Presented at the COMSOL Conference 2009 Milan

Modeling of Heat and Mass Transfer in Food Products

Marcin Blazniak Andreasen

Danish Technological Institute, Kongsvang Allé 29
DK-8000 Aarhus C, Denmark
Telephone: +45 7220 1277 / Fax.: +45 7220 1212
E-mail: marcin.andreasen@teknologisk.dk

Introduction

Food drying and food freezing are the most common and widely used methods to preserve food for later use. Nevertheless, the processing of food is complex and still little understood. The processing and storage conditions of food products are highly related to the product end quality and also to economic factors. Computer-aided simulation makes it possible to obtain insight into the internal process that occurs during food processing and therefore it can be a useful tool for improving the food quality and/or the total economy.

Objective

The main objective of this study is to develop a general model that can account for the food characteristics, the processing and storage conditions and predict the freezing and drying times of the food products.

Conclusion

The developed model allows for the evaluation of freezing and sublimation fronts, freezing times, temperature profiles and weight loss during freezing and storage of frozen food. It can also be used to evaluate the weight loss during drying of the food products. However, in order to have a general model that can account for the food characteristics and the processing and storage conditions it is necessary to carry out additional work on the moisture migration in food products. While the thermal properties seem to be well-documented for a large number of food products, data on moisture diffusivity is difficult to find.

Method

The problem was solved by utilizing heat, mass transfer and moving mesh model in Comsol Multiphysics. In order to predict the heat transfer, the thermo physical properties of food products are evaluated by a composition-based prediction method where the thermal properties of a given food product are evaluated based on major components found in the food. The mass transfer problem in the unfrozen region is solved by the Fickian model and in the frozen region by the receding front model that assumes that the water movement becomes immobilized and that the moisture sublimates first from the surface then throughout the dried area in the food.

Unfrozen region		
	Governing equations	Boundary conditions
Mass transfer	$\frac{\partial C}{\partial t} = \nabla D_{eff} \nabla C$	$-n \cdot (-D\nabla C) = k_c (C_{out} - C_s)$
Heat transfer	$\rho Cp \frac{\partial T}{\partial t} = \nabla \lambda \nabla T$	$-n \cdot (-\lambda \nabla T) = h(T_{out} - T_s) - Q_{evap}$
Frozen region		
Speed of the receding sublimating front	Mass flux of moisture throughout the desiccated layer	Heat flux throughout the desiccated layer
$\frac{\partial \delta}{\partial t} = \frac{\dot{m}}{C(\delta)}$	$\dot{m} = \frac{(C_{out} - C_s)}{\frac{1}{k_c} + \frac{\delta}{D_Y}}$	$q = \frac{(T_{out} - T_{sub})}{\frac{1}{h} + \frac{\delta}{\lambda}}$

Table 1: Applied equations.

	Unfrozen region	Frozen region
Density	$\rho = \frac{1-\varepsilon}{\sum \frac{X_i}{\rho_i}}$	
Thermal conductivity	$\lambda = \lambda_c \frac{2\lambda_c + \lambda_d - 2\varepsilon(\lambda_c - \lambda_d)}{\lambda k_c + \lambda_d + \varepsilon(\lambda_c - \lambda_d)}$	
Specific heat capacity	$Cp_w = \sum Cp_i X_i$	$Cp_w = \sum Cp_i X_i - L_f \frac{\partial X_{ice}}{\partial T}$

Table 2: Equations used for evaluation of thermo physical properties of food products.

Results

Three products were investigated: two vegetables (potato and carrot) and one meat product (lamb). The vegetables were exposed to a convective hot air drying process while the meat was frozen and the weight loss during frozen storage was estimated. From the model the temperature profiles during drying and freezing, drying curves and weight loss curves during frozen storage were obtained.

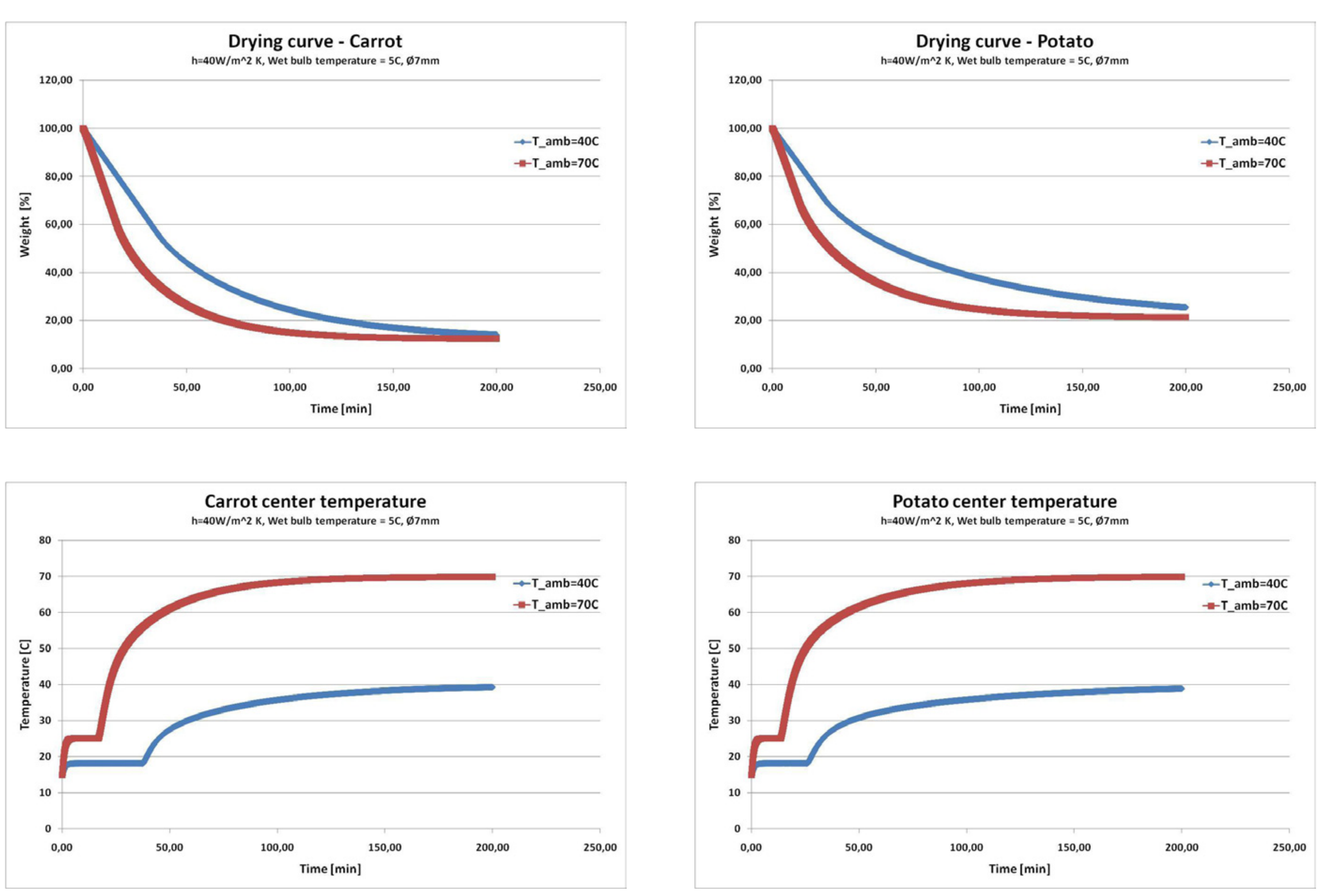

Figure 1: Centre temperatures and drying curves for carrot and potato.

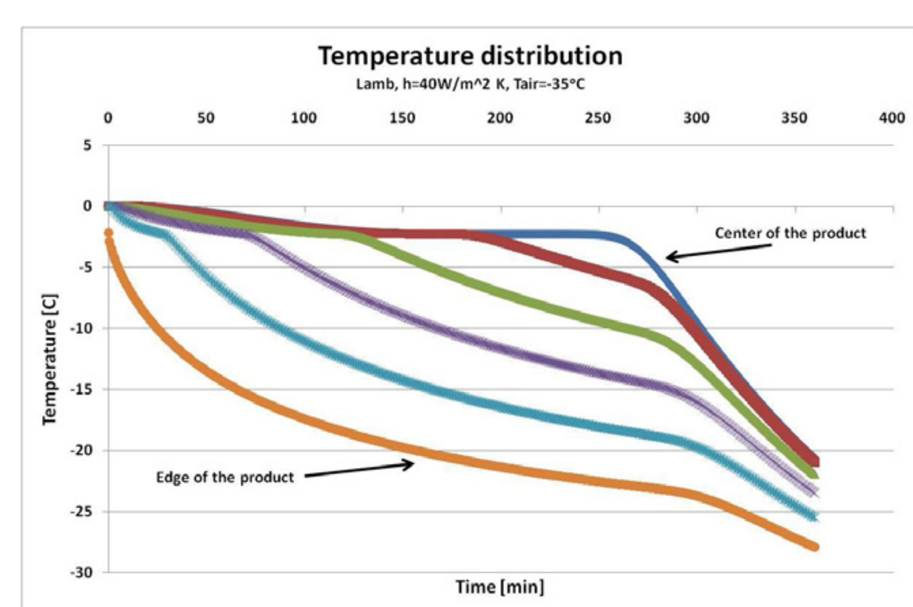

Figure 2: Temperature distribution in lamb during freezing period.

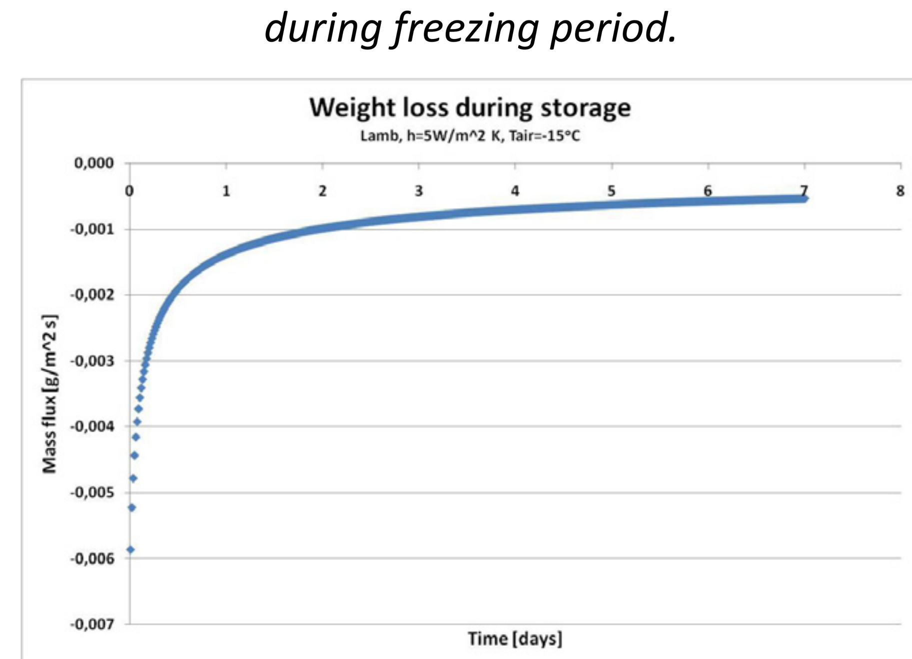

Figure 3: Mass flux of moisture during frozen storage of lamb.

References:

[1] ASHREA, ASHREA Handbook – Refrigeration, Chapter 9 – Thermal Properties of Foods, ASHREA (2006)
[2] Fricke B. A., Becker B. R., Evaluation of thermo physical property models for foods, ASHRAE Transactions. **Vol. 108**, no. 1, p. 261. (2002)
[3] Pham Q.T., Prediction of calorimetric properties and freezing time of foods from composition data, Journal of Food Engineering, **Vol. 30**, p. 95-107 (1996)
[4] Srikiatden Jaruk, Roberts John S., Measuring moisture diffusivity of potato and carrot (core and cortex) during convective hot air and isothermal drying, Journal of Food Engineering, **Vol. 74**, p. 143-152 (2006)
[5] Delgado A.E., Sun Da-Wen, Heat and mass transfer for predicting freezing processes – a review, Journal of Food Engineering, **Vol. 47**, p. 157-174 (2001)
[6] Pham Q.T., Modelling heat and mass transfer in frozen foods: a review, Journal of Refrigeration, **Vol. 29**, p. 876-888 (2006)
[7] Pham Q.T., Mawson R., Moisture migration and ice recrystalization in frozen foods, in: M.C. Erickson, Y.C. Hung (Eds.), Quality in frozen foods, Chapman and Hall, New York, p.67-91 (1997)
[8] Barbosa-Canovas G., Vega-Mercado H., Dehydration of foods, Chapman and Hall, New York, (1996)
[9] Olguin M.c., Salvadori V.O. et.al., An analytical solution for the coupled heat and mass transfer during the freezing of high-water content materials, Journal of Heat and Mass Transfer, **Vol. 51**, p. 4379-4391 (2008)
[10] Vagenas G.K., Marinos-Kouris D., Finite element simulation of drying of agricultural products with volumetric changes, Applied Mathematical Modelling, **Vol. 15 Issue 9**, p. 475-482 (1991)