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## APPLICATION OF PELEG MODEL ON MASS TRANSFER KINETICS DURING OSMOTIC DEHYDRATION OF PEAR CUBES IN SUCROSE SOLUTION

### Article Highlights

- Mass transfer kinetics during osmotic dehydration process of pears in sucrose solution was studied
- Peleg model was applied to the experimental data to describe sorption kinetics curves
- The equilibrium values for moisture and solid content were estimated using Peleg equation
- *Peleg rate constants for WL and SG at all temperatures followed an Arrhenius type relationship*

### Abstract

*The applicability of Peleg model was investigated for predicting mass transfer kinetics during the osmotic dehydration (OD) process of pears, at different concentrations (40, 60 and 70%, w/w) and temperatures (20, 35 and 50 °C) of sucrose solution. Increase in sucrose solution concentration resulted in higher water loss (WL) and solid gain (SG) values through the osmotic treatment period. After 360 min of osmotic treatment of pears, WL ranged from 23.71 to 31.68% at 20 °C, from 24.80 to 40.38% at 35 °C and from 33.30 to 52.07% at 50 °C of initial weight of pears. The increase of dry mass of the samples, SG, after 360 min of osmotic treatment ranged from 3.02 to 6.68% at 20 °C, from 4.15 to 7.71% at 35 °C and from 5.00 to 8.92% at 50 °C. Peleg's rate constants,  $k_1^{WL}$  and  $k_1^{SG}$ , decreased with increasing temperature, as well as decreased with increasing concentration of osmotic solution at constant temperature. Both capacity constants  $k_2^{WL}$  and  $k_2^{SG}$  also exhibited the inverse relationship between capacity constant and temperature, as well as concentration of the osmotic solution. Peleg's rate constants for WL and SG at all temperatures followed an Arrhenius type relationship. The predicted equilibrium values were very close to experimental ones, which was confirmed with high coefficients of determination and by the residual analysis.*

*Keywords: osmotic dehydration, pears, kinetics, temperature effect, Peleg model.*

The pear (*Pyrus communis* L.) is one of the most traditionally cultivated fruits, particularly in temperate climate zones in Europe. This fruit abounds in saccharides and dietary fiber as well as in nutritionally valuable compounds such as antioxidant flavonoids. The fruit contains high quantities of vitamin C, B-complex vitamins (folates and riboflavin), organic and fatty

acids, volatiles and minerals such as copper, iron, potassium and magnesium. The chemical composition, the nature and concentrations of pear's constituents are associated with the organoleptic characteristics of the pear fruits [1-3]. In addition, pear fruit is one of the very low calorie fruits. Due to these beneficial features, regular consumption of pears is highly recommendable in human nutrition [4].

The common fruit processing techniques are conservation in syrup, juice and drying. Dried fruits are used for many purposes in bakery products, gravies and compotes. Ready-to-use intermediate mois-

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ture (IM) food for human consumption has received much attention in recent years. IM products produced by osmotic dehydration (OD) have a higher content of nutrients than those produced by any other drying techniques, because OD has little effect on various internal components. OD of fruits, as a pre-treatment for further steps of drying, presents some benefits such as reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decrease the energy costs [5,6]. OD is a process of partial removal of water by immersing of food (fruit, vegetables, meat and fish) in different types of solutes such as sucrose, fructose, corn syrup, glucose, salts, etc., used as osmotic agents for OD [7].

During the OD process the water and small amounts of natural solutes (such as pigments, sugars, organic acids, minerals, vitamins, etc.) diffuse from fruit to the solution and the solute is transferred from the osmotic solution to the fruit tissue in a counter-current mode. It is an efficient form of moisture removal from solid food, causing no change in phase of the water [8]. The weight reduction is approximately 50% of the original weight due to the osmotic dehydration. Mass transfer during osmosis depends on operating parameters such as concentration and type of the osmotic solution, temperature and period of process [9]. According to previous research, temperature and concentration of osmotic solution have the highest effect on mass transfer kinetics during the process of osmotic dehydration. In addition, the rate of WL during osmotic dehydration is affected by the immersion time, sample to solution ratio and agitation of the osmotic solution [10-13]. Mass transfer during osmosis occurs through a semi-permeable cell membrane and consists of two major simultaneous counter-current fluxes of water and solutes - diffusion of water from food to osmotic solution and diffusion of solute from solution to the food. Leakage of negligible amounts of natural solutes present in the cells into osmotic solution has been considered as third minor flux [14,15].

Mathematical equations describing mass transfer during the osmotic drying enable better comprehension of dehydrated material composition and operating parameters. In this regard, many theoretical and empirical models have been presented in literature, whereas empirical ones have been more popular given their relatively easy application [16-19]. The main goal of existing mathematical models of drying process is prediction of the drying time. The prediction of the drying time is the basic data for the sizing and the optimization of an industrial plant drying. Drying rate is always related to one specific product and

one specific operation. In the case of a constant drying rate period, the phenomenon is in steady state. The mathematical models usually based on Fick's diffusion model for drying studies have been applied to fit drying data of biological materials [20,21].

Peleg model, an empirical one, has been widely used to describe sorption and desorption processes in various foods, *i.e.*, to predict water loss/gain and sugar/salt gain. It has been used to describe water desorption of sago starch, papaya, apricot, cherry tomato, pear, etc. [22-31]. Although it was found that other mathematical model better predict kinetics of the pear osmotic dehydration, according to some authors, Peleg's equation presents the best fitting for WL and the best adjustment to experimental data. Peleg's equation parameters have been subjected to analysis of variance and post-hoc Tukey's HSD test (at 95% confidence limit) to show statistically significant differences between samples [24,29,32].

With the lack of published experimental data for OD conducted with "Abate Fetel" pears as model fruits, our intention was to obtain additional information for practical application in OD process design and control. The objective of this work was to examine mass transfer kinetics in terms of WL and SG as a function of concentrations of osmotic solutions, temperatures and time of immersion during osmotic treatment of pears. Furthermore, the evaluation of applicability of Peleg's equation to experimental data for determination of equilibrium water and solid contents for OD at different concentrations and temperatures as well as the relationship between the Peleg's specific rate constant and temperature using Arrhenius equation for determination of the activation energy ( $E_a$ ) for WL and SG were done.

## MATERIALS AND METHODS

### Preparation of pear samples

Abate Fetel pears were purchased daily from the local market at Belgrade, Serbia. Before experiment, fruits were washed and peeled. The peeled pears were manually cut into cubes of 1 cm<sup>3</sup>, gently blotted with tissue paper to remove the excess of surface moisture and weighed. Initial moisture content,  $M_0$ , was 84.92±0.99%. Analytical grade sucrose was purchased from Merck. The sucrose solution concentrations were 40, 60 and 70 mass%, and were checked by a digital refractometer (Cole-Parmer, USA). Osmotic treatment were carried out at atmospheric pressure, in temperature range from 20 to 50 °C using a circulating water bath (Circulating bath 240 VAC, Cole-Parmer, USA).

The pear cubes were immersed in the sucrose solutions, with a sample to solution ratio of 1:10 (*w/w*). Samples were stirred every 10 min for purpose of easier moving of water that had diffused from the center of the pear cube to its surface and allowing better homogenization of the osmotic solutions. Processing conditions regarding steering, intensity, duration and frequency of stirring were the same for all concentrations of osmotic solutions, at all temperatures, so the results could be comparable. Fruits were removed from the containers after the period of 30, 60, 90, 120, 180, 240, 300 and 360 min, quickly rinsed with distilled water to remove adhered sugar solutions to the surface and gently blotted with tissue paper to remove excess solution from the surface. After each contact time pear cubes were placed in the drying oven (Instrumentaria ST01) at 105 °C for 24 h until constant weight were reached. In order to determine mass change, all samples were weighed before and after treatment using an analytical balance (Mettler-Toledo, JP 1203C, Switzerland). The solid content of osmotic solutions was determined refractometrically (digital refractometer 300034, SPER Scientific Ltd., USA). All analyses were carried out in triplicate and in accordance to AOAC [33].

#### Kinetic parameters determination

*WL* and *SG* of the samples were calculated as follows:

$$WL / \% = 100 \frac{M_0 - M_t}{W_0} \quad (1)$$

$$SG / \% = 100 \frac{S_t - S_0}{W_0} \quad (2)$$

where  $M_0$  (g) is the moisture content in fresh fruit;  $M_t$  (g) is the moisture content at time  $t$  of osmotic treatment;  $S_0$  (g) is the dry matter of fresh fruit;  $S_t$  (g) is the dry matter after time  $t$  of osmotic treatment;  $W_0$  (g) is the mass of fresh fruit before the osmotic treatment. Curves of *WL* and *SG* as a function of time were constructed using experimental data.

Peleg's two-parameter equation [15,21,23,24,34] was used for describe sorption kinetics curves that approaches equilibrium asymptotically:

$$M_t = M_0 \pm \frac{t}{k_1 + k_2 t} \quad (3)$$

where  $M_t$  is moisture or solid content (g) at time  $t$  (h),  $M_0$  is initial moisture or solid content (g),  $k_1$  is the Peleg's rate constant and  $k_2$  is the Peleg's capacity constant. In Eq. (3), "±" becomes "−" for water loss and "+" for solid gain [23].

The first derivative of Eq. (3) gives the rate of sorption ( $R$ ):

$$R = \frac{dM}{dt} = \pm \frac{k_1}{(k_1 + k_2 t)^2} \quad (4)$$

The Peleg's rate constant  $k_1$  relates to dehydration rate at the beginning,  $t = t_0$ , and is inversely proportional to initial rate of dehydration [24]:

$$\frac{dM}{dt} = \pm \frac{1}{k_1} \quad (5)$$

The Peleg's capacity constant  $k_2$  relates to minimum attainable moisture content, so at time  $t \rightarrow \infty$  Eq. (4) gives the relation between equilibrium moisture content ( $M_{eq}$ ) and  $k_2$  [23,31]:

$$M_{eq} = M_0 \pm \frac{1}{k_2} \quad (6)$$

Rearrangement and linearization of Eq. (4) give the possibility for graphical determination of the Peleg's kinetics parameters [24]:

$$\frac{t}{M - M_0} = k_1 \pm k_2 t \quad (7)$$

The plot of Eq. (7) is a straight line, where  $k_1$  is the intercept and  $k_2$  is the slope [23].

The quantification of the drying can be made by the quantification of the energy received by the material that is being dried. This energy is equal to the energy necessary for the vaporization of the water removed during the drying. In the decreasing drying rate period, namely the unsteady state, the behavior of the material during the drying is due to the domination of internal resistance. The distinctions of these drying periods are obtained by drying rates calculations from drying curves. In order to find the effect of temperature on water desorption of pears, an Arrhenius type equation was used for modeling the dependence of Peleg's rate constant ( $k_1$ ) on temperature [28].

The linearized Arrhenius equation represents the temperature dependency of the Peleg's rate constant:

$$\ln k_1 = \ln k_0 - \frac{E_a}{RT} \quad (8)$$

where  $k_1$  is the Peleg's rate constant for *WL* or *SG* ( $\text{h}^{-1}$ );  $k_0$  is a constant ( $\text{h}(\text{g/g dm})^{-1}$ );  $E_a$  is the activation energy ( $\text{kJ/mol}$ ),  $R$  is the universal gas constant ( $8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ ) and  $T$  is absolute temperature in K.

The criterion used to evaluate the best fitting model was their average relative error,  $E$ :

$$E = \frac{1}{n_e} \sum_{i=1}^{n_e} \left| \frac{X_{\text{exp}} - X_p}{X_{\text{exp}}} \right| \quad (9)$$

where  $n_e$  is the number of experimental data,  $X_{\text{exp}}$  is the experimental value for  $WL$  or  $SG$ , and  $X_p$  is the calculated value for  $WL$  or  $SG$ .

**Statistical analysis**

Descriptive statistical analyses for Peleg’s equation parameters were expressed as the mean  $\pm$  standard deviation ( $SD$ ). Post-hoc Tukey’s HSD tests at 95% confidence limit have been calculated to show significant differences between observed samples. These calculations and the residual analysis were performed using StatSoft Statistica 10 software (Statsoft Inc., Tulsa, OK, USA).

**RESULTS AND DISCUSSION**

The experiments of osmotic dehydration of pears were carried out at three different concentrations and three different temperatures. Figures 1 and 2 show the experimental data for  $WL$  and  $SG$  as a function of time of osmotic treatment of pear at different concentrations of sucrose solution, at 35 °C (data obtained of experiments conducted at 20 and 50 °C not shown). Three-dimensional graphics have been plotted for regression model (surface plot) comparison, with experimental data visualization (white colored points). As can be seen,  $WL$  and  $SG$  increased non-linearly with immersion time at all concentrations

and temperatures. From the observed data presented in Figures 1 and 2, the trend of the faster mass transfer rate in the initial period of osmotic treatment is clear, and is followed by slower removal of water and uptake of sugar from fruit tissue in later stages. This reduction of the mass transfer rate might be result of the formation of the solid layers at the surface of the fruit tissue, which hinders transfer of water and solids [35]. The  $WL$  and  $SG$  increase with increasing sucrose concentration at constant temperature, as well as with increasing temperature of the osmotic solution. An initial increase of  $WL$  and  $SG$  probably occurred because of the osmotic driving force difference between the dilute juice of the pear cubes and the surrounding hypertonic sucrose solution. The increase of  $WL$  and  $SG$  with the higher solution concentration is due the high concentration difference between the pear and osmotic solution that increased the rate of diffusion of solute and water exchange with osmotic solution [28,35,36]. Higher temperatures of osmotic solution additionally cause increase in kinetics of mass transfer. Higher temperatures seem to promote faster water loss through swelling and plasticizing of cell membranes as well as the better water transfer characteristics on the product surface due to lower viscosity of the osmotic medium [29,37,38]. This enhanced removal of water and uptake of solids showed that immersion time and concentration of sucrose solution were significant factors affecting  $WL$  during osmotic dehydration of followed by temperature [30].

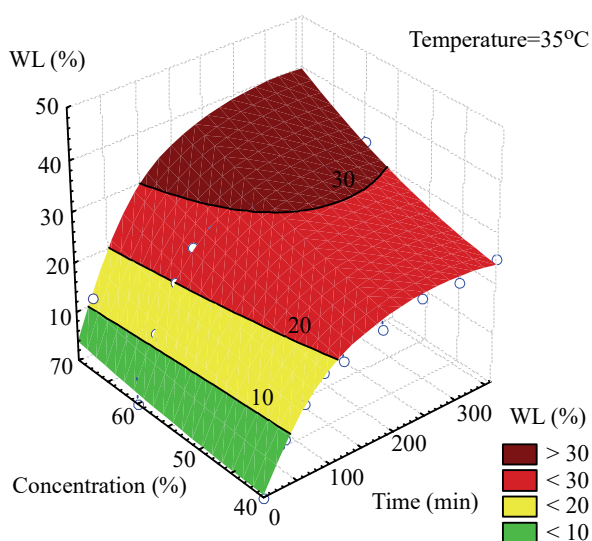


Figure 1. Experimental and calculated values of  $WL$  during osmotic dehydration of pears cubes at 35 °C and sucrose solutions with concentrations: 40, 60 and 70 mass%.

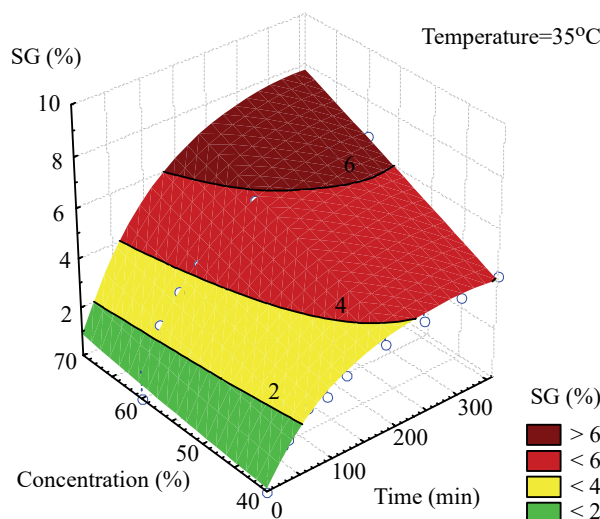


Figure 2. Experimental and calculated values of  $SG$  during osmotic dehydration of pears cubes at 35 °C and sucrose solutions with concentrations: 40, 60 and 70 mass%.

After 360 min of osmotic treatment of pears,  $WL$  ranges from 23.71 to 31.68% at 20 °C, from 24.80 to

40.38% at 35 °C and from 33.30 to 52.07% at 50 °C, of initial weight of pears (Figure 1). The increase of the dry mass of the samples, SG, after 360 min of osmotic treatment ranges from 3.02 to 6.68% at 20 °C, from 4.15 to 7.71% at 35 °C and from 5.00 to 8.92% at 50 °C (Figure 2).

The *WL/SG* ratio is influenced by temperature and concentration of the sucrose solutions, as well as with the duration of the osmotic treatment. Higher values of *WL/SG* ratio implies the intensive water removal from the samples followed by minimal SG. After initial increase of the *WL/SG* ratio during OD treatment of pear at first 30 min of process, *WL/SG* ratio decreased, depending of experimental conditions. The minimal ratio of 4.47 was obtained at 35 °C, 60% sucrose solutions and after 120 min of OD treatment duration. The maximal value of 7.85 was obtained at 50 °C, 40% sucrose solution and after 30 min of OD treatment.

Peleg's equation and equilibrium values for *WL* and *SG* at different experimental temperatures were used to calculate Peleg's rate constant,  $k_1$  and capacity constant  $k_2$  for both processes. Peleg's equation parameters for *WL* and *SG* are shown in Table 1. Peleg's rate constants  $k_1^{WL}$  and  $k_1^{SG}$  decreased from 1.12 to 0.51 h (g/g dm)<sup>-1</sup> and from 5.48 to 2.17 h (g/g dm)<sup>-1</sup> at 20 °C with increasing concentration of osmotic solution from 40 to 70 mass%, respectively. Rate constant  $k_1^{WL}$  decreased from 0.58 to 0.41 h (g/g dm)<sup>-1</sup> and from 0.33 to 0.28 h (g/g dm)<sup>-1</sup> at 35 and 50 °C, respectively. In addition, rate constant  $k_1^{SG}$  decreased from 4.33 to 1.58 h (g/g dm)<sup>-1</sup> and from 0.33 to 0.28 (g/g dm)<sup>-1</sup> at 35 and 50 °C, respectively. The concentration of osmotic solutions, at each experimental temperature, increased from 40 to 70 mass%. Since the reciprocal value of  $k_1$

describes the initial mass transfer rate through the osmotic treatment, observed results indicate an increase of the initial mass transfer rate with increasing the concentration and temperature of osmotic solution [35]. The capacity constant,  $k_2$  is associated with equilibrium moisture content and equilibrium solid content, *e.g.*, the lower the  $k_2$ , the higher the equilibrium moisture content [10,31,35]. Both capacity constants  $k_2^{WL}$  and  $k_2^{SG}$ , also exhibit the same trend, *i.e.*, the inverse relationship between capacity constant and temperature, as well as concentration of the osmotic solution. The statistical parameter ( $R^2$ ) ranged from 0.936 to 0.997 for *WL* and *SG*, respectively.

The equilibrium point is reached when water activities of osmotic solutions and dehydrated fruit product become equal. The experimental equilibrium point were reached after 360 min of the osmotic treatment in some of the samples (Table 2), while in the others experimentally obtained values were very close to the ones calculated by Peleg's model. According to this, it would be reasonable to claim that 360 min is a long enough period to reach equilibrium. Since both *WL* and *SG* influence decrease in water activity, their relationship is important for the attainment of the equilibrium [10,31,35]. The predicted and experimental equilibrium values for moisture content and SG at different experimental temperatures and concentrations of osmotic solutions are shown in Table 2. As can be seen, slight differences between the equilibrium experimental data and predicted values by the Peleg's model were observed (Table 2). Table 2 also shows the residual analysis, which is performed to check the assumptions of independence, normality, homoscedasticity and zero mean of errors. The mean of residuals are close to zero, and the standard deviation of  $M_{eq}$  and  $S_{eq}$  were 0.11 and

Table 1. Peleg's equation parameters and goodness of fit for SG and WL during osmotic treatment of pear; <sup>a-d</sup> values with the same letter within a column are not statistically different at the  $p < 0.05$  level (according to post-hoc Tukey's HSD test)

<i>t</i> / °C	Conc., %	Water loss			Solid gain		
		$k_1^{WL}$ / h (g/g dm) <sup>-1</sup>	$k_2^{WL}$ / h (g/g dm) <sup>-1</sup>	$R^2$	$k_1^{SG}$ / h (g/g dm) <sup>-1</sup>	$k_2^{SG}$ / h (g/g dm) <sup>-1</sup>	$R^2$
20	40	1.12±0.23 <sup>a</sup>	0.52±0.07 <sup>cd</sup>	0.962	5.48±2.87 <sup>a</sup>	5.50±0.84 <sup>a</sup>	0.936
	60	0.64±0.10 <sup>b</sup>	0.51±0.03 <sup>c</sup>	0.991	2.89±0.47 <sup>cd</sup>	3.42±0.25 <sup>c</sup>	0.984
	70	0.51±0.12 <sup>c</sup>	0.48±0.03 <sup>d</sup>	0.984	3.20±0.51 <sup>c</sup>	2.17±0.15 <sup>f</sup>	0.986
							0.936
35	40	0.58±0.13 <sup>bc</sup>	0.62±0.04 <sup>a</sup>	0.989	4.33±0.58 <sup>b</sup>	3.54±0.17 <sup>b</sup>	0.993
	60	0.45±0.09 <sup>cd</sup>	0.45±0.03 <sup>d</sup>	0.990	2.46±0.86 <sup>cd</sup>	1.67±0.14 <sup>h</sup>	0.980
	70	0.41±0.05 <sup>cd</sup>	0.34±0.02 <sup>a</sup>	0.993	1.58±0.35 <sup>cd</sup>	2.75±0.11 <sup>d</sup>	0.995
		0.58±0.13					
50	40	0.33±0.08 <sup>d</sup>	0.54±0.02 <sup>c</sup>	0.994	1.70±0.47 <sup>cd</sup>	3.65±0.14 <sup>b</sup>	0.996
	60	0.15±0.05 <sup>e</sup>	0.49±0.02 <sup>d</sup>	0.997	1.12±0.36 <sup>d</sup>	2.52±0.10 <sup>e</sup>	0.995
	70	0.28±0.07 <sup>d</sup>	0.32±0.02 <sup>e</sup>	0.987	0.97±0.37 <sup>d</sup>	1.85±0.10 <sup>g</sup>	0.991
				0.994			

Table 2. Experimental and Peleg predicted values for equilibrium values for WL and SG during osmotic dehydration treatment

$t / ^\circ\text{C}$	Conc., %	Water loss			Solid gain			
		$M_{\text{eq}}^{\text{experimental}} / \text{g}/(\text{g dm})$	$M_{\text{eq}}^{\text{Peleg}} / \text{g}/(\text{g dm})$	Residual	$S_{\text{eq}}^{\text{experimental}} / \text{g}/(\text{g dm})$	$S_{\text{eq}}^{\text{Peleg}} / \text{g}/(\text{g dm})$	Residual	
20	40	3.845	3.877	0.032	1.068	1.087	0.019	
	60	2.987	3.039	0.052	1.195	1.205	0.01	
	70	3.627	3.516	-0.111	1.331	1.366	0.035	
35	40	3.539	3.507	-0.032	0.968	1.019	0.051	
	60	4.637	4.733	0.096	1.404	1.443	0.039	
	70	2.077	1.984	-0.093	1.253	1.238	-0.015	
50	40	2.732	2.649	-0.083	1.115	1.073	-0.042	
	60	2.403	2.648	0.245	1.276	1.191	-0.085	
	70	1.096	1.036	-0.06	1.236	1.279	0.043	
Residual analysis								
	Mean	Min.	Max.	Variance	Std. dev.	Std. err.	Skewness	Kurtosis
$M_{\text{eq}}$	0.01	-0.11	0.25	0.01	0.11	0.04	1.19	1.22
$S_{\text{eq}}$	0.01	-0.09	0.05	0.00	0.05	0.02	-1.15	0.59

0.05, respectively. These results showed a good approximation to a normal distribution around zero with a probability of 95% ( $2 \times SD$ ), which means a good generalization ability of developed models for the range of observed experimental values (the skewness parameter showed minimal deviations from normal distribution, while the Kurtosis parameter showed almost neglecting difference in "peakedness" compared to normal distribution).

The comparison between experimental and Peleg-predicted values for moisture content and SG during osmotic dehydration treatment of pears at 20, 35 and 50 °C in 40% sucrose solution are shown in Figures 3 and 4. It is observed that the differences between the data and the predicted ones were small. The parameters, statistical  $R^2$ , as well as the relative error,  $E$  (%), were used for characterizing the fitting to the Peleg's model. As statistical parameter,  $R^2$ , ranges from 0.936 to 0.997 for moisture content and SG, and  $E$  (%) value is below 10%, the Peleg model can be account as acceptable for the description of the WL and SG kinetic in the osmotic dehydration of pears cubes.

The influence of temperature on WL and SG kinetics were checked out by applying the Arrhenius type equation for modeling the Peleg's rate constant dependence on temperature. According to Eq. (8), the plot of the  $\ln k_1$  (natural logarithm of Peleg's rate constant) versus reciprocal of temperature,  $1/T$ , resulted in a straight line with the slope equal  $E_a/R$  and intercept equal  $\ln k_0$ . The graphically obtained parameters of Arrhenius equation for the Peleg's rate constant of SG and WL at different sucrose concentrations are presented in Table 3 (figures not shown).

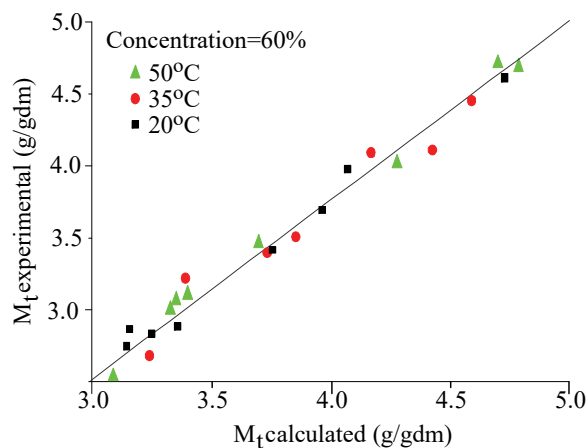


Figure 3. Comparison between experimental and calculated values of moisture content of pears cubes during osmotic dehydration treatment in sucrose solution with concentrations 60% and at 20, 35 and 50 °C.

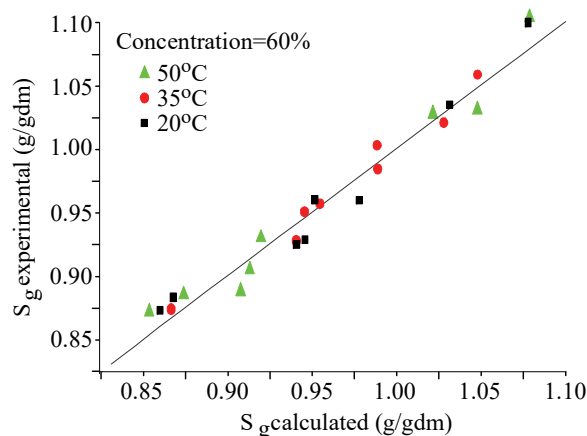


Figure 4. Comparison between experimental and calculated values of solid gain of pears cubes during osmotic dehydration treatment in sucrose solution with concentrations 60% and at 20, 35 and 50 °C.

Table 3. Parameters of Arrhenius equation for the Peleg rate constant of SG and WL at different sucrose concentrations

Parameter	Concentration, %		
	70	60	40
Water loss			
$\ln k_0$	1.12±0.13	-7.61±0.84	-4.87±0.20
$E_a / \text{kJ mol}^{-1}$	15.65±2.91	37.73±1.37	32.09±0.52
$R^2$	0.98	0.95	0.99
Solid gain			
$\ln k_0$	-3.55±0.94	-0.74±0.08	-2.46±0.48
$E_a / \text{kJ mol}^{-1}$	31.40±2.41	24.59±1.17	30.40±1.44
$R^2$	0.99	0.92	0.94

Energy required to initiate water removal and solid uptake, when pear cubes were immersed in 40, 60 and 70% osmotic solutions at 20, 35 and 50 °C were determined using Eq. (8). Activation energy for WL and SG varied from 15.65 to 32.09 kJ/mol and 31.40 to 30.40 kJ/mol, respectively. The lowest activation energy value was found for samples immersed into a 70% sucrose solution. This confirms the report that osmotic dehydration has low energy requirement [34], especially when carried out at higher concentration. The linearity of the data ( $R^2 > 0.92$ ) reveals that the  $k_1$  for all the kinetics terms followed an Arrhenius relationship as a function of temperature for each applied sucrose concentration. Higher values of  $E_a$  revealed the greater temperature sensitivity of rate constant  $k_1$  [35]. Depending on sucrose concentration, it was found that the rate constant for WL is more temperature sensitive than the rate constant for SG (Table 3.) for 40 and 60 mass% sucrose concentration. At higher sucrose concentration (70 mass%) the rate constant for SG is more temperature sensitive compared with the rate constant for WL.

## CONCLUSION

The influence of concentration and temperature on mass transfer kinetics was investigated through WL and SG during osmotic dehydration treatment of pear cubes. The SG and WL increased with increasing sucrose solution concentration and temperature during osmotic treatment of pear. Peleg model was successfully applied to the experimental data and for description of the osmotic dehydration process. From the experimental data, equilibrium values for moisture and solid content were estimated using Peleg's equation. The model predicted equilibrium values fitted very good to experimental ones, which is confirmed with high coefficients of determination and by the residual analysis. The Arrhenius equation was successfully applied to evaluate the temperature

dependency of the Peleg's rate constant and activation energy determination.

## Nomenclature

IM - Intermediate moisture  
 OD - Osmotic dehydration  
 WL - Water loss  
 SG - Solid gain  
 $E_a$  - Activation energy (kJ/mol)  
 $M$  - Moisture content (g)  
 $k_1$  - Peleg's rate constant (h (g/g dm)<sup>-1</sup>)  
 $k_2$  - Peleg's capacity constant (h (g/g dm)<sup>-1</sup>)  
 dm - dry matter  
 $R$  - universal gas constant (8.314 J/g mol K)  
 $R^2$  - coefficient of determination  
 $T$  - temperature (K)  
 $t$  - time (s)  
 $E$  - average relative error (%)  
 $n_e$  - number of experimental data

## Subscripts

eq - equilibrium  
 0 - initial

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НАУЧНИ РАД

## ПРИМЕНА ПЕЛЕГОВОГ МОДЕЛА НА КИНЕТИКУ ТРАНСФЕРА МАСЕ ТОКОМ ОСМОТСКЕ ДЕХИРАТАЦИЈЕ КРУШКЕ У РАСТВОРУ САХАРОЗЕ

*У раду је испитивана применљивост Пелеговог модела за предикцију кинетике трансфера масе током процеса осмотске дехидратације крушака, на различитим концентрацијама (40, 60 и 70 мас.%) и температурама (20, 35 и 50 °C) раствора сахарозе. Повећање концентрације раствора сахарозе доводи до већег губитка воде (ГВ) и повећања суве материје (СМ) током процеса осмотске дехидратације. После 360 min осмотског третмана крушака, ГВ се креће од 23,71 до 31,68% на 20 °C, од 24,80 до 40,38% на 35 °C и од 33,30 до 52,07% на 50 °C од почетне масе крушака. Повећање суве материје у узорцима, СМ, после 360 min осмотског третмана креће се од 3,02 до 6,68% на 20 °C, од 4,15 до 7,71% на 35 °C и од 5,00 до 8,92% на 50 °C. Пелегове константе брзине,  $k_1^{ГВ}$  и  $k_1^{СМ}$ , опадају са повећањем температуре, а такође опадају са повећањем концентрације осмотског раствора на константној температури. Обе капацитивне константе,  $k_2^{ГВ}$  и  $k_2^{СМ}$ , такође показују инверзно понашање у односу на температуру и концентрацију осмотског раствора. Пелегове константе брзине процеса ГВ и СМ на свим температурама прате функционалну зависност Аренијусовог типа. Моделом предвиђене равнотежне вредности су блиске експерименталним, што је потврђено високим коефицијентима одређивања и резидуалном анализом.*

*Кључне речи: осмотска дехидратација, крушке, кинетика, ефекат температуре, Пелегов модел.*