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Osmotic dehydration of apricot: Kinetics and the effect of process parameters

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ABSTRACT

The effect of different parameters on the osmotic dehydration of apricot in terms of water loss and solid gain, such as the different osmotic matter the concentration of solution (40–70%, w/w), temperature (25–45 °C), the ratio of sample/solution (1/4–1/25), time, and geometry of sample were investigated. The increasing of temperature and concentration of osmotic medium caused increased water loss and solid gain. The decreasing of the ratio of sample to solution avoids significant dilution of the medium by water removal and subsequent decrease of osmotic driving force during the process. The water loss and solid gain was increased when the dimension of apricot was decreased.

Effective diffusion and mass transfer coefficients of water as well as solid were estimated. The transport coefficients for water loss and solid gain (D_e and k) increases with an increase in osmotic solution concentration and increase in temperature. Non-linear analysis of the estimated D_e and k of water and solute reveal that these values depend on temperature and concentration of the osmotic solution as well as the combined effect of temperature and concentration. In addition, the effect of the ratio of sample to solution on these transport coefficients was modeled. The statistical comparison methods such as χ^2, MBE and RMSE were used to explore the confidence level of the models.

Keywords: Apricot; Osmotic dehydration; Effective diffusivity; Mass transfer coefficient; Empirical models

1. Introduction

Osmotic dehydration involves the partial removal of water from food, such as fruits and vegetables, by immersing it in a hypertonic solution. A driving force for the diffusion of water from the food into the solution is set up because the food cellular surface structure acts as a semi permeable membrane. The diffusion of water is accompanied by the simultaneous counter diffusion of solute from the osmotic solution into the food. The existence of those simultaneous and opposite fluxes is one of the main difficulties in modeling of osmotic dehydration kinetics (Spiazzi and Mascheroni, 1997). Since the membrane responsible for osmotic transport is not perfectly selective, other solutes present in the food are also leaked into the osmotic solution (Torreggiani et al., 1988; Rastogi et al., 1997). The rate of diffusion of water from any material made up of such tissues depend on factors such as; temperature and concentration of the material, the solution to material mass ratio and the size and shape of food, the level of agitation in the solution, and the vacuum level, if applied. A number of recent publications have described the influence of these variables on mass transfer rates during osmotic dehydration (Torreggiani, 1993; Rastogi and Raghavarao, 1994, 1995, 1997; Rastogi et al., 2002; Azoubel and Murr, 2004; Kaymak-Ertekin and Çakaloz, 1996a, 1996b; Kaymak-Ertekin and Sultanoğlu, 2000).

Much work has been done in developing models to predict the mass transfer kinetics of OD at atmospheric pressure. Nonetheless, it is very difficult to develop a mathematical model capable of including all of the factors involved in the process. Mechanistic and empirical approaches have been proposed by many authors as mentioned by Panagiotou et al. (1998) and Shi and Le Maguer (2002).

Mechanistic approaches describe the underlying phenomena by means of various mechanisms: some authors have used Fick's law of diffusion (i.e. Kaymak-Ertekin and Sultanoğlu, 2000; Rastogi et al., 1997; Salvatori et al., 1999) and some other

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Nomenclature

D	the relative % deviation
D_{es}	effective diffusivity of solute ($m^2 s^{-1}$)
D_{ew}	effective diffusivity of water ($m^2 s^{-1}$)
M	the moisture content (kg [H_2O]/kg [dry matter])
MBE	mean bias error
ML	mass loss (kg [H_2O]/kg [fresh fruit])
Mr	the moisture ratio
RMSE	root mean square error
S	solid content (dry basis kg [dry matter]/kg [dry matter])
SG	solid gain (kg [H_2O]/kg [fresh fruit])
SG_∞	solid gain in the equilibrium (kg [H_2O]/kg [fresh fruit])
Sr	solute ratio
WL	water loss (kg [H_2O]/kg [fresh fruit])
WL_∞	water loss in the equilibrium (kg [H_2O]/kg [fresh fruit])

Greek letter

χ^2	reduced chi-square

authors have proposed models based on the knowledge about cellular physiology of tissues (Spiazzi and Mascheroni, 1997; Toupin et al., 1989; Yao and Le Maguer, 1996).

On the other hand, empirical and semi-empirical models have been proposed. These models correlate processing variables with water loss (WL) or solid gain (SG) without taking into account the underlying phenomena and they include multi-variable regressions, response surface analysis, models derived from mass balances, etc. Relevant examples of these are reviewed by Shi and Le Maguer (2002).

Although mechanistic models give a description of the mass transfer mechanism, diffusion approach has a number of assumptions which are difficult to fulfill (Kaymak-Ertekin and Sultanoğlu, 2000), and the effective diffusivity becomes an adjustable kinetic parameter that strongly depends on the experimental conditions and the physical properties of the fruit (Salvatori et al., 1999). Also, cellular physiology approach depends on a large number of biophysical properties, such as elastic modulus of the cell wall, cell wall void fraction, cell wall tortuosity and membrane permeabilities, which are not always available (Kaymak-Ertekin and Sultanoğlu, 2000; Spiazzi and Mascheroni, 1997).

On the other hand, even though the empirical and semi-empirical models that have been proposed in the literature give a reasonable fit to experimental data, their use is limited because they are only capable of representing data at conditions similar to those on which such models were developed, and they cannot take into account the process complexity (Trelea et al., 1997).

Osmotic dehydration is used as a pretreatment to many processes and improves nutritional, sensorial and functional properties of food without changing its integrity (Torreggiani, 1993). Osmotic dehydration is, generally, used as an upstream step for the dehydration of food before they are subjected to further processing such as freezing (Ponting, 1973), freeze drying (Hawkes and Flink, 1978), vacuum drying (Dixon and Jen, 1977) and air drying (El-Aouar et al., 2003; Piotrowski et al., 2004; Mandala et al., 2005).

The traditional method, which is often used in Turkey for apricot drying, is to spread it on the ground to subject it to the direct sunlight. As we know, in traditional drying methods serious decreases of nutritive and sensorial values are possible, damaging mainly the flavor, color, and nutrients of the product (Lenart, 1996; Lin et al., 1998). Due to the large amount of dry apricot production, it is essential to find better ways for drying apricots. One of these methods is to pre-dry the apricots, before applying warm air or other drying methods, using osmotic dehydration method. A combined process, consisting of osmotic dehydration, followed by air dehydration has been proposed to obtain dry apricot ingredients, having a natural color, without sulphur dioxide, which could be suitable for different applications (Forni et al., 1997).

A continuing interest in dried apricot products has opened avenues for the dehydration of apricot by different methods, such as tray drying (Toğrul and Pehlivan, 2003; Doymaz, 2004), and solar drying (Toğrul and Pehlivan, 2002, 2004). A good quality dried apricot, whole or in slices, commands greater market potential than apricot powder because of its versatile culinary utility.

The purpose of the present work is (i) to study the effect of temperature and concentration of the osmotic solution, various osmotic agents, the ratio of sample to solution and the geometry of sample on the osmotic dehydration of apricot and (ii) to determine the effective diffusion and mass transfer coefficients of water and solute during osmotic dehydration for the whole range of experimental conditions and (iii) to model the effects of procedure parameters such as concentration and temperature of osmotic solution and the ratio of sample to solution, on this calculated effective diffusions and mass transfer coefficients by using non-linear regression and to select the best models by using statistical test indicators.

2. Materials and methods

2.1. Materials

Fresh apricots were directly collected from tree and brought to the laboratory in wooden boxes. The apricots were refrigerated at 5 °C and 80–90% relative humidity until they were used in the experiments. The apricots were sorted visually for maturity and size (average weight of 25 g (range 23.18–26.11 g), average diameter of 3 cm (range 2.82–3.21 cm)). The dimensions of apricots were measured by a digital micrometer. The apricots with above mentioned values were selected. The average initial moisture content was 80.86% in wet basis, gravimetrically measured using an oven at 75 °C for 24 h. Since this is a temperature at which no structural changes occur during drying process this is one of the preferred values in both infrared and oven methods (Toğrul and Pehlivan, 2002, 2003, 2004; Doymaz, 2004).

2.2. Experiments

The osmotic dehydration experiments were carried out in Firat University Chemical Engineering Research Laboratories.

Various osmotic agents such as sucrose, glucose, fructose, maltodextrin and sorbitol have been used for osmotic dehydration of apricot. The initial concentration of solutions varied from 40% to 70% (w/w) and temperatures varied from 25 °C to 45 °C. The ratio of fruit to solution was kept at 1/25 to avoid significant dilution of the medium by water removal, which