POTATOES DRYING DYNAMICS RESEARCH

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Abstract. The aim of this paper is to determine the drying and diffusion coefficients of removed moisture applying convection drying of potatoes slices. In this study was investigated the slices thickness and temperature effect on the potato drying process. The experiments were carried out with potato slices of four different thickness 5 mm, 10 mm, 15 mm and 20 mm on laboratory conditions. There are compared drying processes by three different drying temperatures: 65, 75 and 85 ºC with the purpose to investigate slices thickness and temperature effect on the potato 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. It's dependence can be described by linear equation. The linear equation constant shows the effect of drying temperature on the diffusion coefficient value. The theoretical results are useful for description and modelling of the drying process with time dependent drying coefficient and diffusion coefficient for potato 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: potato drying, drying coefficient, diffusion coefficient.

Introduction

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 [1; 2], white potato – 79 %, red tomato – 94 %, radish – 95 % [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. Agriculture products drying is a most popular method of food preservation [4; 5] which provide the moisture evaporation of the product [6; 7] and the obtaining of concentrated product dry mass. Dried foodstuff can be consumed and used for flavor and dry mix production.

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 [7]. Various techniques can be used for drying, for example, oven, bread oven, and heated hob [4], microwave. In practice are used different methods of vegetables drying such as, hot-air drying, vacuum drying, sun-drying, freeze drying [6] and others. The drying time or duration depends on the drying method and product size. For example, the drying time of the convective technique can be shortened by using higher temperatures which increase moisture diffusivity and by cutting the material into small pieces [6]. In addition, the preservation efficiency of the same product may vary due to the characteristics of the different varieties of product.

Potato is a high moisture food and one of the most potential crops having high productivity and supplementing major food requirement in the world. It is rich with proteins, phosphorus, calcium, vitamins and etc. The better method for drying the high moisture food is to use hot temperature drying.

One of the important factors of drying is diffusion coefficient. The diffusion coefficient of a food is material property and its value depends upon the conditions within the material. Effective moisture diffusivity describes all possible mechanisms of moisture movement within the foods, such as liquid diffusion, vapor diffusion, surface diffusion, capillary flow and hydrodynamic flow. 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 potato drying modeling, but mostly represent experimental data processing with nonlinear regression depending on drying time [8-11].

Our aim was to study drying kinetics of potato (*Solanum tuberosum L*) slices placed on trays with four different thickness (5, 10, 15, 20 mm) by three different temperatures: 65, 75, 85 ºC.

Materials and methods

Potato were washed under running water to remove the adhering impurities, dried and cut into slices with thickness of 5 mm, 10 mm, 15 mm and 20 mm, using a sharp stainless steel knife. They are not peeled and blanched. The potato slices of a certain thickness were imposed on individual trays with a perforated base, respectively, on three trays. The slices of the same thickness were placed in a single layer on the tray.

All samples were dryed at tree constant temperatures: 65 ºC, 75 ºC, 85 ºC. The drying chamber Me mmert 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 potato slices on both sides.

Each tray was weighed before inserting it in dryer. A laboratory balance Kern EW 1500-2M was used for weighing, which is equipped with a digital display and have the 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 8 hours every 60 minutes.

The initial moisture amount was determined using the amount of product dry extract. Dry extract was obtained by drying potato by temperature at 103 ºC until it's did not change the weight during the hour.

Assuming that the product is placed in thin, porous layer can be considered that the potato pieces moisture W depends only on the drying time (at constant drying temperature). Take into account mathematical model of porous material layer drying process [11] we can describe the potato drying process by following mathematical equation:

$$\frac{dW}{dt} = K(t) \cdot \left(W_p - W\right), \text{ with initial condition } W(0) = W_s \,, \tag{1}$$

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

Assuming $K(t)=a \cdot t+b$ we can solve given differential equation (1) analytically:

$$W = W_p + \left(W_s - W_p\right) \cdot e^{-\left(\frac{at^2}{2} + bt\right)} \,. \tag{2}$$

The values of coefficients *a* and *b* was determined using experimental data.

Lack of knowledge of drying coefficient *K*(*t*) makes difficult the drying process modeling. Note that the *K*(*t*) expression depends not only on the drying product but also the drying temperature and 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 (3)

$$\frac{M(t) - M_\infty}{M_o - M_\infty} = \exp(-K \cdot t) \,, \tag{3}$$

where $W(t)$, W_o , $W\infty$ – the moisture content at any time of drying, inital moisture content and equilibrium moisture content.

In another hand diffusion coefficient with constant conditions can be expressed from (4) [12]:

$$\frac{M(t)}{M_\infty} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2 \pi^2} \exp\left(-D \frac{(2n+1)^2 \pi^2 t}{L^2} \right). \tag{4}$$

Taking the first member of sum (4) /next will be more that 10 time less/ can receive the diffusion coefficient

$$D = \frac{L^2 \ln\left(\frac{\pi^2 (M_\infty - M(t))}{8M_\infty}\right)}{\pi^2 t} \quad \text{or } D = \frac{L^2 (\ln 8 - 2\ln \pi + K \cdot t)}{\pi^2 t}, \tag{5}$$

where L – the thickness of material, m.

At each time moment t_i is possible to calculate diffusion coefficient $D(t_i)$

$$D(t_i) = \frac{L^2 (\ln 8 - 2\ln \pi + K(t_i) \cdot t_i)}{\pi^2 t_i}. \tag{6}$$

Results and discussion

In order to compare the drying dynamics of different size of potato 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 potato slices drying. Moisture removal from potato slices with 20 mm thickness is significantly lower. The drying dynamic of potato slices with different thickness differ less by lower temperature.

a) b)

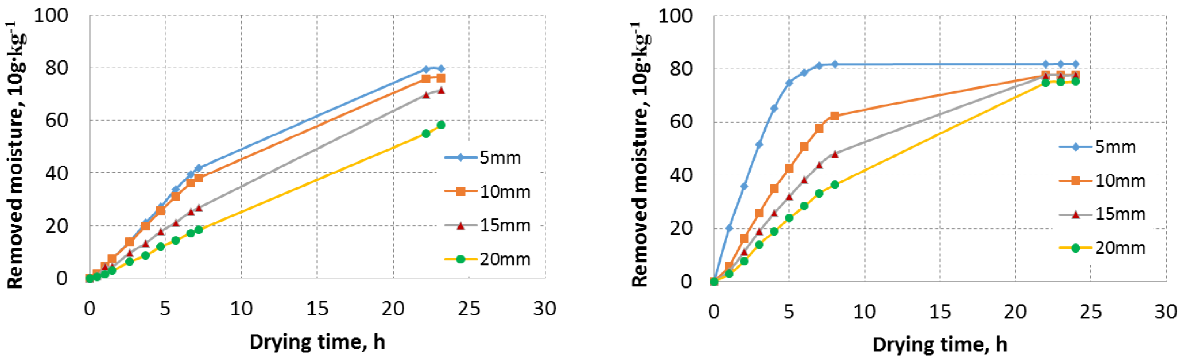

Fig. 1. **The removal moisture content changes in potato samples depending from drying time and sample thickness at temperatures:** a – 65 °C; b – 85 °C

Using experimental data and mathematical packages MathCad and Matlab capabilities was obtained 2nd part nonlinear multivariable expression between removed moisture and temperature T and drying time *t* for different thickness of samples: 5 mm (7), 10 mm (8), 15 mm (9) and 20 mm (10).

$$C(t,T) = 108.72 + 0.235t - 8.773 \cdot 10^{-5} t^2 - 4.49T + 0.04T^2 - 7.712 \cdot 10^{-4} t \cdot T, \ \eta^2=0.95; \tag{7}$$

$$C(t,T) = 152.79 + 0.147t - 5.577 \cdot 10^{-5} t^2 - 4.71T + 0.035T^2 - 1.784 \cdot 10^{-4} t \cdot T, \ \eta^2=0.985; \tag{8}$$

$$C(t,T) = 17.27 + 0.093t - 3.082 \cdot 10^{-5} t^2 - 0.907T + 8.714 \cdot 10^{-3} T^2 + 6.204 \cdot 10^{-5} t \cdot T, \ \eta^2=0.991; \tag{9}$$

$$C(t,T) = 24.03 + 0.028t - 1.45 \cdot 10^{-5} t^2 - 0.933T + 7.882 \cdot 10^{-3} T^2 + 5.395 \cdot 10^{-4} t \cdot T, \ \eta^2=0.996. \tag{10}$$

Experimental results show slices thickness significantly affects the moisture removal (Fig. 2). At slices thickness 10 mm after 14 hours of drying the average moisture removal is about 70 grams per

100 grams of potato. As can be seen, the sample thickness affects the moisture removal changes linearly. At slices thickness 20 mm the temperature influence on moisture removal becomes linear, which means that internal diffusion carried the main role in moisture removal.

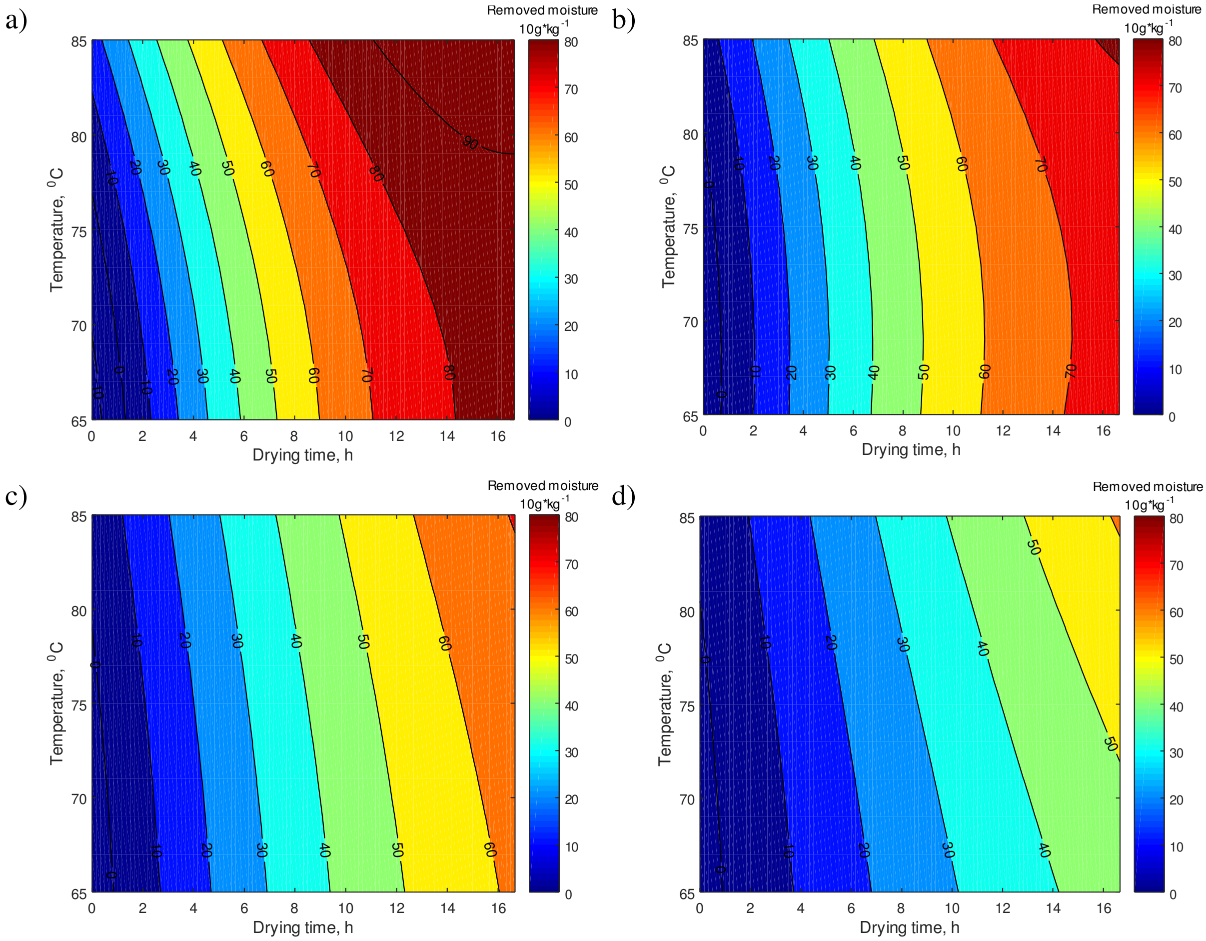

Fig. 2. **The average removed moisture changes in potato samples dependence from drying temperature and drying time at different thickness:** a – 5 mm; b – 10 mm; c – 15 mm; d – 20 mm

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 Fig. 3).

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 (6) shows possibility to obtain the diffusion coefficient depending on the drying coefficient i.e. the time of drying process. 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. The results are shown in Fig. 4 and Fig. 5.

Analysis of results showed the diffusion coefficient changes considerably at first 7 drying hours. Further during drying, diffusion coefficient changes insignificantly. Using the methodology described above and the experimental data was obtained the diffusion rate expression for potato slices of different thickness drying by different temperatures. Diffusion coefficient changes of potato slices with 20 mm layer drying with 65 °C hot air can be described by equation:

$$D(c)=0.0001\cdot c-0.0069 \tag{11}$$

with the coefficient of determination $\eta^2 = 0.9016$. There c – moisture content, %.

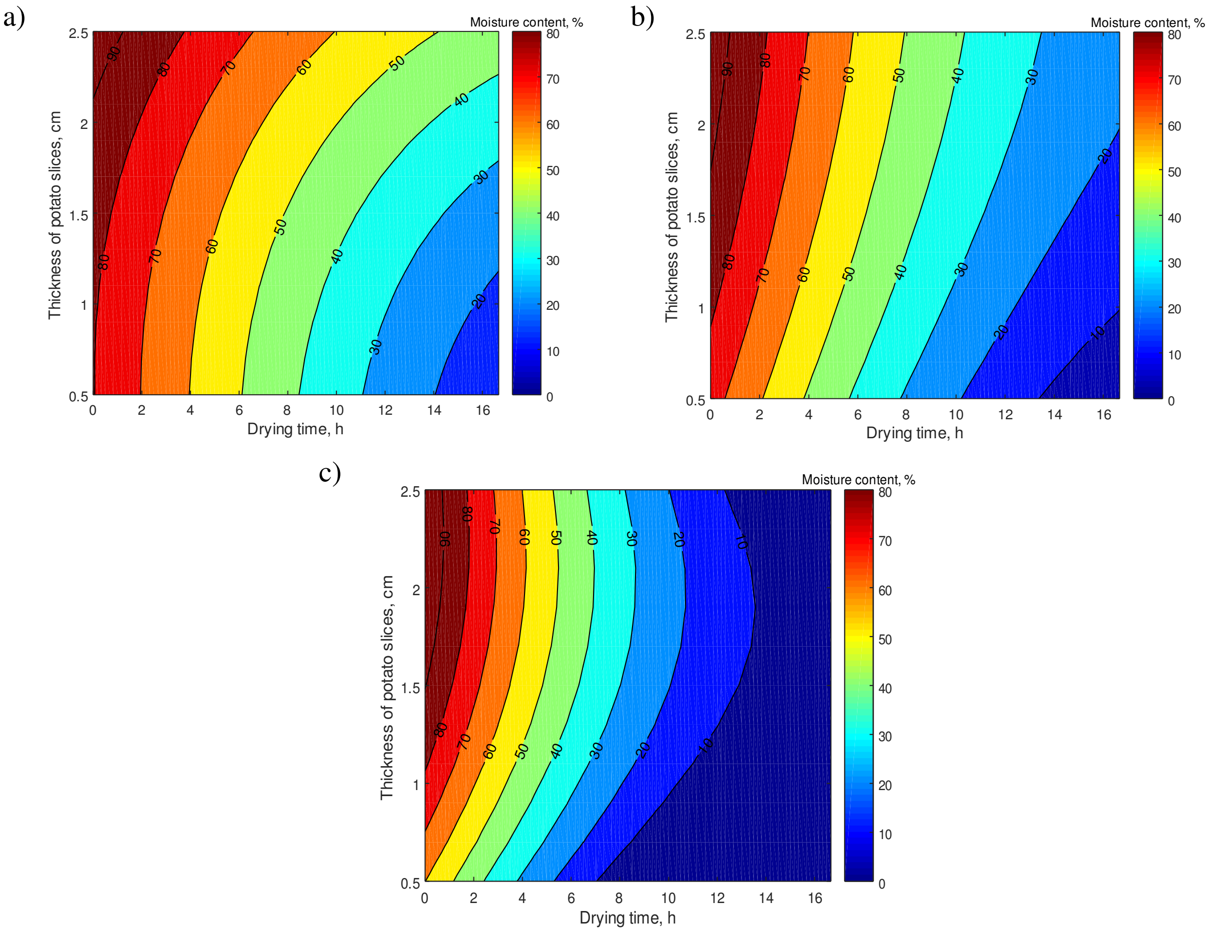

Fig. 3. **The average moisture content changes in potato samples with different thickness during drying with different temperatures:** a – 65 ºC; b – 75 ºC; c – 85 ºC

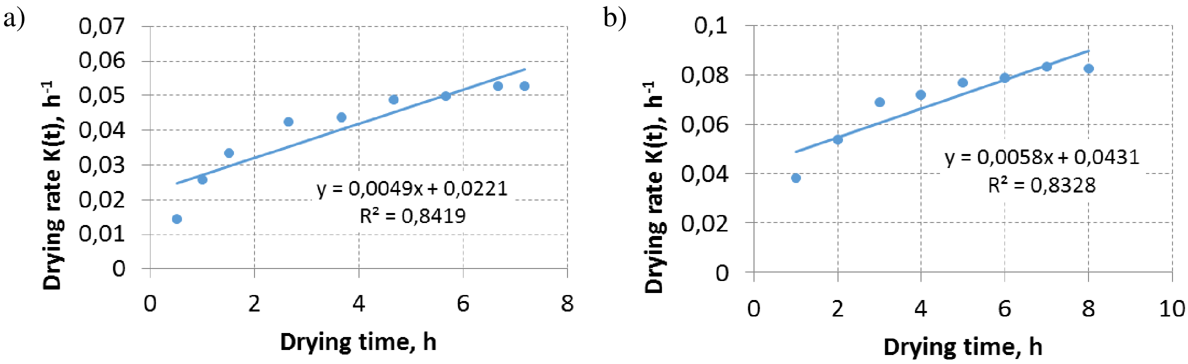

Fig. 4. **The drying coefficient depending on the moisture concentration at different drying temperatures with 20 mm thickness:** a – 65 ºC; b – 85 ºC

Diffusion coefficient changes drying with 85 ºC hot air can be described by equation:

$$D(c)=0.0001\cdot c-0.0048 \quad (12)$$

with the coefficient of determination $\eta^2 = 0.9024$.

As we can see concentration effect on the diffusion coefficient speed changes in both cases is the same (11) and (12). Variable is only the constant that shows the effect of temperature on diffusion coefficient value.

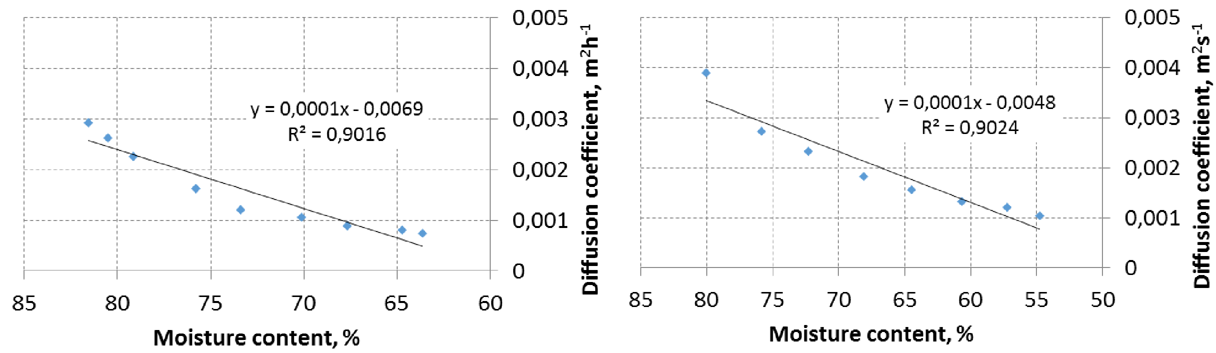

Fig. 5. **The diffusion coefficient D(c) depending on the moisture concentration at different drying temperatures with 20 mm thickness:** a – 65 ºC; b – 85 ºC

Conclusion

1. Using a thin layer drying coefficient is possible to find the linear 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 insignificant. The constant in linear expression shows the effect of temperature to diffusion coefficient value.
4. Variable diffusion coefficient application will accurately describe the moisture removal process in material and predict the drying process.

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