each instant is obtained from the equation[14]:

$$\varepsilon(t)=1-\frac{\rho(t)}{\rho_0} \tag{8}$$

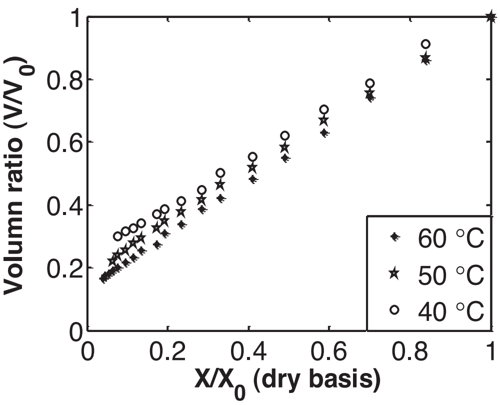
Where ε （t） is the porosity at each time t, ρ_0 evaluated at 1035 kg m^{-3} using a electronic balance and vernier calipers.

3. Results and discussion

3.1. Drying characteristics of sliced carrot

Drying kinetics and of sliced carrots of 30×30×5 mm are given in fig. 1. The drying process were carried out respectively at 40, 50 and 60℃, 2m/s. Each experiment was carried out at least triple to check the exact datas. The results presented in Fig. 1 showed that increasing the medium temperature can increase the drying rates and decrease the drying time for reaching the same moisure. There was no constant drying rate stage in the drying process. From these results, we can infer that most of the sliced carrot drying process was in the falling-rate drying period, And it shows that diffusion is the main physical mechanism during the carrot drying process.

The volume ratio and shrinkage coefficient versus moisture ratio of sliced carrots are presented in Fig. 2a and b and the datas were the average values. Fig. 2a and b shows that the medium temperature has significant effect on the shrinkage coefficient curves. Shrinkage curves were almost linear in the whole drying process.



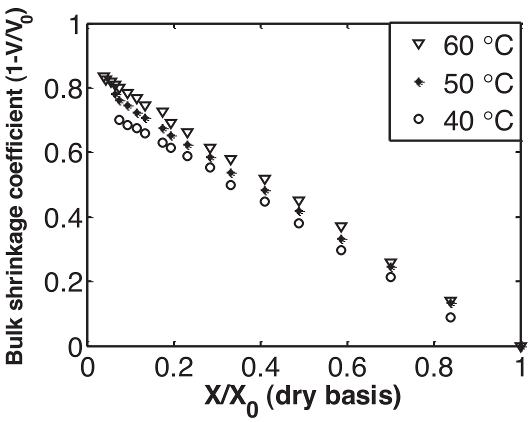


Fig 2(a) The volume ratio of carrot versus moisture different tempertures

Fig 2(b) The shrinkage coefficient of carrot versus for moisture for different tempertures

3.2. Isotropic

The curves of thickness ratio and side ratio versus the moisture were plotted in Fig3 Like in volumetric shrinkage, the thickness and side ratio all presented a linear tendency. In Fig3, we observed an anisotropic shrinkage during carrot drying process. And the side ratio was more than the thickness shrinkage ratio,this phenomenon of sliced carrot was more obvious as the moisture reduces, the isotropicity coefficient varied from 0.39 to 0.8.

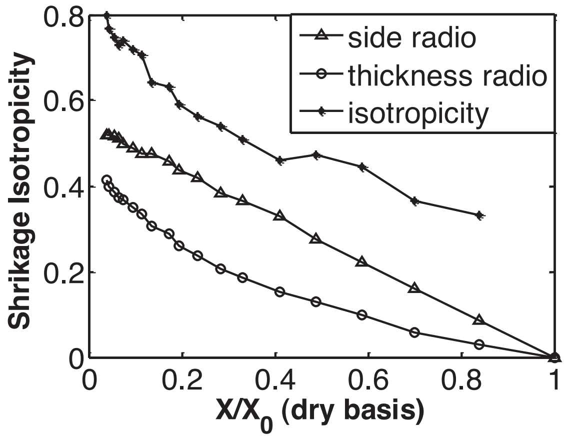


Fig3 Shrinkage isotropicity evaluated between thickness and side during carrot drying process

3.3. Apparent density and porisity

The Apparent density and porosity of Bio-porous Material changed during dehydration due to the loss of moisture and formation of air pores. The apparent density decreased from 1035 kg/m^3 at the initial stage of the experiment to about 885 kg/m^3 at the end of the experiment, but the porisity increased from about 0.26 to 0.36 during the experiment.

The apparent density and porosity for sliced carrot versus to moiture ratio was illustrated in Fig5 and Fig.4, and did not take a linear profile. From Fig4.5,we can infer that initial stage the water evaporated from was equal to the loss of volume basically. But along with the drying process going on, the water evaporated was partial by air and partial by volume shrinkage, and the air proportion more and more until the volume has no changes.

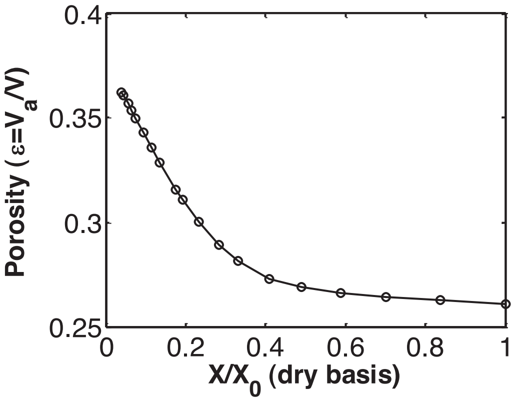


Fig 4 Internal porosity versus moisture ratio during drying process

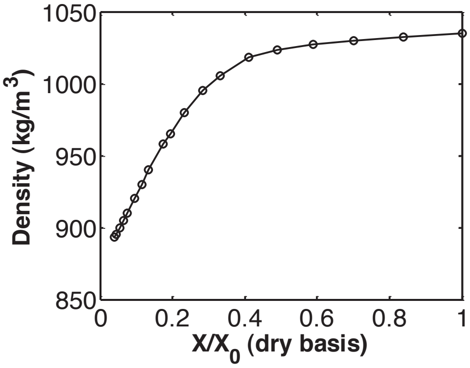


Fig 5 Apparent density versus moisture ratio during drying process

3.4. Drying rates corrected for shrinkage

Drying rates curves per unit of current surface area corrected and non-corrected for shrinkage were presented on Fig6. There was no constant drying rate showed in the curves and it can be deduced that carrot drying percess was cotrolled with internal water diffusivities. Fig.9. showed that drying rate curves corrected with shrinkage was above the curve non-corrected with shrinkage. It can be infered that drying rate non-corrected with shrinkage was under-estimated, so the diffusivity was over-estimated when the was not taken into account.

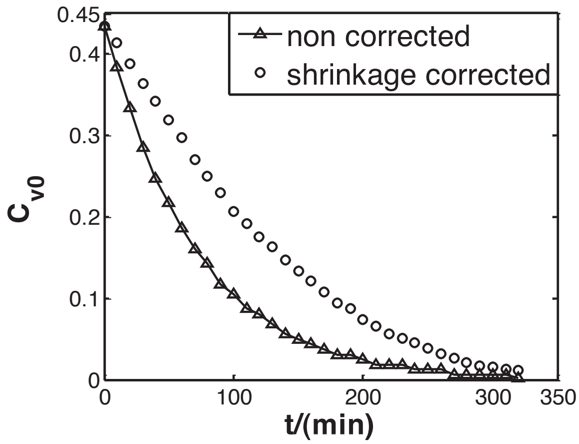


Fig 6 Corrected and non corrected drying rate versus time during drying process

4. Conclusion

In this paper, Shrinkage, porosity, density and drying characteristics of sliced carrots were researched. The shrinkage coefficient has a significant effect on the shrinkage coefficient curves and the curves take a linear profile. The carrots presetent an anisotropic shrinkage during drying process, and its value varied from 0.39 to 0.8. The appratent density and porosity for sliced carrot did not take a linear profile, the appratent density decreased from 1035 kg/m3 at the initial stage of the experiment to about 885 kg/m3 at the end of the experiment, but the porisity increased from about 0.26 to 0.36 during the experiment. Drying rate non-corrected with shrinkage was under-estimated. The diffusivity was over-estimated when the was not taken into account.

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