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Mass transfer mechanisms occurring in osmotic dehydration of guava

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Abstract

Two osmotic dehydration modes were applied to guava segments immersed in a 65 °Brix sucrose solution at 30, 40 and 50 °C: under constant atmospheric pressure and using a pulsed vacuum (5 min under vacuum, then at atmospheric pressure). The effective diffusivity in the liquid phase, D_e and the kinetic constants of net mass transfer, K and K_0, were determined by fitting the experimental data to mathematical models. The highest effective diffusivities were obtained with pulsed vacuum at 40 and 50 °C on account of the hydrodynamic mechanism, with solids diffusion overcoming dehydration at the beginning of the process, at 30 and 40 °C. The effect of temperature on mass transfer kinetics, predictable by the Arrhenius equation, is more relevant at atmospheric pressure, where the pseudo-diffusion mechanism exerts the controlling role.

Keywords: Osmotic dehydration; Kinetics; Effective diffusivity; Guava

1. Introduction

In osmotic drying, water diffusion through the cellular membranes is the main transport mechanism, although there is an overlapping of diffusion and capillary phenomena in the tissue's intercellular spaces (pores). Capillary phenomena occur at low pressure (Fito, 1994), but with the high compression ratios associated with the pulsed vacuum process (low pressure at the beginning of the treatment and atmospheric pressure later on) the entrance of the external liquid phase in the intercellular spaces through the hydrodynamic mechanism (HDM) can play an important role in mass transfer. Consequently, in osmotic dehydration (OD) several mechanisms intervene in different degrees, depending on process conditions. These mechanisms can be divided in two groups (Fito, 1994; Fito et al., 1994):

- A group of mechanisms that depend on concentration gradients, generically labeled as pseudo-diffusional and usually modeled applying the second Fick's law to a non stationary and unidirectional flow.
- A mechanism that depends on pressure gradients, called the hydrodynamic mechanism (HDM) that acts at the beginning of the osmotic treatment.

In previous papers a macroscopic model of the OD process integrating the pseudo-diffusional and hydrodynamic mechanisms has been studied (Barat et al., 1997, 2001; Fito and Chiralt, 1996). It involves the kinetics from two viewpoints: compositional changes of the food's liquid phase (FLP) and changes in the product's total mass.

In the first case the model allows good predictions of the final composition of the product, in terms of a corrected coefficient of effective diffusion with the contribution of the HDM. This parameter can offer valuable information, since it takes into account the compositional changes of the liquid phase of the fruit due to the mass transfer processes that take place under different treatments, determining the

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Nomenclature

M_w	water losses (%)
M_s	solids gain (%)
M	weight loss (%)
M_0	initial weight (g)
M_t	weight at time "t" (g)
X_{w0}	initial moisture (g water/g sample)
X_{wt}	moisture at time "t" (g water/g sample)
X_{s0}	initial solutes concentration (g solutes/g sample)
X_{st}	solutes concentration at time "t" (g solutes/g sample)
Y_S	reduced driving force in the LP of the fruit
Y_S^{HDM}	reduced driving force considering the effect of the HDM
Z_{st}	solute concentration in the LP of the fruit at time t (g solutes/g liquid fraction)
Z_{s0}	solute concentration in the LP in the initial moment (g solute/g liquid fraction)
Z_{se}	concentration of the LP in equilibrium with the osmotic solution, considered similar to that of the solution (g solute/g of liquid fraction)
Z_s^{HDM}	solute concentration in the LP of the sample resulting from the action of the HDM (g solute/g of liquid fraction)
m	sample mass in the initial instant (g)
m_{LP}	mass of the LP (g)
m_i	impregnated mass (g)
m_i^{HDM}	impregnated mass resulting from the effect of the HDM (g)
y_{so}	solute concentration of the osmotic solution (g solute/g of liquid fraction)
K_{s0}	kinetic constant of solute transport occurring at very short treatment times in the pulsed vacuum regimen
K_s	kinetic constant of solute transport
K	kinetic constant of the combined kinetics of the pseudo-diffusional mechanisms
K_0	kinetic constant of the net mass loss after a very short treatment time
t	process time (s)
D_e	effective diffusivity
l	half thickness of the sample (0.00334 m)
D_0	Arrhenius factor (m^2/s)
E_a	activation energy (kJ/mol)
R	universal gas constant
T	absolute temperature (K)

quality and final condition of the product. It can thus become a basis for the design of products and processes.

In the second case the model predicts the changes in total mass through kinetic constants for net mass transfer, which has an important effect on the productivity and profitability of the process.

The reviewed literature includes studies on the kinetics of osmotic dehydration (OD) of guava under vacuum or atmospheric pressure that have yielded advances in process modeling and in controlling the variables that regulate it (Panades et al., 1996, 2003b, 2006). Other studies report on the influence of osmotic drying on product quality (Panades et al., 2003a; Pereira et al., 2004). However, few references deal with the mass transfer mechanisms occurring in the liquid fraction of the product during treatment at different pressure regimens.

The objective of this study was to determine the effective diffusivity in the liquid phase of osmotically dehydrated guava and the kinetic constants of net mass transfer in the process variants at atmospheric pressure and under pulsed vacuum.

2. Materials and methods

2.1. Sample preparation

For the study, hard ripened guavas (*Psidium guava* L.), Enana Roja variety, from the Estacion Nacional de Frutales, in Havana, were selected according to the maturity conditions established in the Cuban Standard (NC 77-52, 1986) and with a 53–59 mm diameter, to ensure the homogeneous size of samples. The fruits were peeled, cut in halves, cored and cut in eighths.

2.2. Osmotic dehydration treatment

Guava slices were weighed in 110 g fractions (about 12 slices) and put in a 1 L glass flask containing 880 g of a sucrose solution of 65 °Brix, for a fruit: solution ratio of 1:8. The flask was then immersed in a thermostatic water bath, connected to a vacuum rotary evaporator with a rotation speed of 100 rpm and subjected to different pressure treatments for different times.

Three temperatures, 30, 40 and 50 °C, six total times, 30, 60, 90, 120, 150 and 180 min and two pressure modes: atmospheric pressure and pulsed vacuum, were tested. In the pulsed vacuum regimen, a vacuum time of 5 min. was used. Absolute pressures of the system were those of the syrup vapor pressure, corresponding to every temperature studied: 30 °C – 4.3 kPa; 40 °C – 5.2 kPa; 50 °C – 10.7 kPa. Each experiment was carried out in triplicate.

2.3. Analyses

After every treatment, samples were removed from the solution, drained and rinsed with distilled water to remove the syrup adhered to the surface, then gently blotted with tissue paper.