1D Axisymmetric Modeling of Shrinkage for Non-Porous Materials

J. M. Meot[1], A. Briffaz [1], J. Jacquin [2], S. Rashidi [2]

[1]Cirad, UMR QualiSud, Montpellier, France
[2]Bureau national Interprofessionnel du Pruneau, Villeneuve, France

Abstract

Introduction
Drying of high-water-content food products like fruits induces large deformations. Unfortunately, classical solid mechanics approaches are only applicable to small deformation. An appropriate and mass-conservative way of modeling large deformations is the use of Eulerian-Lagrangian geometrical transformation coupled locally with water transport. Having a good representation of shrinkage is very useful for parameter identification, model validation, and for communication with process supervisors.

A 1D-axisymmetric model was built to describe the drying of a single d'Ente plum into a d'Agen prune. Underlying assumptions of the model were those of Di Matteo et al. (2003). Sorption isotherms of plum were obtained from Tsami et al (1990) and equation structure of apparent water diffusion coefficients from Sabarez (2001). External heat and mass transfer coefficients were measured and adjusted. The parameters of water transport equation were identified by inverse identification based on experimental data from drying of stones, plums without and with skin.

Use of COMSOL Multiphysics
The plum was assumed spherical so governing equations were written in spherical coordinates as done by Briffaz et al. (2014). The model has been implemented in COMSOL Multiphysics® software using "coefficient form" Partial Differential Equation (PDE) mode. Solving of the governing heat transfer, water transport and deformation was carried out in the "material frame" of the component which matches the initial geometry of the fresh plum.

The movement of each point under the spatial reference frame can be obtained with the following equation (Eq. (1)) of conservation of dry matter
$\forall R \in [0\ R_{max}], \int_0^R \rho_{DM,t}\, 4\pi r_t^2\, dr = \int_0^R \rho_{DM,0}\, 4\pi R^2\, dR$
with r radius under the spatial reference frame (m)
R radius under the reference frame of the component ("Material frame") (m)
$\rho_{DM,t}$ apparent density of dry matter under the spatial reference frame (kg /m3)
So then
$d(\frac{4}{3}\pi r^3)/dR = 4\pi \frac{\rho_{MS,0}}{\rho_{MS,t}} R^2$ with r=0 at R=0

A solution of Eq.(1) is
$d(4/3\ \pi r_t^3)/dR=4\pi\ \rho_{(DM,0)}/(\rho_{(DM,t)})\ R^2$ with $r_0=R$
Volume variations of the internal sphere with radius R (∀

To describe local deformation, implementation of ALE has been made using the imposed deformation of a mobile mesh $dx=-(R-r_t)$.

Results

For several conditions for drying air (temperature, relative humidity and air velocity) and plum characteristics (initial weight and water content), the model was in good agreement with drying kinetic data (figure 1). Nevertheless, some discrepancies between experimental data and model results are observed. It could be due to accuracy of the pilot-scale dryer, which was not designed to measure so small weight variations. The barrier role of the skin at low temperature (figure 2) is consistent with operator know-how and the numerous researches made to facilitate drying at low temperature by increasing skin permeability. At 80°C, skin is not to the limiting factor for drying rate. Revolution representations (figure 3) facilitate a lot communication with process supervisors.

Conclusion

This preliminary work shows that 1D axisymmetric model could be a well-adapted tool to represent drying of d'Agen plums. It needs to be completed and evaluated to know their limits of precision and their sensibility to "year's effect".

Reference

M., Di Matteo et. al., A mathematical model of mass transfer in spherical geometry: plum (Prunus domestica) drying, Journal of Food Engineering 58, 183–192 (2003)

E. Tsami et. al., Water sorption isotherms of raisins, currants, figs, prunes and apricots, Journal of food science 55(6), 1594 - 1625 (1990)

H.T. Sabarez, Modelling of simultaneous Heat ad Mass transfert during drying of prunes, Acta Horiculturae 566, 421 - 428 (2001)

A. Briffaz et. al., Modelling of water transport and swelling associated with starch gelatinization during rice cooking. Journal of food engineering, 121 : 143-151 (2014)

Figures used in the abstract

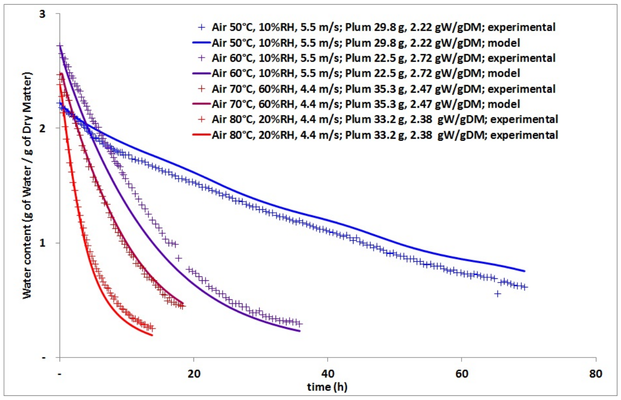

Figure 1: Comparison model – experience for different air conditions and plum characteristics.

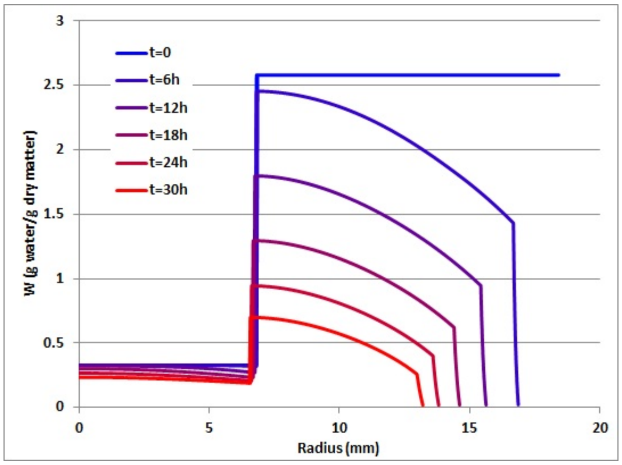

Figure 2: Moisture profiles in a 30g plum dried with air at 20RH, 4 m/s and 60°C (a) or 80°C (b).

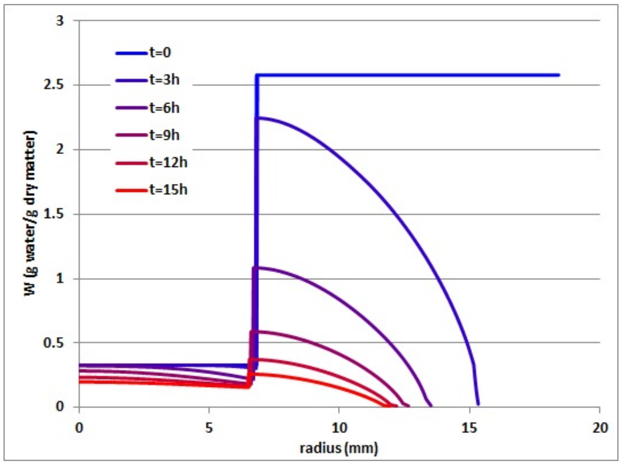

Figure 3: Figure 2b.

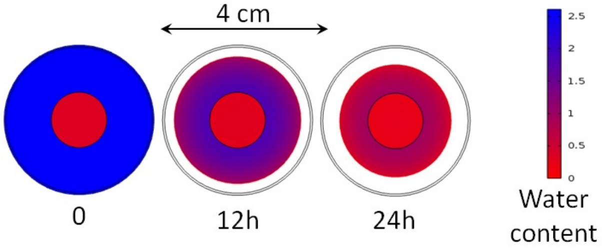

Figure 4: Shrinkage and water repartition in a 30g plum dried at 60°C, 20%RH and 4 m/s.