# Osmotic Drying of Apricot (*Prunus armeniaca*) in Sucrose Solution

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## Summary

Osmotic drying is a process of partial removal of water by submersing fruits in sucrose solution. The goal of this paper is to examine kinetic features of osmotic drying of apricot halves in sucrose solution. For osmotic drying of apricot halves in a thick immovable layer, a planned experiment was conducted. Experimental results were used to create an empirical model of osmotic drying kinetics which expresses the influence of analyzed experiment factors on water loss (WL). The experiment factors were temperature of osmotic solution, varied at two levels, 35 °C and 60 °C, and sucrose concentration varied at two levels, 50 °Bx and 65 °Bx. Using regression analysis of experimental data for water loss (WL) at statistical probability of 99 %, parameters of empirical model and correlation coefficient were calculated for the proposed mathematical model. Experimental results were approximated using the derived equation. Conformance of experimental results with the empirical model was evaluated using correlation coefficient (R). Correlation coefficient calculated for the proposed model was high, R = 0.976. It indicates fine agreement between experimental and model values for water loss.

## Key words

osmotic drying, kinetics, mathematical model, apricot

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Received: November 5, 2008 | Accepted: March 18, 2009

ACKNOWLEDGEMENTS
This research was funded by the Ministry of Science of the Republic of Serbia, through Project no. 20065 entitled "Quality of Dried Fruit Production" within the program of technological development from 01. 04. 2008.

## Introduction

For its biochemical structure, apricot *(Prunus armeniaca)* is considered a fruit very suitable for drying. It features high content of provitamin A, vitamin C as well as a complex of other vitamins which are beneficial to human organism. The complex of mineral matter in apricot fruits - especially high contents of potassium, phosphorus, magnesium and iron - improves blood count, blood circulation and regulates blood pressure in humans (Đurić, 2003).

Conventional drying technologies featuring convective drying as the sole technological drying operation, yield dried apricots of unsatisfactory quality. Using combined drying technology with osmotic drying as one of the fundamental technological operations, rectifies this problem (Babić and Babić, 2003; Babić et al., 2003; Babić et al., 2004a; Riva et al., 2005).

Osmotic drying by submersion in concentrated solutions is used for partial removal of water from plant tissue. The concentration gradient of water influences extraction of water from the tissue, while conditioning penetration of osmotic solution into the tissue. Extraction of water from the tissue is much more intensive than the penetration of osmotic solute into the tissue. Velocity of diffusion of water molecules from biological materials depends on a number of factors such as: temperature and concentration of osmotic solution, solute properties, dimension and geometric shape of submersed material, mass ratio between material and osmotic solution, velocity of solution flow, material preprocessing and other factors (Rastogi et al., 2002; Rahimzade and Hesari, 2007; Pavkov, 2007).

In recent years, numerous empirical models have been developed, of which the Biswal model stands out as the most frequently used. Biswal equation allows simple calculation of water loss and dry matter gain, WL/SG. The results can be used for optimization of the process of osmotic drying (Shi and Le Maguer, 2002; Jokić et al., 2007):

$$WL = k_W \cdot t^{0,5} \tag{1}$$

$$SG = k_S \cdot t^{0,5} \tag{2}$$

where $k_w$ and $k_s$ are coefficients of total mass transfer for water, i.e. osmotic solute; WL/SG is net water loss, i.e. dry matter gain (g), while t denotes drying time (min).

The models derived do not explicitly express the influence of relevant factors on osmotic drying kinetics. For each combination of factors, values of coefficient functions $k_w$ and $k_s$ need to be calculated. This paper presents calculation of water loss (WL) parameters of empirical model, based on experimental data for osmotic drying of apricot halves in thick immovable layer. The proposed model explicitly expresses influence of examined factors on water loss during osmotic drying of apricot halves.

## Materials and method

In the experiment, fresh apricot halves *(Prunus armeniaca)* of the cultivar "Novosadska rodna" were used as material. The picked apricots were at the stage of full technological maturity (3.4 pH). The basic physical properties of the fresh fruits were: average mass of whole fruit 47.5 g and dimensions: $a_{cp}$ = 47.18 mm, $b_{cp}$ = 45.54 mm and $c_{cp}$ =41.08 mm.

The preprocessing of fresh apricots included washing, halving, stoning and sulfurization. Dry sulfurization was performed using sulfur-dioxide ($SO_2$), in a sulfurization chamber. Apricot halves were exposed to $SO_2$ for the duration of four hours. Two grams of technical powdered sulfur were used per one kilogram of fresh apricot halves. The prepared samples, four kilograms, were set in osmotic dryer. After osmotic drying the samples were moved to convective dryer where were further dried until they reached equilibrium moisture.

For osmotic solution, sucrose in the form of crystal sugar was used as solute, while distilled water was used as the solvent. The experiment was conducted in a semi-industrial type osmotic dryer, maximum capacity of 0.032 $m^3$ solution (Figure 1). The principle of operation of this dryer is based on circulation of osmotic solution through a drying chamber with fruit sample and a heat exchanger.

Previous examinations on the process of osmotic drying of fruit tissue and influential parameters, accentuate that the temperature and concentration of osmotic solution are the two parameters with utmost impact on the velocity of mass transfer during osmotic drying (Babić et al, 2004a; Babić et al, 2004b; Riva et al, 2005). Based on this finding, the experiment was performed as a two-factor experiment. The temperature of osmotic solution was varied at two levels, 35 $^{o}$C and 60 $^{o}$C, while the sucrose concentration levels were 50 $^{o}$Bx and 65 $^{o}$Bx. Duration of osmotic drying was two hours. Mass ratio between osmotic solution and a sample of apricot halves was 12:1. Velocity of circulation of osmotic solution through material layer changed only slightly during the experiment due to variable solution viscosity and layer porosity.

Effects of osmotic drying were monitored by taking samples from the dryer during specific time intervals (0, 30, 60, 90, 120 min). The samples were washed in order to eliminate solution remnants and then carefully wiped off with an absorbing cloth. Dry matter was determined by drying at 80 $^{0}$C for the period of 24 hours. Water loss (*WL*) was determined by measuring mass difference before and after the drying. Water loss was calculated as the ratio between net water loss from the fresh sample and the initial mass of the sample:

$$WL(\%) = \frac{M_0 - M_i}{W_0} \cdot 100 \tag{3}$$

where $M_0$ is mass of the fresh sample (g), $M_i$ is mass of the sample after osmotic dehydration (g), $W_0$ is the total mass of the fresh sample (g).

According to the goal of this examination, an empirical model of water loss kinetics was proposed and used for regression analysis. The model is based on the Biswal equation that was extended by the influence of the analyzed experiment factors (Pavkov et al, 2006):

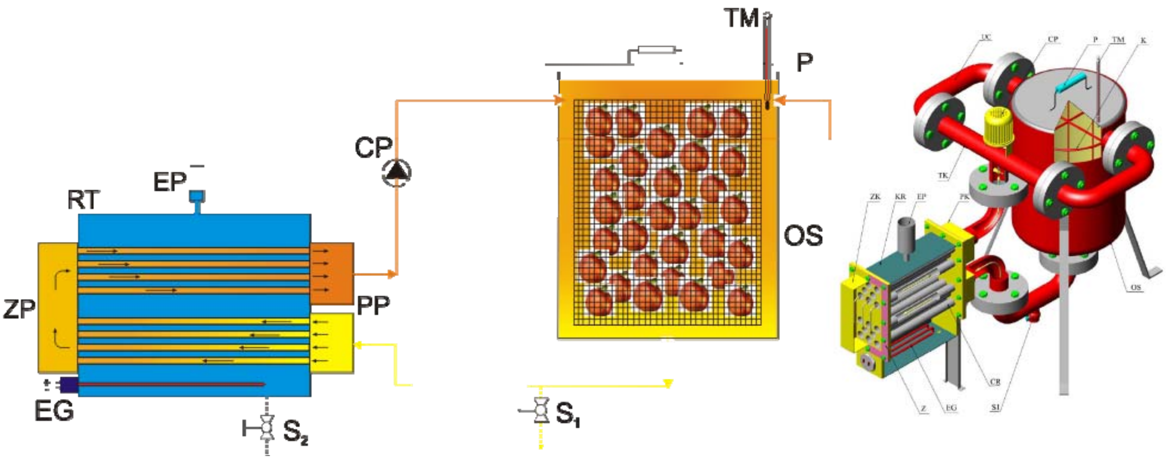

**Figure 1.** Semi-industrial type osmotic dryer (Babić et al. 2004c); OS – drying chamber, P – lid, CP – circulation pump, Z – sealing, CR – piping, KR – heat exchanger housing, TK – T-flange piece, UC – U-flanged pipe, TM – Mercury thermometer, K – basket, EG – electric heater, $S_1$– tap, EP – expansion vessel, PK – front chamber , ZK – aft chamber, direction of solution circulation

$$WL = k_w \cdot \tau^{n_1} \cdot \left(\frac{t}{t_r}\right)^{n_2} \cdot \left(\frac{C}{C_o}\right)^{n_3} \qquad (4)$$

where WL is water loss [%]; τ is duration of osmosis [*min*];. $C_o$, $C_r$ are chosen and referential sucrose concentrations [$^o Bx$]; $t$, $t_r$ are chosen and referential temperatures of solution; $k_w$ is mass transfer coefficient for water [*%/min*], and $n_1$, $n_2$, $n_3$ are equation exponents.

In model (4) the influence of solution temperature and concentration is expressed as a non-dimensional value, namely, as the ratio between the selected factor level and some referential value (Babić, 1995). Referential values of concentration and temperature of osmotic solution are:

$t_r = 100\ ^oC$;

$C_r = 82.87\ ^oBx$ maximal concentration at $t = 100\ ^oC$ according to A. Herzfeld (Šušić, 1980).

Also, the measurement was performed using digital refractometer with the measurement range of 0-85 °Bx, ±0.1°Bx (model Atago, Japan).

For each selected factor-level combination, three iterations were made. In total, twelve experimental units of osmotic drying of apricot halves were performed. Statistical analysis of experimental results was run on Statistica 7.1 (StatSoft Inc., 2003).

## Results and discussion

Changes of moisture content increased with the rise of temperature and concentration of osmotic solution (Figure 2). The most significant changes in water loss took place within the first 90 minutes of the process. Water loss maximum was reached at 65 °Bx concentration of sucrose and 60°C temperature.

The influence of osmotic solution temperature can be explained by the fact that higher temperatures cause changes in cell membrane structure. The membrane becomes more permeable to water molecules which diffuse through apricot tissue towards boundary surface, while the tissue lowers its resistance to liquid diffusion. At the same time, increased temperature lowers viscosity of osmotic solution which, in turn, lowers resistance to transition of liquid molecules from the boundary surface of apricot halves into osmotic solution. In addition, changing permeability of cell membrane intensifies diffusion of solute molecules into intercellular space.

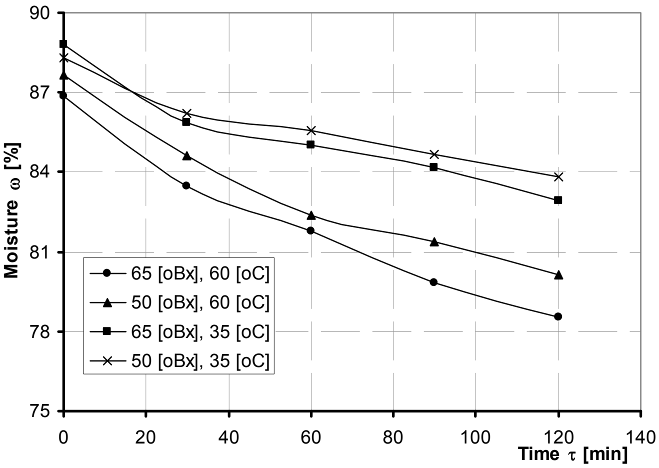

**Figure 2.** Moisture content of apricot halves as a function of time at different temperatures and concentration of sucrose during osmotic drying

Higher concentrations mean higher concentration gradients of water and solute molecules, between the boundary surface of apricot halves and osmotic solution. It is well known that intensity of water molecules' transition from the boundary surface to osmotic solution depends on the area of active surface of interchange, velocity field of solution and, finally, concentration gradient of this component. Furthermore, concentration gradient of solute between apricot halves and

**Table 1.** Results of regression analysis for statistical probability V = 99 %

| Coefficient | Result | Standard deviation | t-value | p-level |
|---|---|---|---|---|
| $k_w$ | 0.7616 | 0.1457 | 5.22515 | 0.000003 |
| $n_1$ | 0.6135 | 0.0403 | 15.1966 | 0.000000 |
| $n_2$ | 0.7899 | 0.0654 | 12.0695 | 0.000000 |
| $n_3$ | 0.5283 | 0.1243 | 4.2503 | 0.000082 |

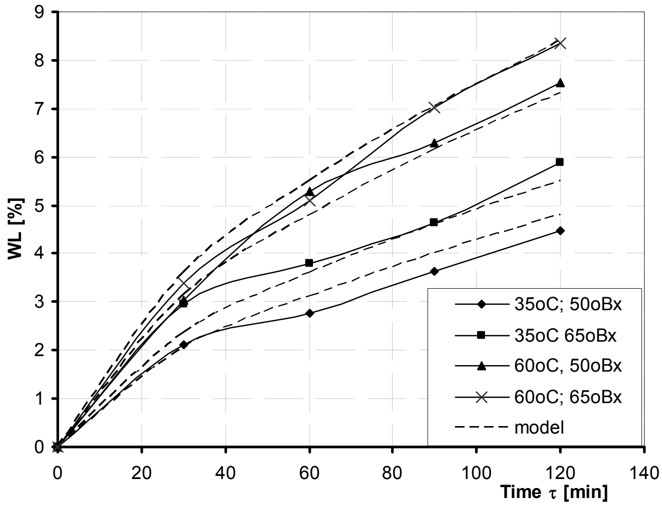

**Figure 3.** Water loss as a function of time at different temperatures and concentrations of sucrose during osmotic drying of apricot halves, experimental and model curve

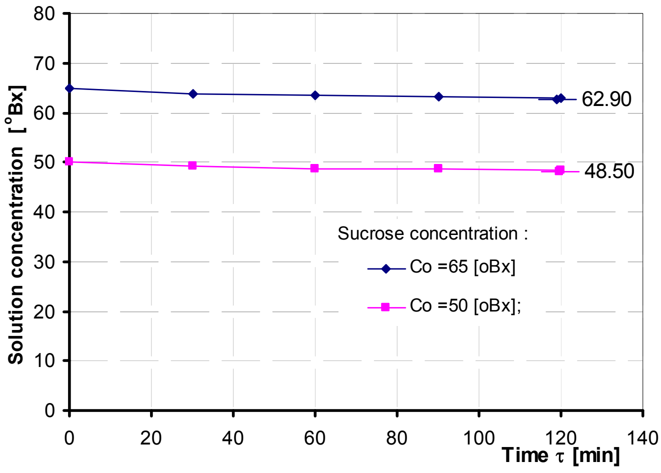

**Figure 4.** Average variation of sucrose concentration in osmotic solutions at 60 °C within a 120 min interval

osmotic solution causes diffusion of solute into apricot tissue. The solute does not penetrate the cell but remains within the intercellular space, thus increasing the active surface of mass interchange between apricot tissue and osmotic solution.

Using regression analysis of experimental data for water loss (WL) at statistical probability of 99 %, coefficients and correlation coefficient were calculated for the proposed mathematical model (4) (Table 1).

Correlation coefficient calculated for the proposed model was high, R = 0.976. It indicates fine agreement between experimental and model values for water loss. Based on statistical significance of coefficients (*p–level*) it is evident that all function coefficients are significant. The final form of empirical model is:

$$WL = 0{,}761 \cdot \tau^{0{,}613} \cdot \left(\frac{t}{100}\right)^{0{,}789} \cdot \left(\frac{C}{82{,}87}\right)^{0{,}528} \qquad (5)$$

The empirical model (5) is applicable within the range of temperature from 35 °C to 60 °C, solution concentration from 50 °Bx to 65 °C and immersion time 120 minutes. Figure 2 shows curves of the moisture content as a function of time for the examined combinations of temperature and concentration of osmotic solution. The graphic presentation (Figure 3) confirms good agreement between the model and experimental water loss curves for apricot halves during osmotic drying.

Monitoring of changes in concentration of osmotic solution during the process of osmotic drying at the 12:1 mass ratio between solution and plant tissue, revealed that the solution concentration changes only slightly. Fig. 4 shows average measurement results for variation of sucrose concentration in osmotic solution at 60 °C during 120 min.

## Conclusions

The model derived (5) yields good approximation of the experimental results of water loss kinetics of apricots in sucrose solutions. The model directly correlates water loss kinetics with temperature and concentration of osmotic solution. In its final form, the model is applicable within the range of temperature from 35 °C to 60 °C, solution concentration from 50 °Bx to 65 °C and immersion time 120 minutes.

At the 12:1 mass ratio between the solution and apricot halves, the solution is mildly diluted. Significant changes occur within the first 90 minutes of the process. During that period the highest water loss occurs at the 65 % sucrose concentration and 60 °C temperature. The increase of total sugars causes change of organoleptic properties of osmotically dried apricot halves, i.e. it causes increased content of sucrose. This occurrence contributes to clogging of pores in apricot tissue, and also hinders the process of convective drying. Considering this, medium concentrated sucrose solutions and higher solution temperatures should be adopted in order to prevent undesirable enzyme reactions in apricot tissue.

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