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Modelling Convective and Microwave Drying of Potatoes Slices

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Abstract

In this work we compare the kinetic of the drying process of potatoes slices in a hot air forced oven and in a microwave oven with provision for controlling temperature. A semi-empirical model was developed to predict the drying kinetics at different temperatures. The model was based on the analytical solution of the mass diffusion equation with appropriate boundary conditions. The effective diffusion coefficient was estimated with a regression analysis on the base of experimental data. The dependence of the effective diffusion coefficient on the process temperature was modelled with an Arrhenius kinetic. Finally, a comparison of the convective and microwave drying kinetics is discussed.

Keywords: potato, microwave, drying

Introduction

A deep comprehension of the phenomena involved in the dehydration process in order to improve process strategies, can be achieved through the use of mathematical models, consisting of energy and mass balances. In this paper, the experimental results of convective and microwave drying potatoes slices is reported.

Experimental design

Potato samples, with a cylindrical geometry (thickness 5 mm, diameter 20 mm), were submitted to two different drying methods: in hot air forced oven (Zanussi, Milan, Italy) at 50, 60, and 70°C; in a microwave oven (De Longhi Milan, Italy). Microwave dehydratation were carried out by power intensity cycles (15 seconds interval times of at 0 and 750W) in order to slow down hot spot phenomena.

Mathematical model and results

The removal of moisture from potatoes is a quite complex process which in general involves both mass and heat transfers. For convective process, we assume negligible the moisture transport through lateral surface of the potato cylinder, constant moisture concentration at the gas-solid interface, heat transport faster than mass transport (so isothermal process is assumed). With these assumptions the mathematical model, written in dimensionless form, is:

$$\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x^2} \qquad (1)$$

The boundary conditions are: $\frac{\partial c}{\partial x}(0,t) = 0; \quad c(1,t) = 0$ (2)

The initial condition is: $c(x,0) = 1 - M_0$ (3)

c is the moisture content, t is the time, x is the space, D is the effective diffusion coefficient, M_0 is the mass of the dried potato. The effective diffusion coefficient includes both mass diffusion and capillarity transport phenomena. The solution of the diffusion equation, obtained through the method of separation of variables, is (Crank, 1975):

$$c(x,t) = \frac{4}{\pi}\left(1 - M_0\right)\cos\left(\frac{\pi}{2}x\right)\exp\left(-\left(\pi/2\right)^2 D\cdot t\right) \qquad (4)$$

Integrating (3) over x ($x \in [-1,1]$) the total amount of moisture in the solid is obtained:

$$M(t) = \left(8/\pi^2\right)\left(1 - M_0\right)\exp\left(-\left(\pi/2\right)^2 D \cdot t\right) \qquad (5)$$

The estimated values of M_0, D and their confidence intervals, at three temperature, were determined using nonlinear regression techniques implemented in Mathematica©, (Tab. 1).

Temperature (K)	Parameter	Value	Confidence Interval
323	D [m^2/s]	$6.383 \cdot 10^{-10}$	$\pm 1.13491 \cdot 10^{-10}$
	M_0	0.215131	± 0.038936
333	D [m^2/s]	$9.71124 \cdot 10^{-10}$	$\pm 1.69413 \cdot 10^{-9}$
	M_0	0.194075	± 0.022093
343	D [m^2/s]	$1.01674 \cdot 10^{-9}$	$\pm 1.74203 \cdot 10^{-9}$
	M_0	0.166093	± 0.019982

Table 1. Estimated parameters at different temperatures for the convective model.

The dependence of the effective diffusion coefficient on the process temperature was modelled with an Arrhenius kinetic ($D_{eff} = D_0 \exp\left(-E_0 / RT\right)$). The corresponding model parameters, estimated on the base of the estimated values of the effective diffusion coefficient at different temperatures, are: $D_0 = 8.56501 \cdot 10^{-7}$ m^2/s, $E_0 = 19089.7$ J/mol.
In order to carry out a comparison between the convective process and a microwave one, a simplified model of the microwave drying was considered. In this case heat equation cannot be neglect, as samples were subjected to marked oscillating temperature profiles because of the imposed discontinuous working conditions of microwave oven.
The mathematical model is:

$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x^2}; \qquad (6)$$

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} + Kw \cdot c\left(x,t\right) \qquad (7)$$

The boundary conditions are: $\frac{\partial c}{\partial x}(0,t) = 0;\ c(1,t) = 0; \frac{\partial T}{\partial x}(0,t) = 0;\ T(1,t) = T_S$ (8)

The initial condition is: $c(x,0) = 1 - M_0; T(x,0) = T_0$ (9)

T is the temperature and α is the thermal diffusion coefficient. The second term in the right hand side of the heat balance take into account the energy source due to electric field. This term is set to be proportional to the moisture content (Constant, et al., 1996). The estimated values of the parameters of the mass balance equation are reported in table 2.

Parameter	Value	Confidence Interval
D [m^2/s]	$6.57679 \cdot 10^{-9}$	$\pm 2.1995 \cdot 10^{-9}$
M_0	0.321459	± 0.078197
α	$6.07703 \cdot 10^{-8}$	$\pm 1.9185 \cdot 10^{-8}$
K_w	$1.26074 \cdot 10^{7}$	$\pm 2.91694 \cdot 10^{6}$

Table 2. Estimated parameters for the microwave model.

As can be seen, comparing results reported in table 1 and table 2, convective drying is less efficient then the microwave one, even if the last one needs a more careful temperature control. We found that a wrong temperature policy can lead to the formation of hot spots which cause burnished zones in the samples.

References

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