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OSMOTIC DEHYDRATION OF CARROT CUBES IN THE SOLUTION OF SUGAR BEET MOLASSES - KINETICS MODEL
OSMOTSKA DEHIDRATACIJA KOCKICA MRKVE U RASTVORU MELASE ŠEĆERNE REPE - KINETIČKI MODEL

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ABSTRACT

The effect of different process parameters on the osmotic dehydration (OD) of carrot cubes, such as the concentration of sugar beet molasses solution (40–80%, w/w), temperature (45–65 °C), and treatment time (1-5 hours) were investigated in terms of water loss (WL) and solid gain (SG). Effective diffusion of water, and solids were estimated, using experimental data. Non-linear analysis of the calculated diffusion coefficients of water and solute reveal that these values depend on temperature and concentration of the osmotic solution as well as to the combined effect of these parameters. The moisture and solid content at any time during OD of carrots could be predicted with sufficient accuracy (r^2 =0.98-0.99) by using diffusivities coefficients calculated from the proposed equations. The optimum conditions generated, using response surface method were: treatment time 4h, temperature 65°C, sugar beet molasses concentration 68% (w/w), with responses: WL=0.7 g/g initial fresh sample., SG= 0.08 g/g initial fresh sample.

Key Words: *Osmotic dehydration, carrot cubes, sugar beet molasses, effective diffusivity, response surface method.*

REZIME

U ovom radu su ispitivani uticaji različitih procesnih parametara tokom osmotske dehidratacije mrkve u melasi šećerne repe na gubitak vode (WL) i priraštaja suve materije (SG). Ispitivani procesni parametri su bili: koncentracija rastvora (40–80%, w/w), temperatura (45–65 °C), i vreme imerzije (1-5 h). U radu su određivane vrednosti efektivnog koeficijenta difuzije za vodu i za čvrstu materiju, korišćenjem eksperimentalnih podataka. Nelinearnom analizom izračunatih efektivnih koeficijenata difuzije pokazalo se da oni zavise i od koncentracije rastvora i od temperature, kao i od nelinearnih kombinacija ovih uticaja. Vlažnost uzorka mrkve koji se suši, kao i količina čvrste materije, mogu se predvideti u svakom trenutku sušenja, sa dovoljnom tačnošću (r^2 =0,98-0,99), korišćenjem efektivnih koeficijenata difuzije, na osnovu predložene jednačine. Optimalne dobijene vrednosti, korišćenjem metode odzivnih površina bile su: vreme imerzije od 4h, temperatura 65°C, koncentracija melase od 68% (w/w), uz odzive WL=0.7 g/g svežeg uzorka, SG= 0.08 g/g svežeg uzorka.

Key Words: *Osmotska dehidratacija, mrkva, melasa šećerne repe, efektivni koeficijent difuzije, metoda odzivnih površina.*

INTRODUCTION

Osmotic dehydration (OD) is an alternative method of drying, to reduce postharvest losses of fruits, and also a common process for producing dried fruits which can be directly consumed or used as an ingredient in cakes, pastries and many others (*Mercali, et al., 2011*). OD is a complementary treatment in the processing of dehydrated foods, since it involves some advantages such as minimizing heat damage, and also the color and flavor losses, inhibiting enzymatic browning and reducing energy costs (*Alkali, et al., 2006; Torres, et al., 2006; Torres, et al., 2007*). The quality of OD products is better and shrinkage is considerably reduced as compared to products from conventional drying processes (*Bekele and Ramaswamy, 2010*). OD aims to dehydrate food products by immersing them in hypertonic solution, where water is removed due to the difference of osmotic pressure between the food and the osmotic solution, reducing the water activity of the food and consequently the water availability for chemical and biological deterioration. During the process two simultaneous flows through the cell walls are created in counter current: one is the water leaving from fruit into the solution, and other is the osmotic solute (usually salt or sugar) from the solution into the fruit (*Bernardi, et al., 2009*).

Solution concentration, temperature, immersion time, sample size, geometry, and ratio of sample to solution are the main parameters that have influence on the mass transfer during the process (*Ganjloo, et al., 2011*).

For fruits and vegetables dehydration, the most commonly used osmotic agents are sucrose and sodium chloride and their combination. Recent research has shown that use of sugar beet molasses as hypertonic solution improves OD processes due to high dry matter content and specific nutrient content. An important advantage of sugar beet molasses used as hypertonic solution, from nutrient point of view, is enrichment of the food material in minerals and vitamins, which penetrate from molasses to the plant tissue (*Koprivica, et al., 2009*).

An adequate control of dehydrated material's composition and the correct operational design are attainable through the knowledge on the kinetics of mass transfer during the process. For the mass transfer modeling during the osmosis process, different approaches based on Fick's second low have been reported. From practical point of view, in food industry, approaches based on Fick's second law are not very useful because of their complexity and unrealistic assumption (i.e., significant mass transfer resistance in high-viscosity hypertonic solution) (*Ganjloo, et al., 2011*). Thus, several simpler semi-empirical approaches concerning parameters with physical meaning are advised to model the kinetics of mass transfers during osmotic dehydration (*Hawkes and Flink, 1978; Peleg, 1988*). Response surface methodology (RSM) is an effective tool for optimizing a variety of food processes including osmotic dehydration (*Azoubel et al., 2003; Ozdemir et al., 2008; Singh et al., 2010; Eren, et. al., 2006*). The main advantage of RSM is reduced number of experimental runs that provide sufficient information for statistically valid results. The RSM equations describe effects of the test variables on the observed responses, determine test variables interrelationships and represent the combined effect of all test variables in the observed responses, enabling the experimenter to make efficient exploration of the process.

The investigation of temperature and concentration effects on the mass transfer phenomena during OD of carrot cubes in sugar beet molasses solution were the objectives of here presented article. The water loss (WL) and sugar gain (SG) were evaluated as a function of the process variables, and the effective diffusion of both water and solute, during OD, for the whole range of experimental conditions were determined. Four non-linear regression models were compared, using statistical test indicators such as χ^2, MBE and RMSE. The optimum OD conditions were evaluated using RSM.

MATERIAL AND METHOD

Carrots, used in experiment, were stored at 4º*C* until use. Initial moisture content, $X_{0,}$ was 89.65 ± 0.48 % w/w. Initial dry matter content in sugar beet molasses was 83.68% w/w. For dilution of sugar beet molasses distilled water was used. Carrots were visually sorted on the basis of maturity, size and the weight. Carrots with the weight of 80±5g were selected. The carrots were washed thoroughly and peeled manually (using a stainless kitchen peeler). The peeled carrots were manually sliced into cubes, dimension 1x1x1 cm using a kitchen slicer. The amount of 100g of sliced carrot cubes were prepared for each treatment. Different concentrations of sugar beet molasses (40.0%, 60.0% and 80.0%w/w) were used as osmotic solution. The effect of temperature was also investigated and the experiments were conducted at temperatures of 45, 55 and 65ºC. The carrot cubes were put in a glass jar with 1000 g of molasses solution with a material/solution ratio of 1:10 (w/w). The jars were placed in the heat chamber and process was performed without agitation. After each sampling time (0, 60, 180, 300 minutes), which is determined according to the experimental design, the carrot cubes were taken out, washed with water and gently blotted with filter paper in order to remove the excessive water and weighed. Dry matter content of the fresh and treated samples was determined by drying the material at 105 ºC for 24h in a heat chamber (Instrumentaria Sutjeska, Croatia). Water activity (a_w) of the osmotic dehydrated samples was measured using a_w measurement device (TESTO 650, Germany) with an accuracy of ±0.001 at 25ºC. Soluble solids content of the molasses solutions was measured using Abbe refractometer, Carl Zeis Jenna at 20 ºC. Evaluation of mass exchange between the solution and sample during OD were made by using the parameters such as WL and SG, calculated according to the following equations:

$$WL=\frac{m_i\cdot z_i-m_f\cdot z_f}{m_i}\quad\left[\frac{g}{g\text{ fresh sample}}\right],$$

$$SG=\frac{m_f\cdot s_f-m_i\cdot s_i}{m_i}\quad\left[\frac{g}{g\text{ fresh sample}}\right]\qquad(1)$$

where m_i and m_f are the initial and final weight (*g*) of the samples, respectively; z_i and z_f are the initial and final mass fraction of water (g water/ g sample), respectively; s_i and s_f are the initial and final mass fraction of total solids (g total solids/ g sample), respectively.

Azuara et al. (*1992*) calculated WL and SG during OD using equations with two parameters obtained from mass balances. Peleg equation was also used in some research instead of equilibrium approach equation *(Azoubel and Murr, 2004; El-Aouar et al., 2003; Park et al., 2002; Palou et al., 1993; Khoyi and Hesari, 2007).* In this paper, Peleg's equation is expressed in term of WL or SG change. In the next equations, Y represents WL or SG.

$$Y=\frac{t}{k_1^Y+k_2^Y\cdot t}\qquad(2)$$

where k_1^Y and k_2^Y are Peleg constants for WL or SG**.**

When evaluating the effective diffusivities of water and solids (De_w and De_s), the carrot cube is considered as a perfect cube with initially uniform water and solid contents. In that case, the solution for Fick's equation for constant process conditions, for long OD time is (*Crank, 1975):*

$$\ln(M_r)=\ln\left(\frac{8}{\pi^2}\right)-\left(\frac{\pi^2 D_{ew}t}{L^2}\right),$$

$$\ln(S_r)=\ln\left(\frac{8}{\pi^2}\right)-\left(\frac{\pi^2 D_{es}t}{L^2}\right)\qquad(3)$$

where M_r and S_r are the moisture and solute ratio; the subscripts 0, e and t represent the relevant concentrations initially, at equilibrium, and at any time; De_w and De_s are effective diffusivities of water and solute, respectively; i is the number of series in the time; L is the sample length, m, t is the time, s.

Data analysis

The experimental moisture ratio data of carrot cubes, obtained during OD process, were fitted to the 17 commonly used models (Table 4). Non-linear least square regression analysis was performed using Levenberg-Marquardt procedure in *Statistica 10* computer program. The coefficient of determination (r^2) was the primary criteria for selecting the best equation to define a suitable model. In addition to r^2, various statistical parameters such as reduced chi-square (χ^2), mean bias error (MBE) and root mean square error (RMSE) were used to determine the quality of the best fitting functions.

These parameters can be calculated as follows:

$$\chi^2=\frac{\sum_{i=1}^{N}(x_{exp,i}-x_{pre,i})^2}{N-n},$$

$$RMSE=\left[\frac{1}{N}\sum_{i=1}^{N}(x_{pre,i}-x_{exp,i})^2\right]^{1/2},$$

$$MBE=\frac{1}{N}\sum_{i=1}^{N}(x_{pre,i}-x_{exp,i})\qquad(4)$$

where $x_{exp,i}$ are experimental values and $x_{pre,i}$ are the predicted values, calculated from the model. *N* and *n* are the number of observations and constants, respectively. For quality fit, r^2 value should be higher, and χ^2, MBE, and RMSE values should be lower (*Yaldiz and Ertekin, 2001a; Yaldiz et al., 2001b; Ertekin and Yaldiz, 2004; Menges and Ertekin, 2006a, 2006b*).

Analysis of variance (ANOVA) and RSM were performed using StatSoft Statistica, for Windows, ver. 10 program. The model was obtained for each dependent variable (or response) where factors were rejected when their significance level was less than p<0.05. The same program was used for generation of graphs and contour plots. The graphs of the responses with significant parameters were superimposed to determine optimum drying conditions, plotted on optimization graphic. After the optimum conditions were established, separate experiments were performed for model validations of the models.

RSM is an effective tool for optimizing a variety of food processes including OD. The main advantage of RSM is reduced number of experimental runs that provide sufficient information for statistically valid results. The RSM equations describe effects of the test variables on the observed responses, determine test variables interrelationships and represent the combined effect of all test variables in the observed responses, enabling the efficient exploration of the process *(Azoubel et al., 2003; Ozdemir et al., 2008; Singh et al., 2010).*

The RSM method was selected to estimate the main effect of the process variables on mass transfer variables and a_w, during the OD of carrot cubes. The accepted experimental design was taken from *Box et al. (1960).* The independent variables were temperature (X_1) of 45, 55 and 65 °C; osmotic time (X_2) of 1, 3 and 5h; molasses concentration (X_3) of 40, 60 and 80% (by weight), and the dependent variables observed were the response: DM (Y_1), WL (Y_2), SG (Y_3), and a_w (Y_4). The experimental data used for the optimization study were obtained using a central composite full factorial design (3 level-3 parameter) with 27 runs (1 block).

After calculation of effective diffusivities values for certain temperature and sugar beet molasses concentration, another 3^2 full factorial experimental design (3 level-2 parameter) with 9 runs (1 block) was accepted The following second order polynomial (SOP) model was fitted to the data. Two models of the following form were developed to relate four responses (Y) such as WL and SG to four process variables (X):

$$Y_k = \beta_0 + \sum_{i=1}^{2}\beta_i X_i + \sum_{i=1}^{2}\beta_{ii} X_i^2 + \sum_{i=1}^{2}\sum_{j=i+1}^{2}\beta_{ij} X_i X_j . \qquad (5)$$

where: β_0, β_i, β_{ii}, β_{ij} are constant regression coefficients; Y_k, response variables X_i, X_j process parameters. The significant terms in the model were found using analysis of variance (ANOVA) for each response variable.

RESULTS AND DISCUSSION

The osmotic process was studied in terms of WL, SG, a_w and DM . The obtained experimental data are presented on Figure 1. An initial high rate of water removal and solid uptake followed by slower removal and uptake in the latter stages were observed. Several research groups have published similar curves for OD of foods (*Azoubel and Murr, 2004; Lazarides et al., 2001; Park et al., 2002).* Increase in solution concentration resulted an increase in the osmotic pressure gradient and, hence, higher WL and SG values throughout the osmosis period were obtained. For instance, final WL after 5h of OD, treated at 65 °C, in 80% sugar beet molasses solution was 0.85w/w, while WL reached only 0.62w/w in 40% solution. These results indicate that, by choosing a higher concentration medium, some benefits in terms of greater WL could be achieved. Also, a much greater gain of solid is observed. The increase in SG is accompanied with the increase in DM and the decrease in a_w. SG obtained at concentration of molasses of 80% was 0.19 w/w, and at concentration of 40%, SG was 0.07w/w, after 5 hours of OD at 65 °C.

High regression coefficients obtained for Peleg constants (r^2>0.985) indicates good fit to the experimental data. The Peleg rate constant varied from 0.144 to 0.785 (g/g initial fresh sample) and from 2.006 to 4.436 (g/g initial fresh sample) for WL and SG, respectively. The Peleg capacity constant varied from 1.142 to 1.553 (h g/g initial fresh sample) and from 8.254 to 11.930 (h g/g initial fresh sample) for WL and SG, respectively. Also, the equilibrium WL_∞ and SG_∞ were obtained from experimental results, estimated using Peleg model, Eqn. (2). These data are presented in the Table 1, according to OD process conditions. Both WL_∞ and SG_∞ increase with the enlargement in temperature and/or concentration, as seen from experimental data represented on Figure 1.

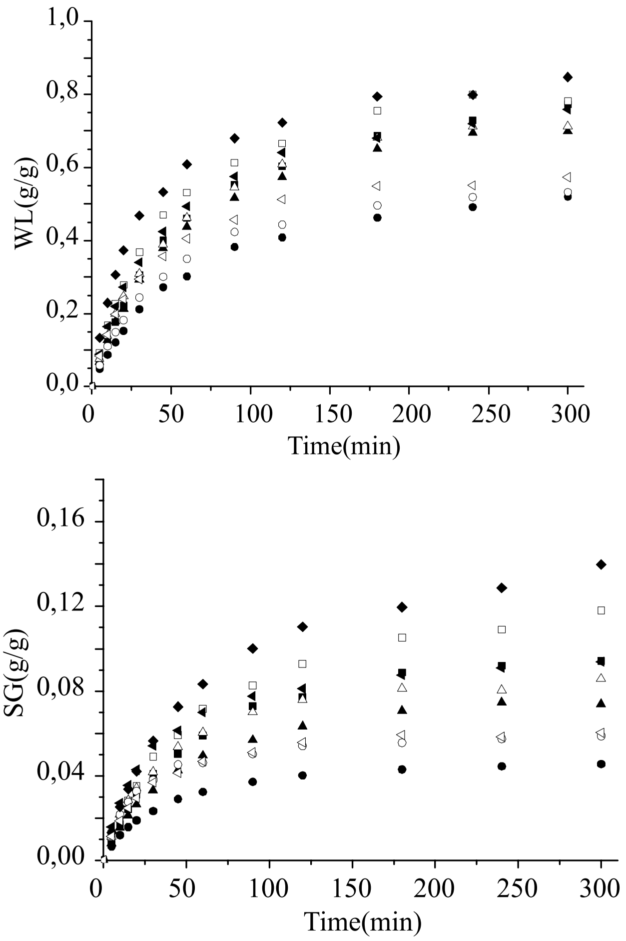

Fig. 1. Changes in WL and SG values during OD of carrot in sugar beet molasses solutions (■ – 80%, 45°C, ▲ - 60%, 45°C, ♦ - 40%, 45°C, □ - 80%, 55°C, Δ - 60%, 55°C, ◊ - 40%, 55°C, • - 80%, 65°C, ◄ - 60%, 65°C, ► - 40%, 65°C)

Experimental data of WL and SG were used to evaluate the adequacy of the Peleg's equation. Coefficient of determination values, r^2, varied from 0.976 – 0.997 for both WL and SG. Such high values of r^2 indicate a good fit to the experimental data and suggest that Peleg's equation adequately describes mass transfer kinetics terms during OD of carrot in sugar beet molasses.

The effective diffusivity D_e was calculated at each corresponding moisture/solid content and time in this article. The average effective diffusivity $D_{e,avg}$ was calculated from positive D_e obtained using the data for all effective moisture and solute diffusivity as:

$$D_{e,avg} = \frac{1}{t_f} \cdot \int_0^{t_f} D_e(t) \cdot dt \qquad (6)$$

where t_f is the final process time. $D_{e,avg}$ for moisture and solute content, can be also calculated as average of D_e obtained using process data, when time intervals are equal *(Singh & Gupta, 2007).*

The effective diffusivities of WL and SG were calculated by Eqn. (3) using experimental values and WL_∞ and SG_∞ from Table 1. The average effective diffusivity values, evaluated using Eqn. (6), are presented in Table 2, according to OD process conditions. These coefficients were determined, and then the effects of process parameters (concentration and temperature) on these coefficients were modeled by using non-linear regression analyses (StatSoft Statistica 10).

Table 1. Pelegs rate (k_1) and capacity (k_2) constants and goodness of fit of Peleg model at different conditions of molasses concentration and temperature, also WL and SG at equilibrium, for different temperature and concentration, (all k_1^{WL}, k_1^{SG}, k_2^{WL}, k_2^{SG} , WL_∞, , SG_∞, and r^2 values are significant at 0.05 level

Temp. (ºC)	Conc.	WL (g/g initial fresh sample)				SG (g/g initial fresh sample)			
	(% w/w)	k_1^{WL}	k_2^{WL}	WL_∞	r^2	k_1^{SG}	k_2^{SG}	SG_∞	r^2
45	80	0.20±0.01	1.26±0.02	0.79	0.997	4.44±0.33	11.93±0.29	0.08	0.994
	60	0.40±0.04	1.36±0.04	0.74	0.991	3.32±0.26	10.24±0.25	0.10	0.983
	40	0.79±0.14	1.55±0.10	0.64	0.975	2.62±0.22	9.32±0.22	0.11	0.979
55	80	0.17±0.01	1.19±0.02	0.84	0.997	4.14±0.29	11.80±0.27	0.08	0.995
	60	0.35±0.03	1.29±0.03	0.78	0.992	2.84±0.20	9.91±0.21	0.10	0.990
	40	0.72±0.12	1.49±0.09	0.67	0.976	2.21±0.17	8.69±0.19	0.11	0.980
65	80	0.14±0.01	1.14±0.01	0.88	0.997	3.92±0.29	11.47±0.27	0.09	0.994
	60	0.31±0.02	1.23±0.03	0.82	0.993	2.66±0.208	9.33±0.21	0.11	0.991
	40	0.54±0.07	1.40±0.06	0.72	0.985	2.01±0.165	8.25±0.19	0.12	0.978

Table 2. The diffusion coefficient for WL and SG

Run No.	1	2	3	4	5	6	7	8	9
$D_{ew,avg}$ ($\times 10^{-9} m^2/s$)	2.95	2.90	2.86	3.02	2.98	2.94	3.08	3.02	3.00
$D_{es,avg}$ ($\times 10^{-9} m^2/s$)	2.84	2.81	2.79	2.95	2.93	2.80	3.16	3.05	3.02

The diffusivity dependence on the temperature can be represented by the Arrhenius type equation ($D_{e,avg} = D_0 \exp(-E_a/RT)$), where E_a is the activation energy, D_0 the Arrhenius factor, and T is the absolute temperature, R is the gas constant, 8.314 $x10^{-3}$ kJ/mol K^{-1}. Ea/R was obtained as the slope of the straight line of nature log of $De_{,avg}$ vs. 1/T (evaluated using Statistica 10.0 software). Evaluated E_a for water were in the range of 15-17 kJ/mol (sugar beet molasses concentration from 80 to 40%, respectively), while E_a for solute were between 6 and 12 kJ/mol, for mentioned range of concentrations.

The accuracy of developed models regarding the effect of concentration and temperature, and also their interrelations on transport parameters is given in Table 3. As seen from Tables 1-3, this driving force depends on concentration and temperature of the osmotic solution. The increase in osmotic solution concentration increases this gradient and also the driving force. The transport coefficients for WL and SG ($D_{e,avg}$) rise with an increase in osmotic solution concentration due to change in the physical properties of the food (such as porosity and cell permeability). These coefficients decrease in time, to the end of the OD process, as seen from Eqns. (3).

Table 3. The non-linear regression diffusion models (where C is concentration expressed in %, T is temperature in degree centigrade, $Y = D_{w,avg.}, D_{s,avg.}$*)*

No	Model	r^2	
	Y	$D_{ew,avg.}$	$D_{es,avg.}$
1	$a+b\cdot C+c\cdot T$	0.952	0.958
2	$a+b\cdot C+c\cdot T+d\cdot C\cdot T$	0.954	0.962
3	$a+b\cdot C+c\cdot T+d\cdot C\cdot T+e\cdot C^2+f\cdot T^2$	0.958	0.976
4	$a+b\cdot C+c\cdot T+d\cdot C\cdot T+e\cdot C^2+f\cdot T^2+g\cdot C^2\cdot T^2$	0.979	0.999

The average effective diffusion of water ($D_{ew,avg}$) and solid ($D_{es,avg}$), which are obtained for different combinations of concentration and temperature of osmotic solution, were modeled by using best four non-linear regression models (*A. Ispir, I. T. Togrul, 2009*). The best model, obtained for transport parameters and statistical analysis results, is given in Table 4. The values of effective diffusion for WL and SG were found to be dependent on the concentration and temperature of the osmotic solution in addition to the combined effect of both of these parameters. This equation (Table 4) can be confidently used for explaining the effect of concentration and temperature used in these experiments.

Table 4. Statistical analyses results and the best models expressed the relationship between transport properties and solution concentration and temperature (where C, % w/w, is concentration, $kg[solute] \times 100\ kg^{-1} [H_2O]$ and T , °C, is temperature)

Model 4, Dw,awg, Ds,awg = a+b C+c T +d C T + e C^2 + f T^2 + g C^2 T^2		
	D_w	D_s
r^2	0.979	0.999
χ^2	$1.50\cdot 10^{-21}$	$7.30\cdot 10^{-23}$
MBE	$-1.35\cdot 10^{-22}$	$-1.40\cdot 10^{-21}$
RMSE	$4.04\cdot 10^{-22}$	$4.19\cdot 10^{-21}$

After obtaining the best fitting model, the RSM study was conducted to determine the optimum OD conditions for sliced carrot cubes. Additional two variables (a_w, and DM) were used in calculation.

Table 5. ANOVA table showing the variables as a linear, quadratic and cross terms effect on each response variable

Term	Source	Sum of Squares				
		df	WL	SG	a_w	DM
Linear	Time	1	0.2555*	0.0035*	0.0252*	2336.4578*
	Temperature	1	0.0288*	0.0023*	0.0038*	226.0099*
	Concentration	1	0.2329*	0.0104*	0.0123*	847.8083*
Quadratic	Time (quad.)	1	0.0297*	0.0003*	0.0000^{ns}	76.8936*
	Temp (quad.)	1	0.0002^{ns}	0.0000^{ns}	0.0003*	23.6357*
	Conc (quad.)	1	0.0095*	0.0000^{ns}	0.0000^{ns}	3.4979^{ns}
Crossproduct	Time Temp.	1	0.0012^{ns}	0.0000^{ns}	0.0008*	1.9301^{ns}
	Time Conc.	1	0.0045*	0.0008*	0.0064*	182.9891*
	Temp Conc.	1	0.0006*	0.0003*	0.0012*	28.6005*
Error	Error	17	0.0059^{ns}	0.0002^{ns}	0.0010^{ns}	34.3237^{ns}
	Total SS	26	0.5687	0.0179	0.0509	3762.1466
r^2			98.962	98.874	98.116	99.088

*Significant at $p<0.05$ level, **Significant at $p<0.10$ level, ^{ns}Not significant.

Table 5 shows the ANOVA calculation regarding the response models developed when the experimental data were fitted to a response surface. The analysis revealed that the linear terms contributed substantially in all cases to generate a significant SOP model. The SOP models for all variables were found to be statistically significant and the response surfaces were fitted to these models. The linear terms of SOP model were found significant, at $p<0.05$ level, and their influence were found most important in model calculation. The residual variance where the lack of fit variation represents other contributions except the first order terms is also shown in Table 5. All SOP models had insignificant lack of fit tests, which means that all the models represented the data satisfactorily (*Montgomery, 1984)*. A high r^2 is indicative that the variation was accounted and that the data fitted satisfactorily to the proposed model (SOP in our case). The r^2 values for WL (0.990), SG (0.989), a_w (0.981) and DM (0.990), were very satisfactory and show the good fitting of the model to experimental results. The contour plot for WL showed a saddle point configuration, and its value raised to the upper right corner of the plot, with the increase of all process variables, temperature, treatment time and molasses concentration. This result is in accordance with literature values (*Panagiotou et al.,* *1999; Waliszewski et al., 1999).* Contour plots of both DM and SG showed that maximum value is a bit lower then the upper right corner of the plot, tending to raise with temperature and processing time. On the other hand, a_w decreased with all process parameters. For the OD of carrot cubes, in this study, the optimum conditions would be similar to that in literature and meet the desired product specifications. The desired responses for the optimum drying conditions: WL=0.7, SG= 0.08, a_w = 0.88, and DM =55%.

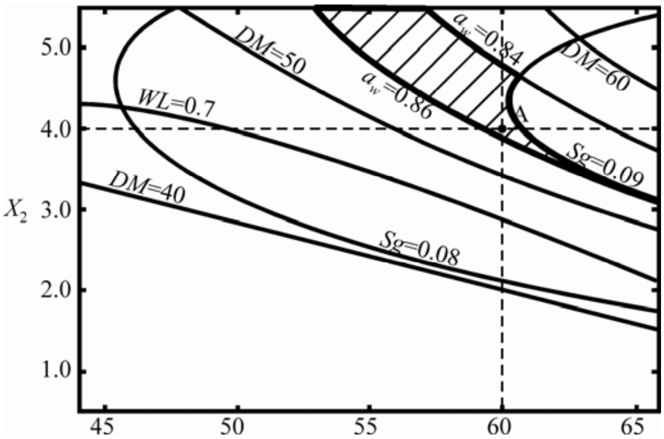

Fig. 2. Optimum regions obtained after superimposing the contour plots of the responses

Figure 2 shows the superimposed graph of the dehydration conditions. An optimum operating area was derived and point A was deduced by approximating the optimum position in obtained area on each graph. Optimization of the dehydration process is performed to ensure rapid processing conditions yielding an acceptable quality product and a high throughput capacity. The optimum osmotic drying conditions for carrot cubes dehydrated in sugar beet molasses were: soaking time of 4 h, sugar solution concentration and temperature of 70% and 54°C. Products, dehydrated under mentioned optimal conditions, resulted in a high values of DM, WL and SG, while the low value of a_w showed that these products are microbiologically stabilized in respect to the growth of most of bacteria and yeasts. High value of SG indicate reasonably sweet product that is acceptable to consumers in terms of good taste (*Filipčev et. al., 2010).* Deviating of point A (Fig. 2) to the right and upper corner, will increase DM which is the most important response variable in OD (Table 5) which will provide the optimum responses of osmotic system.

CONCLUSION

The OD of carrot cubes at various conditions has been studied. The effects of concentration and temperature of solution were investigated.

OD process of carrot cubes is directly related to the concentration and temperature of solution. The WL and SG were increased with the treatment time, concentration and temperature.

The Peleg equation described adequately the WL and SG behavior of carrots during OD in sugar beet molasses in the studied range of solution concentration and temperature. Solution concentration and temperature had a significant effect on the Peleg constants at 0.05 level, (95% confidence limit). The OD kinetics by using effective diffusivities was also determined. The moisture and solid content at any immersion time during the OD of carrots could be predicted with sufficient accuracy (r^2 =0.98-1.00) by using diffusivities coefficients calculated from the proposed model equations.

SOP models for all system responses were statistically significant and predicted and observed responses correspond very well. The optimum dehydration process parameters were found by superimposition of the contour plots of all responses, for treatment time of 4 h, sugar beet molasses solution concentration of 70% and temperature of 54°C were obtained. Predicted values of responses at optimum conditions were: WL =0.7, SG =0.08, a_w =0.88, and DM =55%.

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