MODELLING OF RED BEETS REHYDRATION WITH DIFFERENT INITIAL MOISTURE CONTENT USING EMPIRICAL MODELS

[1]Krzysztof Górnicki, [1]*Krzysztof Kosiorek*

keywords: rehydration, modelling, red beets, initial moisture content

INTRODUCTION

With the development of our civilization the demand for dried vegetables and fruits is growing. The dried products are less vulnerable to quality changes in storage and they are more convenient to store. Drying is often followed by rehydration to prepare product for consumption or further processing.

Rehydration is a complex process aimed at the reinstatement of the features the dried material had before the drying [Witrowa – Rajchert, 1999]. The process is influenced by the parameters of the drying process and the parameters of the rehydration process.

The aim of this study is to analyse and to model rehydration process of red beets dependant on the initial moisture content.

WAYS OF DESCRIBING THE REHYDRATION

Three ways of describing rehydration process have been recently proposed [Górnicki, 2014]:

• rehydration indexes – these indicators are the quantitative determination of certain parameter changes in the rehydration process,

• empirical models – these models allow to calculate parameter changes during the rehydration process e.g. moisture content, dry matter of material. Parameters of such models have no physical interpretation. They also allow to determine equilibrium value. Peleg model is the most common model applied to drying and rehydration phenomena,

• theoretical models – they are the most complex among another method but they allow to take into account external and internal conditions of the process [Crank, 1975]. Fick's second law is frequently applied for the purpose of the mathematical modelling of rehydration. According to it, water transfer takes place on the basis of the diffusion mass movement.

MATERIAL AND METHODS

High–quality Wodan F1 red beets (inital moisture of raw material was assumed at 11 kg H_2O/kg d.m.) bought at a Warsaw market were used in the research. The material was cut into 10 mm cubes and dried under forced convection conditions in temperature of 60°C (KCW–100, PREMED, Marki) until it reached the assumed moisture content on dry basis: 0.1, 0.5, 1, 3, 8 kg H_2O/kg d.m. This process has been followed by storing the material in closed glass jar for 24 hours. The rehydration took place in distilled water with temperature of 20°C. The weight of the dried material to the weight of the rehydrating medium amounted to 1:20. The WPE 300 scales (RADWAG, Radom) were used for the measurement of the sample mass and dry matter mass (according to PN–90/A–75101/03). The maximum relative error in the determination of the mass amounted to 0.1%. Mass, mass of the dry matter, and volume have been measured 6 times during the process. Moisture content has been calculated on the obtained data. In order to determine the moisture content as a function of drying time, rehydration curves obtained in the experiments were fitted to three different models (1) – (3).

A non– linear regression analysis was conducted to fit the models by the Lavenberg–Marquardt method using the computer program STATISTICA 13. The process has been described using Peleg, Pilosof–Boquet–Batholomai, and Singh–Kulshrestha models. These models are presented below:

1. The Peleg model [Peleg, 1988]:

$$m(\tau) = m_0 \pm \frac{\tau}{A_1 + A_2\tau} \qquad (1)$$

where: m – mass, m_0 – initial mass, A_1 – Peleg rate constant, A_2 – Peleg capacity constant, τ – time.

2. The Pilosof–Boquet–Batholomai model [Pilosof et al., 1985]:

$$m(\tau) = m_0 \pm \frac{A_3\tau}{(A_4 + \tau)} \qquad (2)$$

where: m – mass, m_0 – initial mass, A_3 , A_4 – model coefficients, τ – time.

3. The Singh–Kulshrestha model [Singh et al., 1987]:

$$m(\tau) = m_0 \pm \frac{A_5 A_6 \tau}{(A_6\tau + 1)} \qquad (3)$$

where: m – mass, m_0 – initial mass, A_5 , A_6 – model coeffcients, τ – time.

For modelling mass (*m*), volume (*V*) and moisture content (*u*) formulas (1) – (3) uses (+). For modelling mass of the dry matter (*d.m. m*) (–) must be applied.

RESULTS AND DISCUSSION

These models are relatively simple and depend on time only. They do not take into consideration any other external conditions. Parameters of these models (1) – (3) can be also used to calculate equilibrium values of abovementioned models.

Experimental data (for 0.1 and 1 kg $H_2$0/kg d.m.) with its models has been presented on Figure 1.

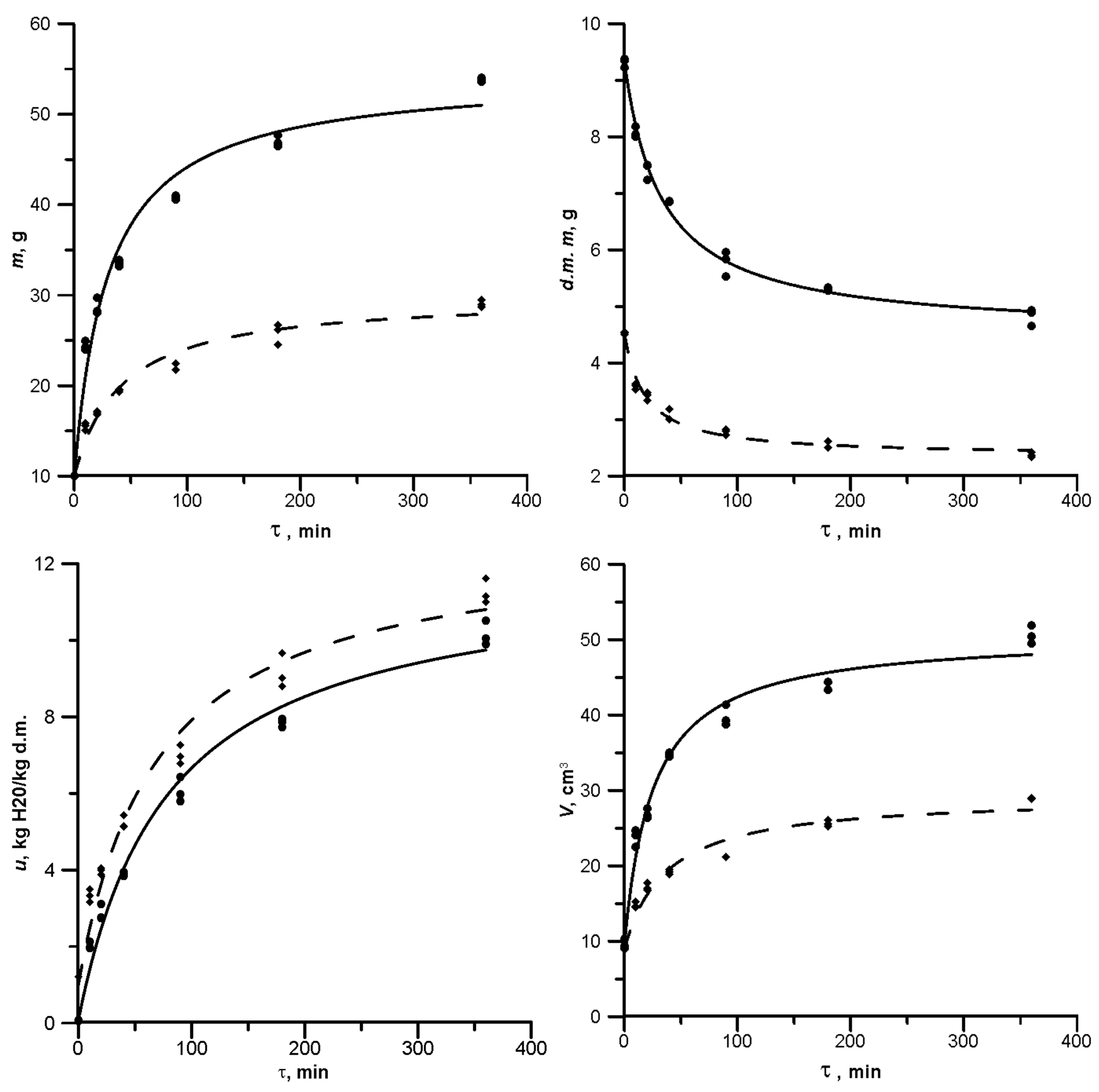

Figure 1. Experiment results for the rehydration of beet cubes in different initial moisture content: (•,♦) experimental data (—, ——) Peleg model (0.1 and 1 kg $H_2$0/kg d.m. respectively)

Data obtained from experiments indicates influence of initial moisture content on rehydration kinetics.

Parameters of these models with statistics (R and RMSE) are shown in the Table 1.

Table 1. Models constants, correlation coefficients (R) and root mean square error (RMSE) for the rehydration of beet cubes with different initial moisture content

Models		Parameters	u_0 ,kg $H_2$0/kg d.m.					R	RMSE
			0.1	0.5	1	3	8		
m	1	A_1	20.674	1.481	2.062	5.968	4.611	0.841 - 0.989	0.472 - 2.124
		A_2	0.023	0.035	0.050	0.102	0.229		
	2	A_3	44.395	28.807	19.93	9.793	4.377	0.841 - 0.989	0.472 - 2.124
		A_4	29.926	42.638	41.09	58.44	20.181		
	3	A_5	44.396	28.807	19.932	9.793	4.377	0.841 - 0.989	0.472 - 2.124
		A_6	0.033	0.024	0.024	0.017	0.023		
d.m. m	1	A_1	6.809	6.617	8.161	28.611	$3 \cdot 10^8$	0.395 - 0.995	0.077 - 2.124
		A_2	0.208	0.322	0.462	1.415	$-8 \cdot 10^{-5}$		
	2	A_3	4.814	3.104	2.174	0.707	604.01	0.060 - 0.996	0.077 - 2.124
		A_4	32.776	20.536	17.74	20.216	$4 \cdot 10^5$		
	3	A_5	4.814	3.104	2.174	0.707	98.552	0.278 - 0.996	0.077 - 2.124
		A_6	0.031	0.049	0.056	0.051	$1 \cdot 10^{-6}$		
u	1	A_1	6.703	7.185	5.926	8.758	15.971	0.685 - 0.993	0.413 - 2.687
		A_2	0.085	0.095	0.086	0.137	0.221		
	2	A_3	11.794	10.542	11.690	7.289	4.517	0.685 - 0.993	0.413 - 2.687
		A_4	79.056	75.747	69.253	63.832	27.137		
	3	A_5	11.795	10.542	11.694	7.289	4.518	0.685 - 0.993	0.413 - 2.687
		A_6	0.013	0.013	0.014	0.016	0.014		
V	1	A_1	0.618	1.285	1.774	7.713	4.933	0.862 - 0.994	0.714 - 1.846
		A_2	0.024	0.036	0.049	0.082	0.206		
	2	A_3	41.094	27.904	20.357	15.516	4.867	0.862 - 0.994	0.714 - 1.846
		A_4	25.38	35.864	36.109	96.526	24.009		
	3	A_5	41.095	27.904	20.358	12.517	4.867	0.862 - 0.994	0.714 - 1.846
		A_6	0.039	0.028	0.028	0.013	0.042		

Models (1) – (3) have similar statistics. however they are not suitable for whole range of initial moisture content. The lowest corelation coefficient has been calculated for dry matter mass of red beets with highest initial moisture ratio (8 kg $H_2$0/kg d.m.).

EVALUATION OF THE MODELS

Abovementioned coefficients (Table 1.) had been modelled with quadratic and linear functions. Subsequently, obtained parameters have been implemented into equations (1) – (3).

Examples of new models are presented in Figure 2.

Functions used to model parameters, correlation coefficients (R) and root mean square error (RMSE) for models are shown in Table 2. .

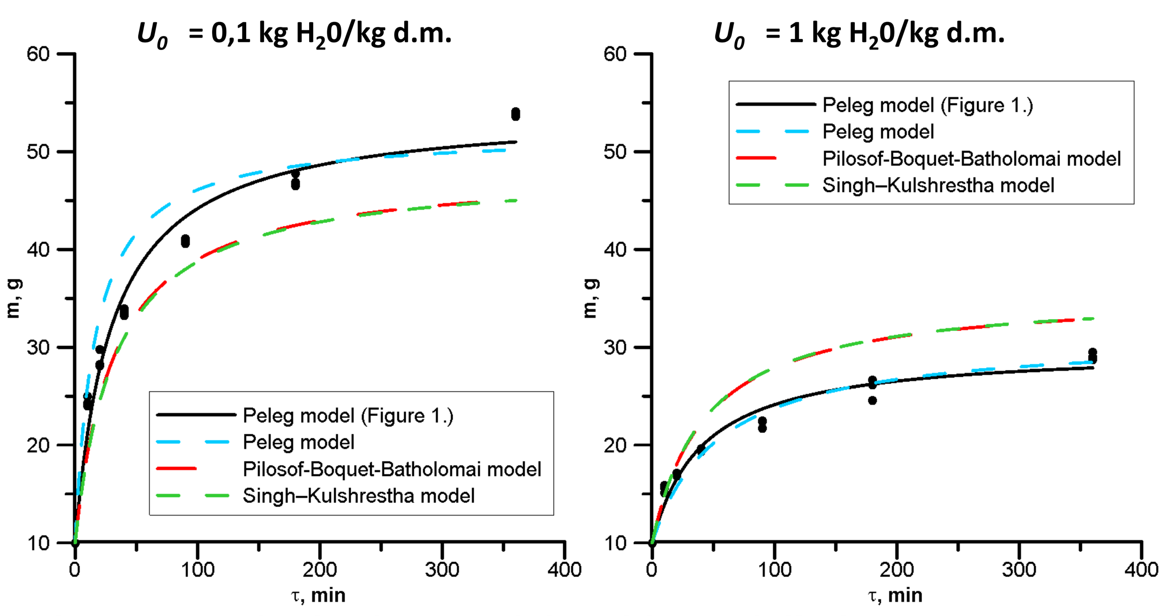

Figure 2. Rehydration models with modelled parameters for mass of beet cubes with initial moisture content 0.1 and 1 kg $H_2$0/kg d.m. : (•) experimental data, (—) models

Table 2. Results of modelling model's parameters with equations based on initial moisture content with correlation coefficients (R) and root mean square error (RMSE) for the rehydration of beet cubes with different initial moisture content. (u_0 – initial moisture ratio)

Models		Equations of models parameters	R	RMSE
m	1	$A_1 = -0.258u_0^2 + 2.625u_0 + 0.203$	0.987	1.918
		$A_2 = 0.025u_0 + 0.022$		
	2	$A_3 = 1.321u_0^2 - 14.89u_0 + 39.27$	0.963	2.984
		$A_4 = -2.087u_0^2 + 15.37u_0 + 30.79$		
	3	$A_5 = 1.321u_0^2 - 14.89u_0 + 39.27$	0.960	3.097
		$A_6 = 0.001u_0^2 - 0.009u_0 + 0.031$		
d.m. m	1	$A_1 = 3.011u_0^2 - 1.786u_0 + 6.869$	0.981	0.446
		$A_2 = 0.424u_0 + 0.116$		
	2	$A_3 = 0.753u_0^2 - 3.679u_0 + 4.974$	0.772	3.200
		$A_4 = 6.341u_0^2 - 23.32u_0 + 33.22$		
	3	$A_5 = 0.753u_0^2 - 3.679u_0 + 4.974$	0.637	11.247
		$A_6 = -0.011u_0^2 + 0.040u_0 + 0.028$		
u	1	$A_1 = 0.108u_0^2 + 0.320u_0 + 6.490$	0.977	0.719
		$A_2 = 0.017u_0 + 0.080$		
	2	$A_3 = 0.103u_0^2 - 1.784u_0 + 12.11$	0.978	0.708
		$A_4 = 0.893u_0^2 - 7.960u_0 + 78.75$		
	3	$A_5 = 0.103u_0^2 - 1.784u_0 + 12.11$	0.602	2.990
		$A_6 = -0.000u_0^2 + 0.001u_0 + 0.012$		
V	1	$A_1 = -0.370u_0^2 + 3.637u_0 - 0.372$	0.930	5.955
		$A_2 = 0.022u_0 + 0.022$		
	2	$A_3 = 1.011u_0^2 - 12.01u_0 + 36.52$	0.980	5.955
		$A_4 = -4.782u_0^2 + 39.39u_0 + 15.55$		
	3	$A_5 = 1.011u_0^2 - 12.01u_0 + 36.52$	0.968	2.666
		$A_6 = 0.002u_0^2 - 0.015u_0 + 0.038$		

CONCLUSIONS

Red beets rehydration process was investigated: changes in mass, dry matter mass, volume, and moisture content.

The effect of initial moisture content dried red beets on the rehydration model parameters was investigated. Three empirical models were considered: Peleg model, Pilosof–Boquet–Batholomai model and Singh–Kulshrestha model. The correlation coefficient (R) and root mean square error (RMSE) were examined for the applied models to compare their goodness of fit to the experimental data. The rehydration models with the model parameters determined taking into account the initial moisture content (linear or quadratic form) were quite suitable for predicting the rehydration curve behaviour of red beets.

The Peleg model can be recommended: goodness of fit to the experimental rehydration data is as follows: R = 0.930 – 0.987.

REFERENCES

Crank J. 1975. The mathematics of diffusion. Clarendon Press. Oxford.

Górnicki K. 2011. Modelling of selected vegetables and fruits rehydration process. Treatises and Monographs / Publications of Warsaw University of Life Sciences – SGGW.

Górnicki K., Kaleta A., Winiczenko R., Chojnacka A., Janaszek M. 2013. Some remarks on modelling of mass transfer kinetics during rehydration of dried fruits and vegetables. [In:]H. Nakajima (ed.) Mass transfer–advances in sustainable energy and environment oriented numerical modelling. In Tech. Rijeka. Croatia: 431–458.

Peleg M. 1988. An empirical mode for the description of moisture sorption curves. Journal of Food Science 53(4): 1216–1219.

Pilosof A.M.R., Boquet R., Batholomai G.B. 1985. Kinetics of water uptake to food powders. Journal of Food Science 50: 278–282.

Singh B.P.N., Kulshrestha S.P. 1987. Kinetics of water sorption by soybean and pigeonpea grains. Journal of Food Science 52(6): 1538–1541.

Witrowa–Rajchert D. 1999. Rehydratacja jako wskaźnik zmian zachodzących w tkance roślinnej w czasie suszenia. Fundacja „Rozwój SGGW". Warszawa.

[1] Department of Fundamental Engineering; Faculty of Production Engineering, Warsaw University of Life Sciences, Warsaw, Poland

krzysztof_górnicki@sggw.pl; krzysztof_kosiorek@sggw.pl