ISSN 1392-1134 / eISSN 2345-0371
Agricultural Engineering, Research papers, 2016, vol. 48, 1-7 p.

CARROT SLICES THICKNESS AND TEMPERATURE INFLUENCE ON THE HIGH TEMPERATURE DRYING DYNAMICS

***Aivars Aboltins, *Tatjana Rubina, *Janis Palabinskis, ***Egle Jotautiene**
* Latvia University of Agriculture
** Aleksandras Stulginskis University

The aim of this paper is to determine the drying and diffusion coefficients of removed moisture applying convection drying of carrot slices. In this study was investigated the slices thickness and temperature effect on the carrot drying process. The experiments were carried out with potato slices of three different thickness 10 mm, 15 mm and 20 mm on laboratory conditions. There are compared drying processes by four different drying temperatures: 60, 70, 80 and 90ºC with the purpose to investigate slices thickness and temperature effect on the carrot drying process. Using the experimental data the theoretical drying coefficient and diffusion coefficient were calculated. The results of this research showed that the diffusion coefficient is directly proportional to the moisture content in material. Diffusion coefficient dependence on the moisture content better describe exponential equation. The theoretical results are useful for description and modelling of the drying process with time dependent drying coefficient and diffusion coefficient for carrot slices and pieces on two- and three-dimensional case. Calculated parameters can be used for further research work and for improvement of the whole drying process.
Keywords: carrot drying, drying coefficient, diffusion coefficient.

Received 2016-07-14, accepted 2016-12-21

INTRODUCTION

Carrot constitutes an important vegetable for human nutrion due to its high vitamin, fibre and other valuable nutrients content and to its organoleptic properties. The importance of carrot is reflected by its global production, which FAO was estimated at more that 37 million metric tons in 2013. Latvian in 2014 were produced 191 thausand tons of vegetables, of which more than 47 thausand tons of the carrot.

Carrots are perhaps best known for their rich supply of the antioxidant nutrient that was actually named for them: beta-carotene. However, these delicious root vegetables are the source not only of beta-carotene, but also of a wide variety of antioxidants and other health-supporting nutrients. The areas of antioxidant benefits, cardiovascular benefits, and anti-cancer benefits are the best-researched areas of health research with respect to dietary intake of carrots.

Carrot is used fresh or dehydrated in the elaboration of a number of foodstuffs, such as salads, saups, sauces, prepared meaals and healthy snacks. Consumers choose products with specificē health effects together with the increasing popularity of high quality dried food [1].

Vegetables contain large quantities of water in proportion to their weight that is promoter of many biological and chemical processes. For example, carrot contains about 87 % water [2; 3]

The presence of moisture is favorable environment for micro-organisms that can grow and reproduce in an environment where moisture content is about 25-30 %, except mold which can grow in an environment with water content at least 10-15 %. Water evaporation causes unfavorable environment for evolution of micro-organisms and allows for a longer period of time to store the product quality.

Drying is generally carried out for two main reasons, one to reducē water activity which eventually increase the self life of food and second to reducē weight and capacity of producēt for cheaper transport and storage.

In food industry , carrot must usually be dried prior to its use.The drying process should be considered carefully to select the most suitable type of drying, the optimum drying temperature and duration. Depending on the vegetable size, shape and thickness, there can be dried whole, sliced/cut and chopped vegetables [4].

The drying time or duration depends on the drying method and product size. The drying time of the convective technique can be shortened by using higher temperatures which increase moisture diffusivity and by cutting the material in to small pieces [5]. In addition, the preservation efficiency of the same product may vary due to the characteristics of the different varieties of product.

Increased consumers awareness for better quality, safety and nutritional value of food, drying research has been devoted to improved processing technlogies, which give rise to quality of final products. The effect of drying temperature and air velocity on the vitamin content of carrots dried by convection are investigated [6, 7]. The thermal degradation of beta-carotine during air drying of carrots at different air temperatures was described in [8].

Predicting drying coefficients and internal moisture and temperature profiles are necessary for drying process optimization. A knowledge of effective moisture diffusivity is necessary for designing and modeling mass-transfer processes such as dehydration, adsorption and desorption of moisture during storage. There are many research of carrot drying modeling, but mostly researchers represent experimental data processing with nonlinear regression depending on drying time [9-12].

The objective of this work was to study the influence of drying temperature (60, 70, 80 and 90 ºC) and carrot slices thickness (10, 15, 20 mm) on drying kinetics.

MATERIALS AND METHODS

Carrot were washed under running water to remove the adhering impurities, wiped and cut into slices with thickness of 10 mm, 15 mm and 20 mm, using a sharp stainless steel knife. They are not peeled and blanched. The slices of a certain thickness were imposed on individual trays with a perforated base. The slices of the same thickness were placed in a single layer on the tray forming certain thin porous layer.

All samples were dryed at four constant temperatures: 60 ºC, 70 ºC, 80 ºC and 90 ºC. The drying chamber *Memmert* was used for the drying experiments with accuracy of temperature control ± 0.3 ºC. The drying chamber is a vertical type camera in which the air flows upwards through the sample trays that provide the access of hot air to the carrot slices on both sides. During drying process free ventilation was performed. Each tray was weighed before inserting it in dryer.

A laboratory balance Kern EW 1500-2M was used for weighing, with measurement accuracy ± 0.01 g. The samples were regularly weighed during the experiment and values were recorded to determine the mass changes on drying time at certain temperature. For measuring the weight of the sample, the trays with samples was taken out of the drying chamber, weighed on the digital balance and placed back into the chamber. Each measuring tray was weighed during the first 7 hours every 15 minutes.

The initial moisture amount was determined using the amount of product dry matter. Dry matter was obtained by drying carrot by temperature at 103 ºC until it's did not change the weight during the hour. The total duration of each experiment amounted approximately 24 hours.

Assuming that the product is placed in thin, porous layer can be considered that the carrot pieces moisture W depends only on the drying time (at constant drying temperature). Take into account mathematical model of porous material layer drying process [12] we can describe the carrot drying process by following mathematical equation:

$$\frac{\partial W}{\partial t} = K(t) \cdot (W_p - W), \text{ with initial condition } W(0)=Ws \quad (1)$$

where Ws – the content of moisture at the beginning of experiment, %; Wp– equilibrium moisture content, dry basis, %; K(t) – drying coefficient, h^{-1}; t – drying time, h.

Lack of knowledge of drying coefficient K(t) makes difficult the drying process modeling. K(t) expression depends not only on the drying product but also the drying temperature and drying conditions. In addition, the drying rate is variable during drying due to the different moisture transport mechanisms such as surface diffusion, pure diffusion, capillary flow, evaporation, thermo-diffusion, etc. The theoretical drying coefficient K(t) at certain moment in time was calculated using the experimental data and methodology described by Aboltins [11].

Experimentally drying rate can be expressed from (2)

$$\frac{M(t)-M_\infty}{M_0-M_\infty}=\exp[-K(t)\cdot t\,], \tag{2}$$

where M(t), M_0, M_∞ - moisture weigh at any time of drying, initial moisture weigh and equilibrium moisture weigh corresponding.

In another hand weigh changes can be expressed with diffusion coefficient D [13]:

$$\frac{M(t)}{M_\infty}=1-\sum_{n=0}^{\infty}\frac{8}{(2n+1)^2\pi^2}\exp\left(-D\frac{(2n+1)^2\pi^2 t}{L^2}\right), \tag{3}$$

where L-thickness of material,m.

Taking the first member of sum (3) and expression (2) we can calculate diffusion coefficient $D(t_i)$ at each time moment t_i using simplified formula:

$$D(t_i)=\frac{K(t_i)\cdot L^2}{\pi^2}. \tag{4}$$

RESULTS AND DISCUSSION

In order to compare the drying dynamics of different size of carrot slices calculation was made per 100 g of product. Results which are presented in Fig. 1 show the drying temperature and layer thickness have a significant impact on the carrot slices drying. Moisture removal from carrot slices with 20 mm thickness is significantly lower. The drying dynamic of carrot slices with different thickness differ less by lower temperature.

At low drying temperatures the sample thickness significantly affects the same drying process i.e. time. Increasing the thickness of the sample surface affect decreases and increases the internal moisture transport role (see Figure 1).

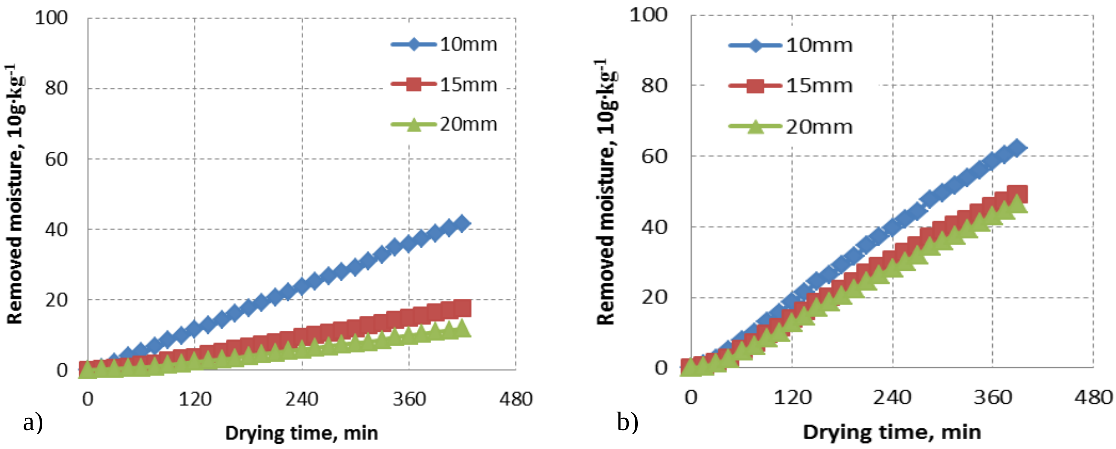


Figure 1. The removal moisture content changes in carrot samples depending from drying time at different temperatures: a – 60 ^{0}C; b – 90 ^{0}C.

Using experimental data and mathematical packages MathCad and Matlab capabilities was obtained 2nd part nonlinear multivariable expression between removed moisture *C*(t,T), temperature *T* (^{0}C) and drying time t (min) for samples thickness: 15 mm (5) and 20 mm (6).

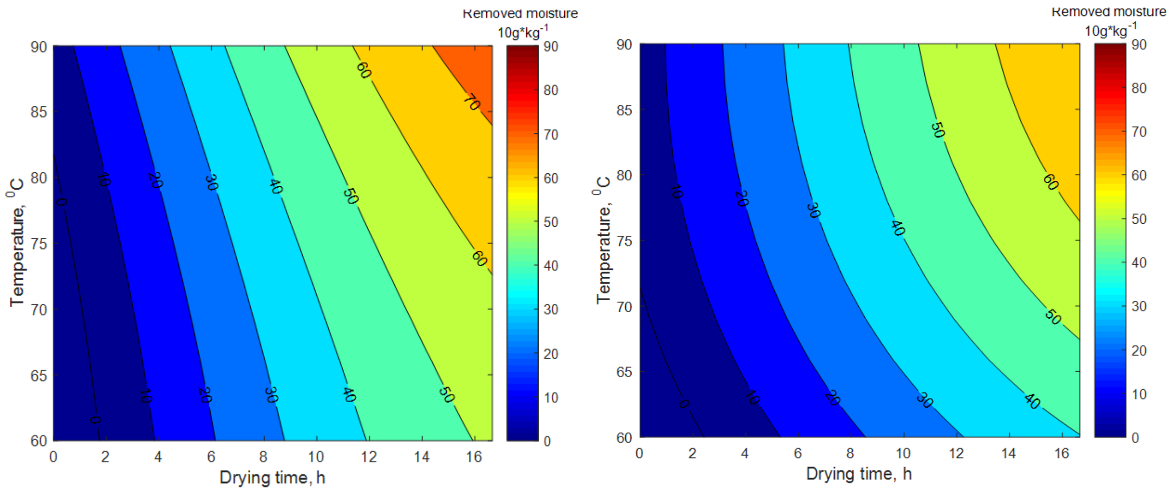
$$C(t,T)=8.828+0.069t-2.884\cdot 10^{-5}t^2-0.806T-8.621\cdot 10^{-3}T^2+3.391\cdot 10^{-4}t\cdot T \tag{5}$$

with determination coefficient $R^2=0.977$

$$C(t,T) = -130.018 + 0.034t - 1.634 \cdot 10^{-5} t^2 + 3.035T - 0.017T^2 + 5.197 \cdot 10^{-4} t \cdot T \qquad (6)$$

with determination coefficient $R^2 = 0.965$

Experimental results show slices thickness significantly affects the moisture removal (Figure 2). At slices thickness 15 mm after 12 hours of drying the average moisture removal is about 60 grams per 100 grams of carrot at drying temperature 90^{0}C, but at slices thickness 20 mm - about 50 grams per 100 grams of carrot. As can be seen, the drying temperature effect to the moisture removal changes more or less linearly at sample thickness 15 mm, but increasing the thickness becomes non-linear. At slices thickness 20 mm the temperature influence on moisture removal becomes non-linear, which means that internal diffusion carried the main role in moisture removal.



a) b)

Figure 2. The removal moisture content changes in carrot samples depending from drying temperature and drying time at different thickness: a – 15 mm; b – 20 mm

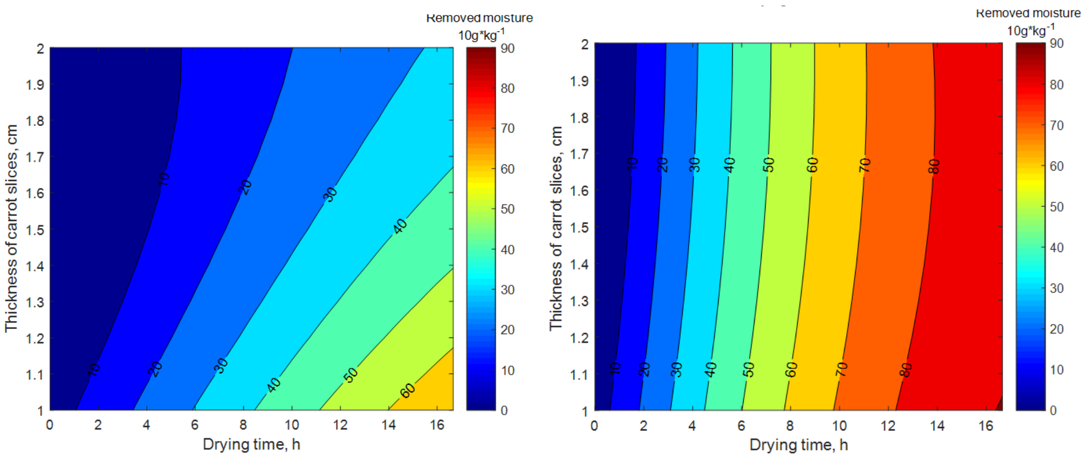
Using experimental data was obtained nonlinear multivariable equations between removed moisture *C*(t,l), samples thickness l and drying time t at different drying temperatures: 60 ºC (7) and 90 ºC (8).

$$C(t,l) = 28.729 + 0.142t - 6.234 \cdot 10^{-5} t^2 - 3.122l + 0.072l^2 + 6.031 \cdot 10^{-4} t \cdot l \qquad (7)$$

with determination coefficient $R^2 = 0.987$

$$C(t,l) = 52.615 + 0.101t - 9.19 \cdot 10^{-6} t^2 - 6.631l + 0.191l^2 - 2.813 \cdot 10^{-3} t \cdot l \qquad (8)$$

with determination coefficient $R^2 = 0.99$



a) b)

Figure 3. The removal moisture content changes in carrot samples depending from drying time and sample thickness at temperatures: a – 60 ºC; b – 90 ºC

The effect of temperature on moisture removal may well see in Figure 4. Thicker samples (20mm) temperature effect is proportional to each other, but with less thickness samples (10 mm), the temperature rising to 90 degrees water removal significantly increasing. It should be noted that at temperatures 70^0C and 80 ^{0}C for different thickness samples, in particular, 15mm and 20mm, the differences of amount of removal moisture are minor.

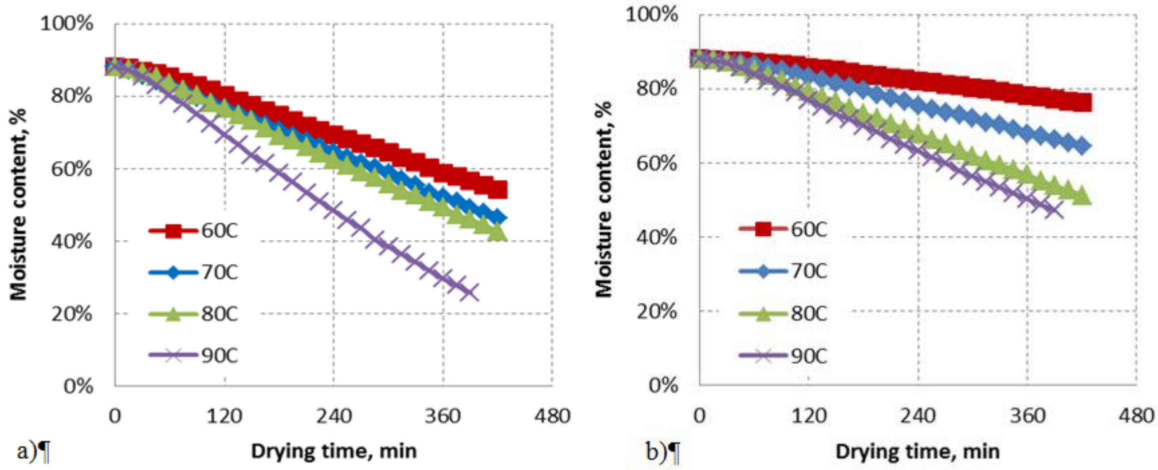


Figure 4. The moisture content changes in carrot samples depending from drying time and temperatures with thickness: a – 10mm; b – 20mm**.**

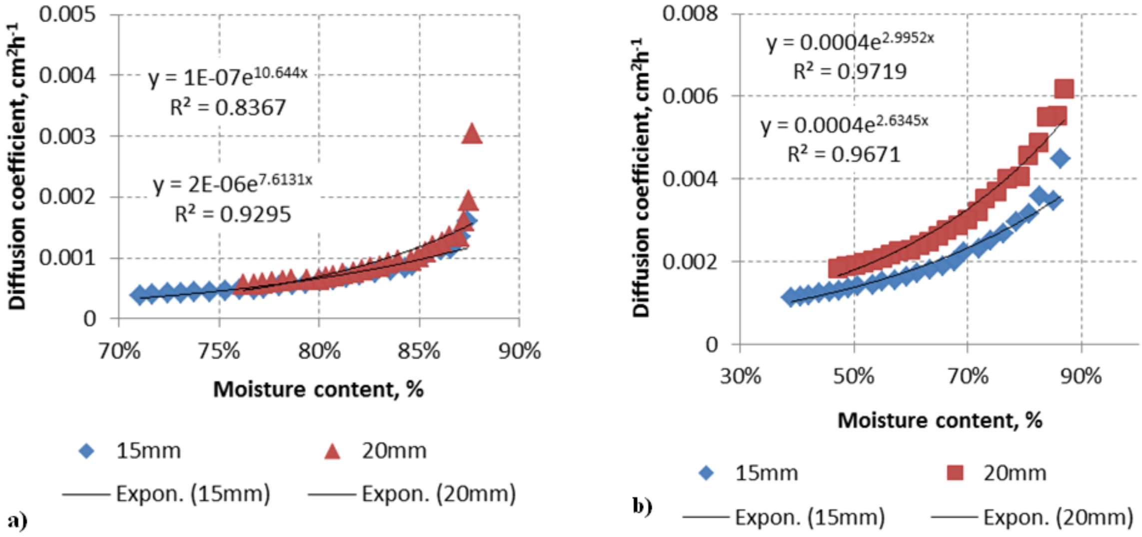


Figure 5. The diffusion coefficient D(c) depending on the moisture concentration at different drying temperatures with two different thickneses: a– at drying temperature 60 ^{0}C; b– at drying temperature 90 ^{0}C.

The problem is to determine the diffusion coefficient. Experimental data shows that the diffusion coefficient, in general, depends on the moisture concentration of the material. The equation (4) shows possibility to obtain the diffusion coefficient depending on the drying time. As drying temperature all drying time is constant, temperature effect is not taken into account in the diffusion coefficient calculation. In another hand, each moment of drying time complies with moisture content in product and is possible to find diffusion coefficient depending from moisture content or concentration. Obtained results are shown in Fig.5. and corresponds to one of diffusion coefficient types described by Crank [13]. Analysis of results showed the diffusion coefficient D changes considerably at first 7 drying hours. Further during drying, diffusion coefficient changes insignificantly. For example, diffusion coefficient of carrot drying with 90 ºC air temperature can be expressed as

$$D(c) = 0.0004e^{0.03c} \tag{9}$$

with determination coefficient $R^2 = 0.9719$ (Fig.5 d).

It should be noted that the diffusion coefficient we understand as the effective diffusion coefficient, which combines surface diffusion, thermo diffusion, inside diffusion and etc. The formula differences in picture a and picture b can be explained with surface diffusion effect. Nevertheless temperature effect is much greater that corresponds to research results [14] performed by Guinē and Barroca. Carried out research enabled them to conclude that the raise in temperature originated an important increase in the value of the diffusivity.

CONCLUSION

1. Using a thin layer drying coefficient is possible to find the exponential diffusion coefficient dependence on the concentration.
2. Using a thin porous layer is possible to express a variable of diffusion coefficient dependence on the concentration.
3. The concentration effect on diffusion coefficient speed changes is more significant at higher drying temperature regardless of thickness. At lower temperature, drying coefficient values decrease rapidly but the moisture concentration remains high, i.e. more than 70% after 7 drying hours at drying temperature 60 ^{0}C.
4. Application of variable diffusion coefficient will accurately describe the moisture removal process in material and can be used for the drying process prediction.
5. The diffusion coefficient values of 20mm thick carrot slices are about 1.5 times higher than it values of 15mm thick carrot slices and about 2 times higher than it values of 10mm thick carrot slices at the same drying temperature. The smaller the thickness of carrot slices the more coefficient values differ from thicker slices.

REFERENCES

[1] Y.Yue-Horng, S.Chia-Ho, C.Ching-Hui. 2008. Effect of adding ascorbic acid and glucose on the antioxidative properties during storage of dried carrot. Food Chemistry. Vol.107 (1), 265-272 p.p. http://dx.doi.org/10.1016/j.foodchem.2007.08.013

[2] S.Bastin, K.Henken. Water Content of Fruits and Vegetables, University of Kentucky: Colleague of Agriculture, 1997, 1 p.

[3] M.Rashidi, I.Ranjbar, M.Gholami, S.Abbassi. 2010. Prediction of Carrot Firmness Based on Carrot Water Content, American-Eurasian J. Agric. & Environ. Sci., Vol.7 (4), 402-405 p.p.

[4] Ch.Bratucu, A.L.Marin, C.C.Florea. 2013. Research On Carrot Drying By Means Of Solar Energy. Bulletin of the Transilvania University of Braşov Series II: Forestry Wood Industry. Agricultural Food Engineering, Vol. 6 (55) No. 1, 91-98 p.p.

[5] H.Darvishi, H.Khafajeh, A.Banakar, M.Lofti. 2013. Effect of Shape Potato Chips on Drying Characteristics. International Journal of Agriculture and Crop Sciences, Vol. 5, No. 18, 2009-2018 p.p.

[6] J.Gamboa-Santos, A.Soria, T.Formari, M.Villamier, A.Montilla. 2013. Optimisation of convective drying of carrots using selected processing and quality indicators. International Journal of Food Science and Technology, 48, 1998-2006 p.p. doi: 10.1111/ijfs.12076

[7] D.Urrea, V.S.Eim, M.R.Gonzalez-Centeno, R.Minjares-Fuentes, A.Castel-Palau, M.D.Juarez, C.Rosselo. 2011. Effects of air drying temperature on antioxidant activity and carotenoids content of carrots. European Drying Conference-EuroDrying'2011, Palma, Spain, 26-28 October 2011, P. 3

[8] A.Goula, K.Adamopoulos. 2010. Kinetic models of β-carotine degradation during air drying of carrots. Drying Technology, Vol. 28 (6), 752-761 p.p. doi: 10.1080/07373937.2010.482690

[9] J.Srikiatden, J.S. Roberts. 2008. Predicting moisture profiles in potato and carrot during convective hota ir druing using isothermally measured effective diffusivity. Journal of Food Engineering, Vol. 84 (4), 516-525 p.p. http://dx.doi.org/10.1016/j.jfoodeng.2007.06.009

[10] A.Aboltins, A.Upitis. 2011. The mathematical model of carrot slices drying. Scientific journal: Agricultural Engineering. XXXVI, 2, 69-75 p.p.

[11] A.Aboltins. 2013. Theoretical study of material drying coefficient. International Scientific Conference Engineering for Rural Development. Latvia University of Agriculture, Jelgava, 153-158 p.p.

[12] H.Togrul. 2006. Suitable drying model for infrared drying of carrot. Journal of Food Engineering, Vol. 77 93), 610-619 p.p. http://dx.doi.org/10.1016/j.jfoodeng.2005.07.020

[13] J.Crank. 1956. The mathematics of diffusion. Oxford, Clarendon Press, P.347

[14] R.Guinē, M.Barocca. Estimation of the Diffusivities and Mass transfer Coefficients for the Drying of D.Joaguina Pears. Proceedings of the World Congress on Engineering, London, U.K., July 3-5, 2013, Vol II, pp.1-4

Author for contacts:
Aivars Aboltins, Dr.sc.ing.
Latvia University of Agriculture, Faculty of Engineering,
Institute of Agricultural Machinery,
Cakstes blvd.5, Jelgava, LV-3001,
E-mail: aivars.aboltins@inbox.lv

Tatjana Rubina, Dr.sc.ing.
Latvia University of Agriculture, Faculty of Information technologies,
Department of Computer Systems,
Liela street.2, Jelgava, LV-3001,
E-mail: tatjana.rubina@llu.lv

Janis Palabinskis, Dr.sc.ing., Assoc. Prof.
Latvia University of Agriculture, Faculty of Engineering,
Institute of Agricultural machinery,
Cakstes blvd.5, Jelgava, LV-3001,
E-mail: janis.palabinskis@llu.lv

Egle Jotautiene, Dr.sc.ing.,Prof.
Aleksandras Stulginskis University, Faculty of Agricultural Engineering,
Institute of Agricultural Engineering and Safety,
Studentu 15, Akademija, LT-53361,
E-mail: egle.jotautiene@asu.lt