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ANALYSIS OF CONVECTIONAL DRYING PROCESS OF PEACH

Ewa Golisz*[1], *Małgorzata Jaros*[1], *Monika Kalicka

Faculty of Production Engineering
Warsaw University of Life Sciences

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Abstract

In this study the convectional drying process of peach were investigated. Peaches were cut longitudinally into eight similar pieces and were dried in a laboratory air-drier with forced horizontal air flow. Drying experiments were carried out at temperatures of 50, 60, 70°C and for two air velocities: 1.0 and 1.2 m/s. The results are shown graphically on the charts. It was found that a greater effect on increasing the rate of drying is the drying air temperature than the increase in flow velocity. The verification of theoretical models of the first and second drying period indicates that the drying process of peach is determined by internal conditions of heat and mass transfer, therefore to describe the drying process were used models of the second period of drying. Global relative error calculated for the whole process was less than 5%.

Introduction

Drying is one of the basic way of preserving food. It involves the removal of water from the product by its evaporation. With this method, water (80-90%) is discharged from the fresh product and a large amount of nutrients are preserved. Drying of agricultural products is one of the oldest and most important methods of food preservation which allows for market surplus management.

Peaches (*Prunus persica* L.), by apricots and nectarines, are the richest source of vitamins and minerals. Therefore they should be eaten throughout the year fresh or dried. Raw peaches and apricots in more than 86% consist of water. In warm countries (India, Iran, Turkey) the most commonly used

* Corespondence: Ewa Golisz, Zakład Podstaw Nauk Technicznych, Szkoła Główna Goispodarstwa Wiejskiego, ul. Nowoursynowska 164, 02-787 Warszawa, phone: 48 22 593 46 14, e-mail: ewa.golisz@sggw.pl

method of drying these fruits is sun drying, which requires little capital, simple equipment and low energy input (TOGRUL, PEHLIVAN 2004, KINGSLY et al. 2007). To achieve consistent quality dried product industrial dryers should be used. The drying kinetics of food is a complex phenomenon and requires simple representations to predict the drying behaviour, and for optimizing the drying parameters.

In literature there are lot of studies on drying kinetics of fruits e.g.: apricot (SARSILMAZ et al. 2000, TOGRUL, PEHLIVAN 2002, 2003, DOYMAZ 2004, IGUAL et al. 2012); bananas (DANDAMRONGRAK et al. 2003); melon, papaya (Pereira et al. 2006); grapes (YALDIZ et al. 2001), plum (GOYAL et al., 2007) and some studies on drying peach. TOGRUL and PEHLIVAN (2004) modelled thin layer drying kinetics of peach under open-air sun drying process. WANG and SHENG (2006) studied microwave and far-infrared dehydration characteristics and two-stage drying process involving far-infrared following microwave drying on peach. SAHARI et al. (2006) investigated physicochemical properties of sliced peach during osmotic pre-treatment and dehydration, the optimum condition of the dehydration and sensory evaluation of dried products. KINGSLY et al. (2007) investigated the effect of pre-treatments (potassium meta. bisulphite and ascorbic acid) and drying air temperature (55 and 65°C) on drying behaviour of peach slices. GERMER et al. (2010) evaluated the influence of temperature and concentration of the sucrose syrup on the pre-osmotic dehydration of peaches. However, there is little detailed information on drying kinetics and modelling of drying process of peach. Since drying is an energy-intensive process, its optimization is extremely important for both environmental and economic reasons. In order to optimize drying process, it is necessary to develop its mathematical model to predict the process course. Such model should take into account drying kinetics model that is versatile and has strong theoretical basis.

The objective of this study was to identify the conditions governing of the heat and mass exchange in the convection drying process of peach, using models of the kinetics drying. The external conditions of the heat and mass exchange are dominant from the initial moisture content to the critical one, which in the case of peach is not known. Therefore, the second objective of this study was to indicate the critical moisture content symbolically separated first and second drying period.

Materials and methods

Fresh peaches (Reliance variety) were purchased from local market in Warsaw, Poland. The initial moisture content of fresh samples was 6.7 kg H_2O/kg db (dry basis). For each drying experiment fruits of similar size and shape and initial mass of 800g were cut longitudinally into eight similar pieces, pips removed. Samples were dried in a laboratory air-drier with forced horizontal air flow. Moisture loss was measured at 15–30 min intervals during experiments with accuracy of ±0.01 g (Radwag WPX 4500). Drying experiments were carried out at temperatures of 50, 60, 70°C and for two air velocities: 1.0 and 1.2 m/s. Originally in the methods of research planned air velocity were 1 and 1.5 m/s, however, due to technical conditions in the drying tunnel managed to get the velocity maximum 1.2 m/s, therefore such measurements were made and the relevant results were presented. Drying of peach started at the initial moisture content and continued, until moisture content reached equilibrium value (till was no large variation in the moisture lost). Experiments were replicated three times to minimise error, then mean values was used. For each experimental setup a relative humidity of the ambient air was controlled and a series of mass measurements were conducted. Mass of dry solid was determined with accuracy of 0.01 g for each individual sample by oven drying at 105°C for 24 h (PN-A-75101-03:1990).

Results and discussion

Drying kinetics

The effect of temperature and air velocity on moisture content changes during drying of peach pieces is shown on Figure 1. Figure 2 shows the effect of air velocity on the drying rate of peach at a fixed temperature.

Air velocity had less effect on the drying time than the drying temperature. It may be concluded that the surface of the fruit dried faster and drying rate is determined by the external water exchange to a lesser extent than by the internal one. The air velocity in the range 1-1.2 m/s has any effect on the drying time for air temperature 50°C but this effect is visible with increasing temperature. Further studies including temperature measurements of dried material would be valuable.

Mathematical modelling

According to the theory, in the initial drying phase, drying rate of the material with high initial moisture content should be determined by external conditions of water exchange. It means that water exchange takes place only on the surface of the dried material. The heat supplied to the body is consumed for the evaporation of water from its surface, and the surface temperature

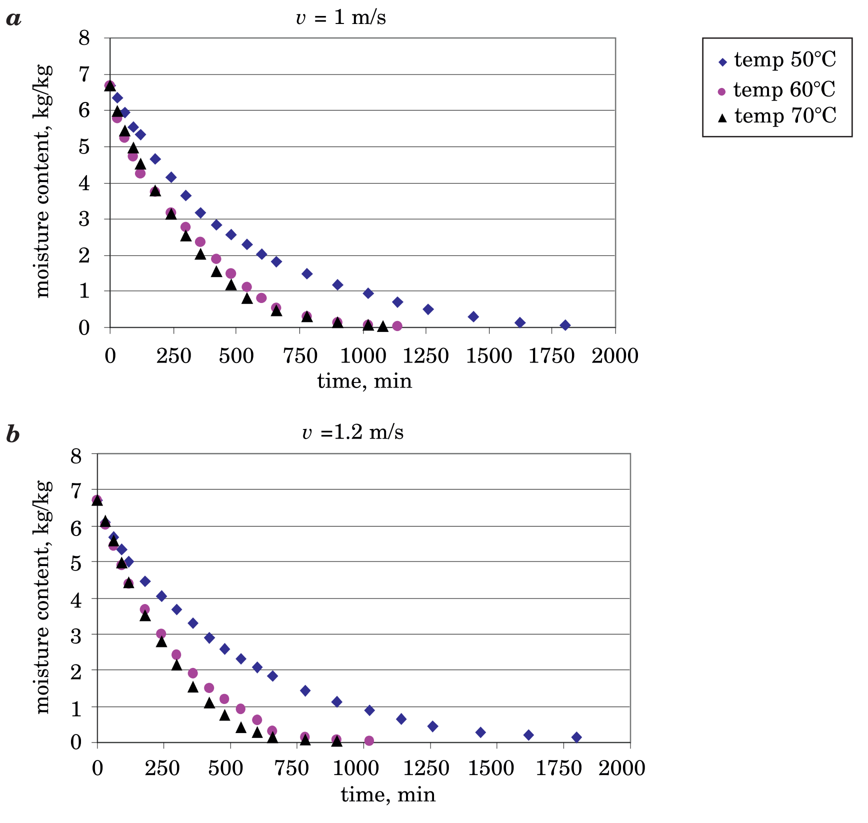

Fig. 1. Drying kinetics depending on temperature at a fixed velocity: *a* – velocity 1.0 m/s, *b* – 1.2 m/s

of the dried material is approximately equal to the wet bulb temperature. According to the theory of convectional drying of agricultural products this kind of water exchange is called the first drying period (PABIS 1982). During this period the drying rate of solid surface is constant. First drying period ends when the water molecules are vaporized from the surface. The moisture content at this point is called the critical moisture content. This period is always present in products with high initial moisture content such as fruits and vegetables and also peach.

Decreasing drying rate is characteristic for the second drying period. The temperature of dried material increases, water from inner layers changes its state to vapour and moves to the sample surface. This phenomenon is called inner diffusion and its rate is lower than water evaporation on the sample surface. The second drying period ends when the moisture content reaches the equilibrium and remains constant.

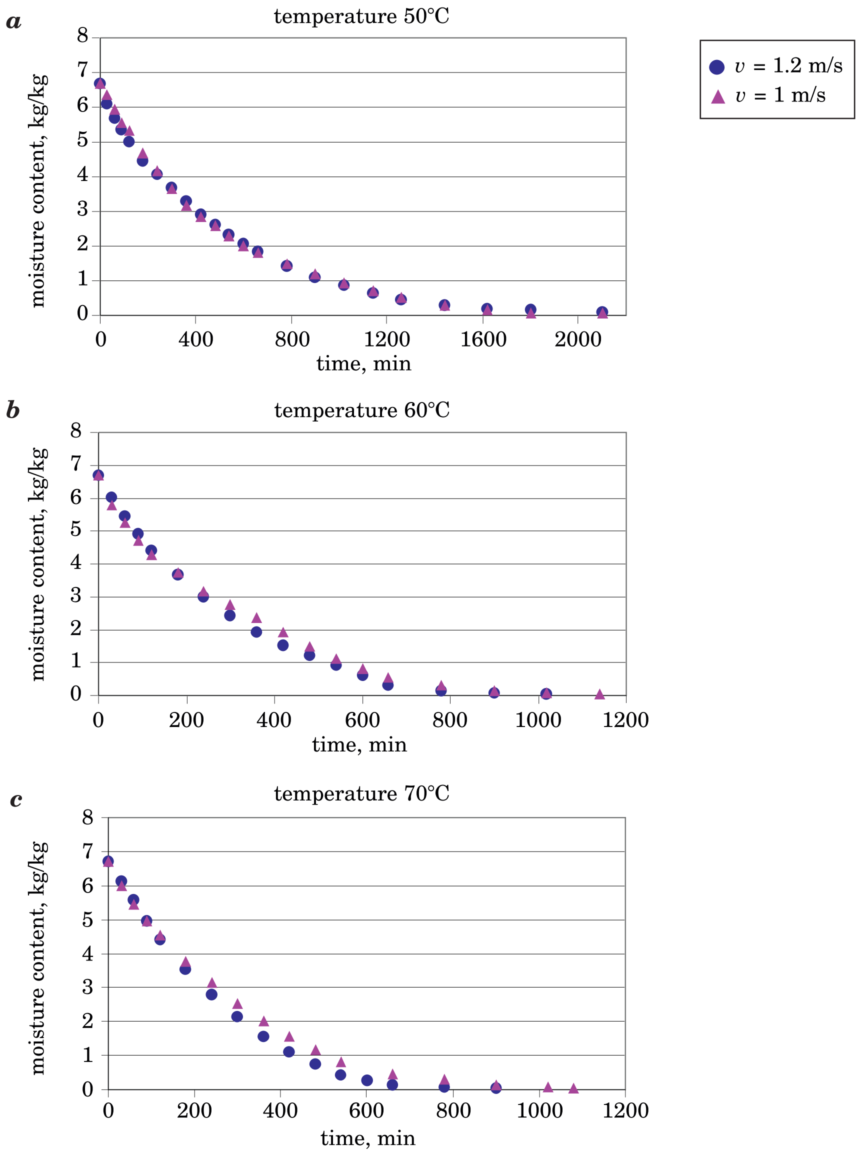

Fig. 2 Drying kinetics depending on hot-air velocity at a fixed temperature: *a* – 50°C temperature, *b* – 60°C, *c* – 70°C

Drying kinetics in this study according to PABIS (1994, 1999), was modelled by means of: first drying period equation in terms of shrinkage (Eq. 1).

$$u_I(\tau) = u_0\left[\frac{1}{1-b}\left(1 - \frac{1-b}{Nu_0}k_0\tau\right)^N - \frac{b}{1-b}\right] \tag{1}$$

where:
u_0 – initial moisture content [kg/kg]
k_0 – coefficient of initial speed of drying [1/min]
τ – time of drying [min]
N – correction factor, the rate of anisotropic changes [–]
b – maximum rate of shrinkage, [–]
V_s – volume of dry basis [m^3]
V_0 – initial volume of the material [m^3]
and second drying period equation (Eq. 2), which is a simplified diffusion equation of mean moisture content $u(\tau)$:

$$u_{\mathrm{II}}(\tau) = u_r + (\mathrm{u}_0 - u_r)\, \mathrm{e}^{-\mathrm{K}\tau} \tag{2}$$

where:
$K = \mathrm{f}(a_m, \mathrm{x}, \tau)$ – factor depending on the shape of the dried sample [–]
u_r – equilibrium moisture content [kg/kg]
a_m – mass diffusion coefficient [m^2/s]
x – characteristic dimension [m]

Verification of models described by Eq. 1 and Eq. 2 leads to the conclusion about the type of conditions governing the drying process.

Determination of critical moisture content occurrence is contractual. This moment corresponds to change from external mass transfer dominance to internal one. Drying rate in the first period is then equal to the rate of drying in the second period (PABIS 1999). This allows to estimate the value of the coefficient of drying rate in second period (K from Eq. 2):

$$K = \frac{k_0}{u_{cr} - u_r}\left(1 - \frac{1 - b}{Nu_0}\, k_0 \tau_{cr}\right)^{N-1} \tag{3}$$

Since critical moisture content was unknown in this study, therefore three different moisture contents were assumed:

1. $u_{cr} = 2$ kg H_2O/kg db – according to JAROS (1999) it was assumed that such critical moisture content of fruits and vegetables separates the first "surface" and the second "diffusive" drying period
2. $u_{cr} = 4$ kg H_2O/kg db – intermediate value between $u_{cr} = 2$ and $u_0 = 6{,}7$ kg/kg
3. $u_{cr} = u_0$ – assuming that the process runs only in the second period of drying.

Coefficients k_0 and N were selected for each model in order to minimize its errors.

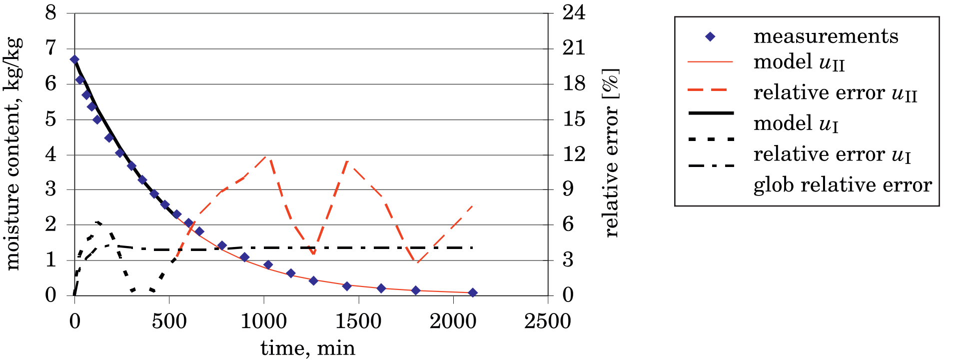

Fig. 3. Models of moisture content changes during the 1st and the 2nd drying period and error plots for assumed critical moisture content u_{cr} = 2 kg/kg, temperature 50°C and air velocity v = 1.2 m/s

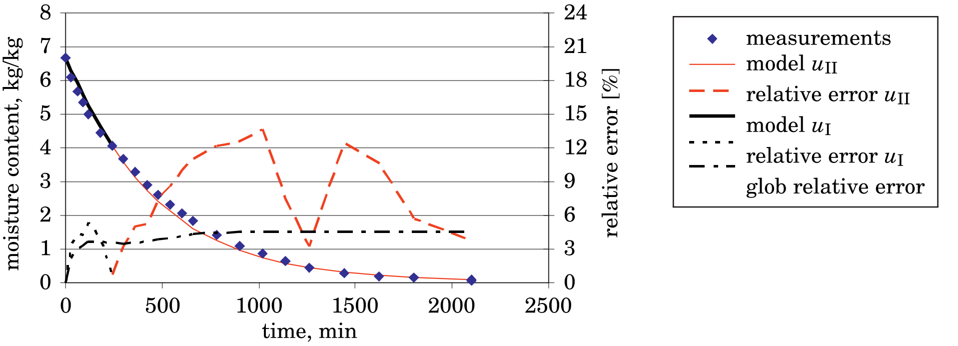

Fig. 4. Models of moisture content changes during the 1st and the 2nd drying period and error plots for assumed critical moisture content u_{cr} = 4 kg/kg and temperature 50°C, air velocity v = 1.2 m/s

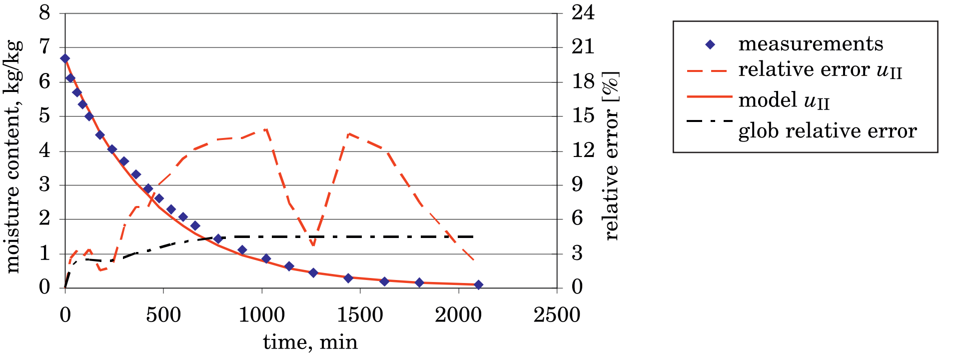

Fig. 5. Models of moisture content changes during the 1st and the 2nd drying period and error plots for assumed critical moisture content u_{cr} = u_0, temperature 50°C, air velocity v =1.2 m/s

Modelling results of moisture content changes of drying peach presented in figures 3–5, for exemplary temperature 50°C and air velocity v = 1.2 m/s. Results include original data and those obtained by means of mathematical modelling.

Analyzing the graphs in Figures 3–4 can be seen, the relative errors model u_I for the assumed critical moisture content of 2 and 4 kg/kg (drying time 500 and 250 min) were higher than for model u_{II} (Figure 5). Thus, assumption that the process of drying peach in the initial period is determined by external mass transfer conditions was not confirmed.

It is possible to use empirical models to describe the kinetics of the second drying period. In the literature some models of moisture content changes which do not arise directly from the theory of heat and mass transfer were also reported. Such models are based on specific solution of diffusion equation for convective drying of solids. To describe falling drying rates in literature have been widely used semi-theoretical models, for example: the Newton, the Henderson and Pabis, the Logarithmic and the Page models. These models are generally derived by simplifying general series solutions of Fick's second law and considering a direct relationship between the average moisture content and the drying time. They neglect the fundamentals of the drying process and their parameters have no physical meaning (SIMAL et al. 2005). Despite this, Pages's model (PAGE'S 1949) has been used to describe the drying kinetics of various agricultural materials, such as fruits: grapes (DOYMAZ, PALA 2002), apricots (BOZKIR 2006), strawberry, apple (CONTRERAS et al. 2008), kiwi (SIMAL et al. 2005) in convective and microwave-convective drying.

Also in this work drying kinetics was modelled by means of Page's model (Eq. 4):

$$U = \frac{u(\tau) - u_r}{(u_0 - u_r)} = \exp(-k^n) \tag{4}$$

Results obtained by means of Page's model in exemplary temperature 50°C are shown in figure 6.

As seen in Figure 6 Page's model does not better fit experimental drying kinetics data in the falling rate period than theoretical model (Eq. 2). Because it is empirical model which does not arise directly from the theory of heat and mass transfer therefore it was considered that in the case of peach, the Page's model was not well suited to describe the kinetics of drying. In this work was focused on theoretical models described by equations 1 and 2.

Model coefficients (N, k_0) were chosen so that the relative error of the 1st drying period model was about 5% and of 2nd drying period does not exceed 15%. The global relative error calculated for the whole process should have been less than 5% (Eq. 5):

$$\delta_g = \sqrt{\frac{\sum_{i=1}^{n} [u_{\exp \cdot i} - u_{\mathrm{mod} \cdot i}]^2}{\sum_{i=1}^{n} u_{\exp \cdot i}}} \cdot 100\% \tag{5}$$

where $u_{\exp}$ and u_{mod} – moisture content measured and calculated from model.

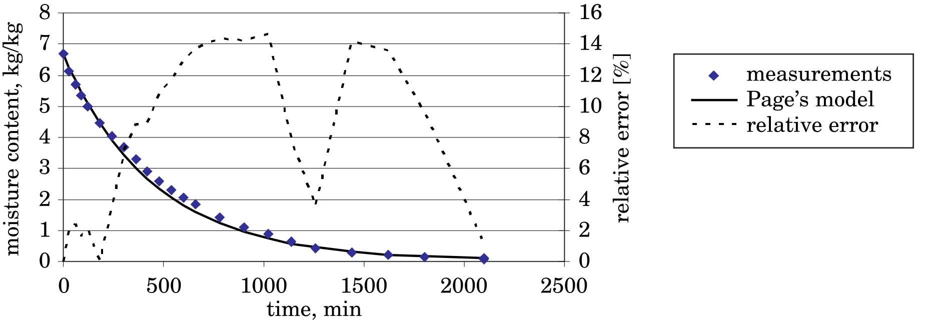

Fig. 6. The Page's model of moisture content changes and error plot, at temperature 50°C, air velocity v = 1.2 m/s

Absolute errors of every model were of 0.2 kg H_2O/kg db. Table 1 presents coefficients N, k_0 and K for all cases.

Table 1

Coefficients N, k_0 and K in mathematical models (Eq. 1 and 2)

Critical moisture content	Coefficient	50°C		60°C		70°C	
		1 m/s	1.2 m/s	1 m/s	1.2 m/s	1 m/s	1.2 m/s
u_{cr} = 2 kg/kg	N k_0	10 0.01205	15 0.0124	20 0.0196	8 0.0208	6,2 0.021	6 0.023
u_{cr} = 4 kg/kg	N k_0	3.9 0.0125	6.4 0.0131	6 0.0195	8 0.022	8 0.0215	2 0.022
$u_{cr} = u_0$	k_0 K	0.0145 0.00218	0.0145 0.00218	0.0219 0.00329	0.0245 0.00368	0.024 0.00361	0.026 0.00392

There can not be seen logical relationship between the coefficient N and the parameters of the drying process. However, the coefficient k_0 of the initial drying rate is logically correct, that is larger for higher temperature and drying air velocity.

Conclusions

The effect of temperature and velocity on thin-layer drying of peach slices in a tunnel dryer was investigated. Increase in drying air temperature decreased the drying time. Velocity has less effect on drying rate than temperature.

The critical moisture content in drying process of peach was not identified. The verification of theoretical models of the first and second drying period indicates that in the drying process of peach can not take into account the first drying period, which means that external conditions of mass exchange does not significantly influence the process of the drying. The reason of this fact can be quick formation on the cross-sectional area of the fruit layer of the crystallized sugar and then the caramelization, which prevents wetting the surface by water transported in the form of liquid from inside the fruit.

The drying process of peach occurred in the falling rate period and is determined by internal conditions of heat and mass transfer. Full verification of the theoretical model requires conducting apart from the empirical verification, also the logical verification, for example the analysis and interpretation of physical numerical coefficients in the model, therefore work needs to be continued.

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