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COURSE PREDICTION OF DRYING CURVE OF PARSLEY ROOT PARTICLES UNDER CONDITIONS OF NATURAL CONVECTION

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The mathematical model describing the course of drying curve of single parsley root particles under conditions of natural convection was formulated on the basis of the general theory of heat and mass transfer laws. The course of the drying curve was described in two ways: using the linear model of the first drying period (without shrinkage) and then using the models of second drying period and the models of first drying period taking into account shrinkage and finally the models of second drying period. The second drying period was described in both cases by the same models which approximated the shape of dried particles as follows: infinite plane (slices cut crosswise and along the root, axial cylinder slices), finite cylinder (slices cut crosswise the root, axial cylinder slices), finite in two dimensions plane (bark rings), infinite cylinder (bark rings). The verification confirmed that the following mathematical models describe the course of drying curve with satisfactory accuracy: for crosswise and lengthwise slices and axial cylinder slices – the linear model or models with shrinkage in the first drying period and the model of infinite plane in the second drying period, for bark rings – the linear model or models with shrinkage in the first drying period and the model of finite plane in the second drying period. The values of relative error were not higher than: 1% for linear model, 4% for models with shrinkage, 29% for models of the infinite and finite plane drying. The results of modelling pointed out the need of the model formulation of moisture content changes in parsley root particles dried in transition period. The results obtained allowed the statement that parsley root can be regarded as an anisotropic and heterogeneous body.

NOTATION

A, A_0 – surface area of dried solid, initial surface area of dried solid, (m^2);
a, n – empirical coefficients, dimensionless;
c – specific heat, (J/(kg·K));
D – moisture diffusion coefficient, (m^2/s);
Fo_m – Fourier number;
k – initial drying rate, (s^{-1});
M_s – dry matter of solid, (kg);
Nu – Nusselt number;
R – characteristic dimension, (m);
r_w – latent heat of water vaporization, (J/kg);
t, t_A, t_a, t_{wb} – temperature, temperature of solid surface, temperature of drying air, wet-bulb temperature, (°C);
$U = \frac{u - u_e}{u_c - u_e}$ – dimensionless moisture content;
u, u_c, u_e, u_0 – moisture content of the dried solid, critical moisture content of the dried solid, equilibrium moisture content of the dried solid, initial moisture content of the dried solid, (kg H_2O/ kg d.m.);
V, V_0, V_s – volume of the dried solid, initial volume of the dried solid, volume of the dry matter, (m^3);
w, w_0 – moisture content of the dried solid, initial moisture content of the dried solid, (% w.b.);
α – heat transfer coefficient, (W/(m^2·K));
λ – thermal conductivity, (W/(m·K));
ρ_s – density of dry matter, (kg/m^3);
τ, τ_{II} – drying time, drying time in the first drying period, (s).

INTRODUCTION

A variety of dried products offerred on the market is possible due to the continuous development of the dehydration methods, which allow obtaining the final products of high nutritive and sensory quality [Sereno & Medeiros, 1990; Kompany *et al.*, 1993]. At present a great stress is laid on the optimization of the drying process. Hence, well verified mathematical drying models, which will enable the determination of optimum parameters of the process are necessary. It is necessary to apply bicriterial optimization, which enables not only reduction of used energy but also obtaining of dried products of good quality in the case of food products [Rosselló *et al.*, 1997]. Mathematical models also enable to control the process. They influence the efficiency of the process and improve dried material properties [Jayaraman & Das Gupta, 1992; Kiranoudis *et al.*, 1992].

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The complete theory of convective vegetable drying has not been formulated yet, though many authors undertook this task, for example Fortes and Okos [1980]. Publication written by Wanaanen *et al.* [1993], in which authors classified and analysed mathematical models of porous solids drying, can be useful for the formulation of the convection drying theory. Extensive literature review concerning the modelling of vegetable convection drying could be found in the work written by Górnicki [2000] and Kaleta and Górnicki [2002].

There are not many publications in the literature concerning convection drying of parsley. They mainly deal with very fragmentary research of drying process of parsley root or qualitative research [Bugrova, 1971; Daudin & Richard, 1982; Stehli *et al.*, 1988; Domagała *et al.*, 1996 a, b; Witrowa-Rajchert, 1999]. Publication concerning modelling of the convection drying process of parsley roots was not found in literature.

The aim of the study was to formulate the mathema-tical model (based on the general theory of mass and heat transfer laws) describing the course of the drying curve of single parsley root particles under conditions of natural convection.

MATERIAL AND METHODS

Cleaned parsley roots "Berlinian" were used in research. The following samples were examined: (i) parsley slices cut crosswise; (ii) parsley slices cut lengthwise; (iii) slices of parsley axial cylinder cut crosswise; (iv) ring of parsley root bark cut crosswise.

Thickness of parsley slices and rings was: 3, 6 and 9 mm. Temperatures of drying air were: 40, 50, 60, 70 and 80°C.

The following measurements were made under laboratory conditions: (i) moisture content changes of the examined samples during drying; (ii) temperature changes inside and on the surface of the examined samples during drying; (iii) volume changes of the examined samples during drying.

Details relative to measurement methodology could be found in the work written by Górnicki [2000] and Górnicki and Kaleta [2002].

MATHEMATICAL DESCRIPTION OF THE COURSE OF DRYING CURVE

General assumptions of the mathematical description of the course of drying curve. The drying process of parsley root particles was divided into two drying periods: the first one and the second one.

The course of drying curve of parsley root particles was described in two ways:

1. applying linear model of the first drying period (without shrinkage) followed by the models of the second drying period:

Such mathematical description means that the following assumptions were accepted: constant drying rate $du/d\tau$ occurred during the first drying period (that means acceptance of assumption that during this period shrinkage and connected with it change of the heat and mass transfer surface have a weak influence on the course of the process) and the temperature of the dried particle after preliminary heating reached almost constant value. Then the drying rate decreased during the second drying period and the temperature of dried particle increased reaching the temperature of the drying air at the end of the process. The criterion which was used for the division into the first and the second drying period was a drying rate and temperature of the dried particle.

2. applying the models of the first drying period taking into account drying shrinkage followed by the models of the second drying period:

Such a mathematical description of the drying process means that the following assumptions were taken into account: drying rate decreased at the beginning of the process very slightly during the first drying period (assumption of the drying shrinkage occurrence means that changes of the heat and mass transfer surface during drying were taken into consideration). At the end of this period, temperature of the dried particle increased rapidly. During the second drying period, the drying rate decreased and the temperature of the dried particle was approximately equal to the temperature of the drying air. Criterion of division into the first and the second drying period was the drying rate and the temperature of the dried particle.

The second drying period was described in both cases by the same models which approximated the shape of the dried particle to the following forms: infinite plane, finite plane, infinite cylinder, finite cylinder. The initial instant at which these models began to simulate the second drying period was however different in both cases, because the linear model of the first drying period described the process in the shorter period of time than the models with the drying shrinkage. In connection with this the moisture content regarded as a critical one was different for each particular model. Dimensions of the dried particles, that were changing under the influence of the drying shrinkage, were taken into consideration in the models of the second drying period. The water diffusion coefficient in parsley root particles was assumed to be changeable and dependent on moisture content and temperature of the particle during drying.

The first drying period. The course of the drying process at the first drying period is determined by the external conditions of mass transfer.

Models used in describing the first drying period are presented in Table 1. The linear model (1) was obtained by solving differential equation [Pabis, 1965; 1982]:

TABLE 1. The models of first drying period [Pabis, 1965, 1994; Murakowski, 1994].

The models of first drying period		Remarks
$u(\tau)=-k\tau+u_0$	(1)	the linear model
$u(\tau)=\frac{u_0}{a}\left[\left(1-\frac{ak\tau}{3u_0}\right)^3+a-1\right]$	(2)	the model of shrinkage is determined by formula: $\frac{V}{V_0}=a\frac{u}{u_0}+1-a$ (3)
$u(\tau)=\left[\frac{(2n-3)k\tau+3u_0}{3u_0^{2n/3}}\right]^{\frac{3}{3-2n}}$	(4)	the model of shrinkage is determined by formula: $\frac{V}{V_0}=\left(\frac{u}{u_0}\right)^n$ (5)

$$\frac{du}{d\tau} = -\frac{\alpha A_0}{M_s r_w}(t_a - t_A) = -k = \text{const} \quad (6)$$

with assumption:

$$t_A = t_{wb} \quad (7)$$

with initial condition $u(\tau=0)=u_0$ and with assumption that all parameters on the right side of the equation (6) are constant. On the other hand, the solution of equation (6), (if beforehand A was replaced by A_0, that means acceptance of assumption that the surface of dried body changes because of the shrinkage) with assumption (7), initial condition $u(\tau=0)=u_0$, equation:

$$\frac{A}{A_0} = \left(\frac{V}{V_0}\right)^{\frac{2}{3}} \quad (8)$$

and with the use of shrinkage model (3) or (5), are the models of the first drying period which take into account drying shrinkage (2) and (4), respectively. Equation (8) means that the constancy of the body shape during drying was taken into consideration. Such an assumption means that the dried body shrinks in three dimensions in the same degree.

The parameter k, which occurs in the models of the first drying period, determines the initial drying rate. The drying rate was evaluated using linear regression assuming that the equation (1) describes the function approximating four repetitions of the moisture contents measurement in the dried particles with the relative error not greater than 1%. The initial value of the drying rate determined that way was applied to all models of the first drying period (1, 2, and 4). It was assumed that the models describe drying kinetics correctly when values of the relative error of model (1) do not exceed 1%, and of models (2) and (4) do not exceed 4%. A decision was taken to increase the value of the relative error to 4% due to the nature of the course of the relative errors for models of the first period with drying shrinkage. At first, the relative error for these models reached negative value, afterwards it increased reaching zero value and then grew rapidly.

Parameters a and n occurring in the shrinkage models were chosen using Statistica program as parameters appearing in equations (models (3) and (5), respectively) approximating measurement points of volume changes of particles during drying.

The second drying period. It was described using the following form of the equation of the solid convection drying:

$$\frac{\partial u}{\partial \tau} = \nabla(D\nabla u) \quad (9)$$

TABLE 2. The models of second drying period [Łykov, 1968].

Forms by which particular kinds of dried particles were approached	The models of second drying periods, where $Fo_m = \frac{D(\tau - \tau_{II})}{R^2}$	Remarks
Infinite plane (slices cut crosswise the root, slices cut along the root, axial cylinder slices), Infinite cylinder (bark rings)	$U(\tau) = \frac{u(\tau) - u_e}{u_c - u_e} = \sum_{n=1}^{\infty} B_n \exp(-\mu_n^2 Fo_m)$ (10)	$B_n = \frac{2}{\mu_n^2}$, $\mu_n = (2n-1)\frac{\pi}{2}$, R – half of infinite plane thickness $B_n = \frac{4}{\mu_n^2}$, μ_n – root of Bessel's equation of first type and zero order, $J_0(\mu_n)=0$, R – radius of infinite cylinder
Finite cylinder (slices cut crosswise the root, axial cylinder slices)	$U(\tau) = \frac{u(\tau) - u_e}{u_c - u_e} = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} B_n B_m \exp[-(\mu_n^2 + \mu_m^2 K^2) Fo_m]$ (11)	$K = \frac{R}{L}$, $B_n = \frac{4}{\mu_n^2}$, μ_n – root of Bessel's equation of first type and zero order, $J_0(\mu_n)=0$, $B_m = \frac{2}{\mu_m^2}$, $\mu_m = (2m-1)\frac{\pi}{2}$, R – radius of cylinder, L – half of cylinder height
Finite (in two dimensions) plane (bark rings)	$U(\tau) = \frac{u(\tau) - u_e}{u_c - u_e} = \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} B_n B_m \exp[-(\mu_n^2 K_1^2 + \mu_m^2 K_2^2) Fo_m]$ (12)	$\frac{1}{R^2} = \frac{1}{R_1^2} + \frac{1}{R_2^2}$, $K_i = \frac{R}{R_i}$, (i=1; 2), $B_n = \frac{2}{\mu_n^2}$, $B_m = \frac{2}{\mu_m^2}$, $\mu_n = (2n-1)\frac{\pi}{2}$, $\mu_m = (2m-1)\frac{\pi}{2}$, R – equivalent dimension, R_1, R_2 – half of plane thickness

It could be accepted that the water movement inside the dried solid is only a diffusion movement in the convection drying process of agricultural products [Pabis, 1982].

The equations which model the second drying period were obtained taking into consideration the following simplifying assumptions in the equation (9): constant shape and volume of dried particle, constant value of the water diffusion coefficient, the same moisture content at any point of dried solid at the beginning of the second drying period and constant initial conditions of the first type. Equations applied to the description of the second drying period of parsley root particles and forms which approximated the shapes of the dried particles are presented in Table 2.

Knowledge of the value of the water diffusion coefficient was necessary for using models of the second drying period. On the basis of the assumed variability of dimensions of parsley root particles and variability of water diffusion coefficient during drying, the coefficient was determined applying the method of inverse problem [Jaros, 1993].

Equations (10, 11 and 12) in general form could be written as:

$$U(\tau) = \frac{u(\tau) - u_e}{u_c - u_e} = f_n(Fo_m) \quad (13)$$

where n=1, 2 ..., the Fourier number for mass transfer depends on the water diffusion coefficient, time and particle dimension:

$$Fo_m = \frac{D(\tau - \tau_{II})}{R^2} \quad (14)$$

Functions f_n (equation (13)) could be treated as continuous functions, which approximate the sums of series from respective equations (10, 11 and 12) [Jaros, 1993]. Therefore, it is possible to find functions f_n^{-1}, which are inverse to f_n:

$$Fo_m = f_n^{-1}(U(\tau)) = f_m(\tau) \quad (15)$$

Five terms of each series were taken into consideration during determination of the reduced moisture content U(τ) from the infinite series (10, 11 and 12). Functions approximating dependencies (13) were determined using the method of function "sticking" [Jaros, 1993]. The reduced moisture content can be made dependent on time if the values of the critical and equilibrium moisture contents are known. Fourier number was made dependent on reduced moisture content and consequently on duration of the drying process (15) and then using the dependence of Fourier number upon the water diffusion coefficient (14) the values of the coefficient were determined for given moisture content, temperature and particle dimension. Calculation results, for all forms with which dried particles were described, were approximated using statistical program Statistica to the often occurring in the literature expression (16) (*e.g.* [Parti & Dugmanics, 1990])

$$\frac{D}{R^2} = A \cdot \exp[-B/(273.15 + t)]\exp(C \cdot u) \quad (16)$$

where: A, B, C – constants.

The moisture content which occurs in the equation (16) changed its value from critical to equilibrium. Various critical moisture contents and various temperature values were considered depending on how the first drying period was modelled. When the first drying period was described using linear model, the temperature of the dried particles was determined from equation of the heat balance. When the first drying period was described using model with the drying shrinkage, then according to the assumptions, the temperature of the particle already at the beginning of the second drying period is similar to the temperature of the drying agent. Therefore, the temperature in equation (16) was treated as constant and equal to the temperature of the drying agent. Equivalent particle dimension was the dimension which determined the particle size in the second drying period. The quantity took into consideration the changes of the dimensions caused by the shrinkage during the drying process.

Equation of heat balance. Equation of heat balance of the dried solid heating [Pabis, 1982], after applying appropriate dependences and assuming, that the average value of the dried solid temperature does not differ in essential manner from the temperature value of the solid surface in the same moments of the process duration, obtains the following form:

$$c(u+1)\frac{dt}{d\tau} = -\frac{\alpha A}{\rho_s V_s}(t - t_a) + r_w \frac{du}{d\tau} \quad (17)$$

(appropriate transformations could be found in the work written by [Górnicki, 2000]).

The following dependences of specific heat of parsley root upon moisture content were used for solution of the differential equation:

$c = 1382 + 28.05w$, $0 \le w \le w_0$,
$20 \le t \le 90°C$ [Gromov, 1971] (18)

$c = 1373 + 28.14w$, $0 \le w \le w_0$,
$t = 20°C$ [Ginzburg & Gromov, 1987] (19)

Power shrinkage model (5) and expression (8) were used for determination of the surface area of dried solid presented in equation (17).

The heat transfer coefficient for all kinds of parsley root particles was determined using two methods: the linear model of the first drying period (6) and Nusselt number

$$\alpha = \frac{Nu \cdot \lambda}{L} \quad (20)$$

where: L – characteristic dimension.

General form of the dimensionless equation of the heat movement, for simultaneous heat and mass transfer, for natural convection is as follows:

$Nu = f(Ar, Pr)$, (21)

where: Ar – Archimedes number, Pr – Prandtl number.

Due to the lack of appropriate dimensionless equation for the investigated range of product (Ar·Pr), a decision was taken to apply dimensionless equation determined for heat movement only [Pohorecki & Wroński, 1977; Strumiłło, 1983]

$Nu = 0.54(Gr \cdot Pr)^{0.25}$, (22)
for $5 \times 10^2 < Gr \cdot Pr < 2 \times 10^7$

where: Gr – Grashof number.

Such a decision is often taken in practice. The expression du/dτ was obtained by differentiation of function u(τ) which approximates the results of four measurement repetitions of moisture content changes during drying.

The equation (17) was used for temperature modelling of parsley root particles during the second drying period, when the first drying period was described by the linear model. Simulation program CSSP was applied to solve the equation.

RESULTS

Mathematical models of the first and the second drying period were verified using experimental data. Values determined from the discussed models were compared to the values calculated from the function (empirical formula) approximating results of the four measurement repetitions of the moisture content changes in time.

Examples of drying curve approximation of crosswise cut slices (6 mm thick, dried at 60°C) by using the linear model of the first drying period and slices from the axial cylinder of parsley root (6 mm thick, dried at 50°C) by using models of the first drying period taking into account shrinkage and with models of the second drying period were presented in Figures 1 and 2. In the second period of drying, the slices discussed were described using infinite plane and with shape of finite cylinder.

Consistency verification of calculation results with empirical data were conducted using diagrams presenting moisture contents determined from the models as a function of moisture contents determined from empirical formula which is a function approximating results of the four measurement repetitions of the moisture content changes in time. Relative and absolute errors of drying curve approximation by using discussed models were also taken into account. Analysis of graphs obtained (Figures 1 and 2) shows that the results of calculations obtained from the discussed models are very well correlated with empirical data (correlation coefficient amounts to 0.99). The model of infinite plane drying approximates drying curve in the second period with slighty lower relative and absolute error.

Consistency of calculation results with empirical data for the remaining experimentally-obtained drying curves was verified in analogous way. The correlation between the data obtained from mathematical models and empirical data was high (the lowest correlation coefficient amounted to 0.95). Therefore it could be stated that both the linear model and two models with shrinkage approximate the drying curve in the first drying period well. Taking additionally into account relative and absolute error, it could be accepted that the model of infinite plane drying approximates the drying curve in the second drying period for crosswise and lengthwise cut slices of parsley root and slices from the axial cylinder a little more accurately. The model of finite plane

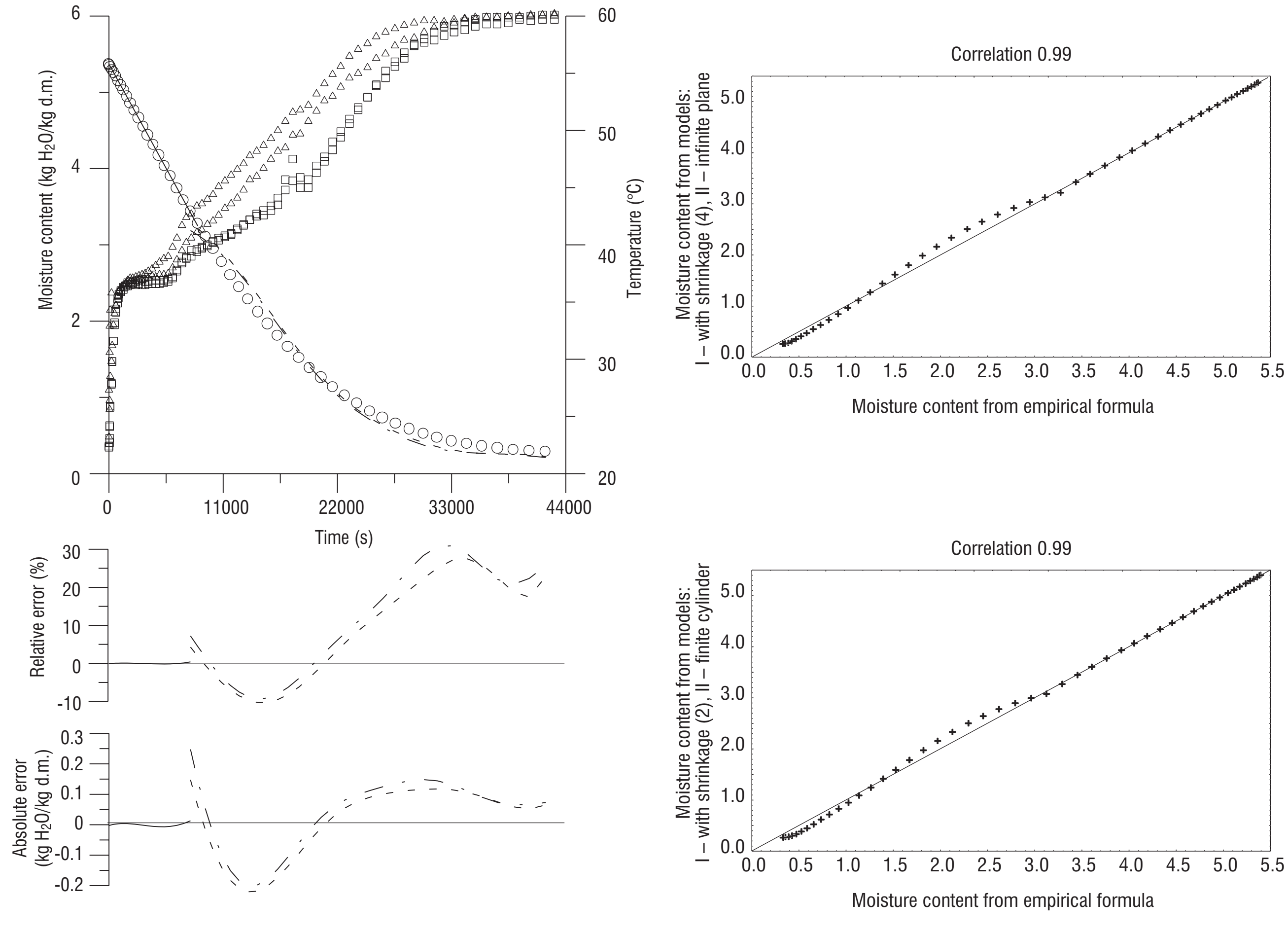

FIGURE 1. Approximation of drying curve for 6 mm thick crosswise cut parsley slices dried at 60°C; (○) – moisture content, (△) – temperature on the solid surface, (□) – temperature inside the solid, (——) – linear model of the first drying period (1), (- - -) – model of the second drying period (infinite plane (10)), (– - –) – model of the second drying period (finite cylinder (11)).

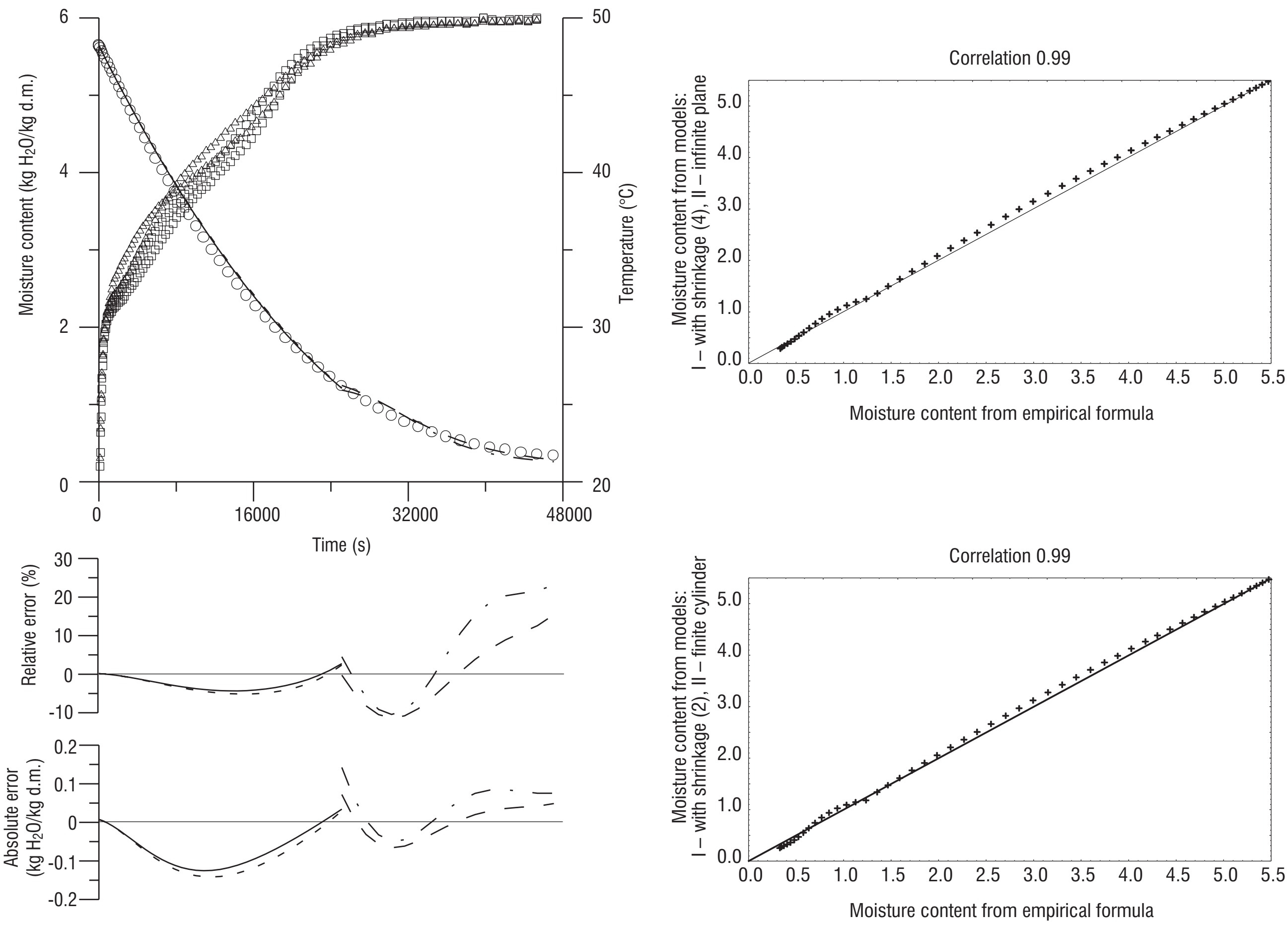

FIGURE 2. Approximation of drying curve for 6 mm thick slices from axial cylinder of parsley root dried at 50°C; (○) – moisture content, (△) – temperature on the solid surface, (□) – temperature inside the solid, (——) – model of the first drying period taking into account shrinkage (4), (– –) – model of the first drying period taking into account shrinkage (2), (— —) – model of the second drying period (infinite plane (10)), (—-—) – model of the second drying period (finite cylinder (11)).

drying was slightly better for bark rings when relative and absolute error were taken into account.

The maximum value of the local relative error of drying curve approximation by the models of second drying period amounted to 29%. This fact could be explained by very small values of moisture contents for which the error was calculated.

The values of parameter n applied in the model of the first drying period with shrinkage (4) are presented in Figure 3. For all kinds of particles, the values of the parameter increase with the decreasing temperature of drying air and depend on the kind of particle but not on particle thickness. Analogous dependences were obtained for the parameter a.

The following dependences were obtained as a results of mathematical modelling of drying curves of single parsley root particles under conditions of natural convection.

Initial drying rate of parsley root particles increases with the increasing temperature of drying air and with a decrease in particle thickness (well then with an increase in comminution degree) and depends on the kind of particle. The values of initial drying rate for axial cylinder slices are presented in Figure 4.

The critical moisture content which conventionally divides the first and the second drying period decreases with the increasing temperature of drying air and a decrease in particle thickness. Such a trend is caused by the above-discussed dependence of initial drying rate on the mentioned parameters. Critical moisture content depends also on the kind of parsley root particle. The values of critical moisture content for 3 mm thick different kinds of parsley root particle are presented in Figure 5.

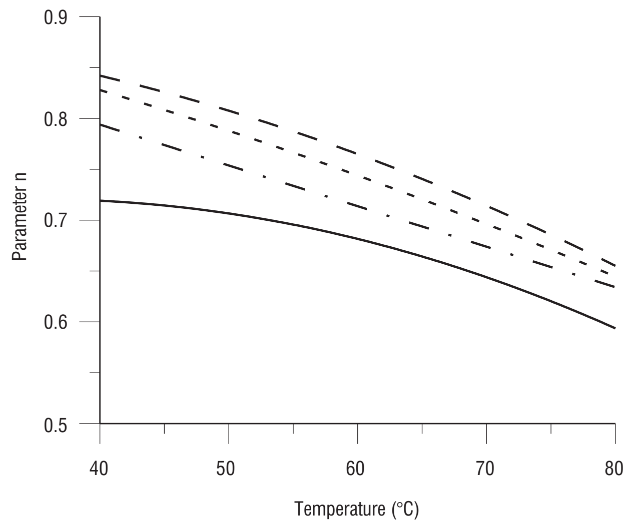

FIGURE 3. Parameter n in the model of shrinkage (5) for different parsley root particles dried at different temperatures; (——) – ring of bark, (- -) – axial cylinder slice, (— · —) – crosswise cut slice, (— —) – lengthwise cut slice.

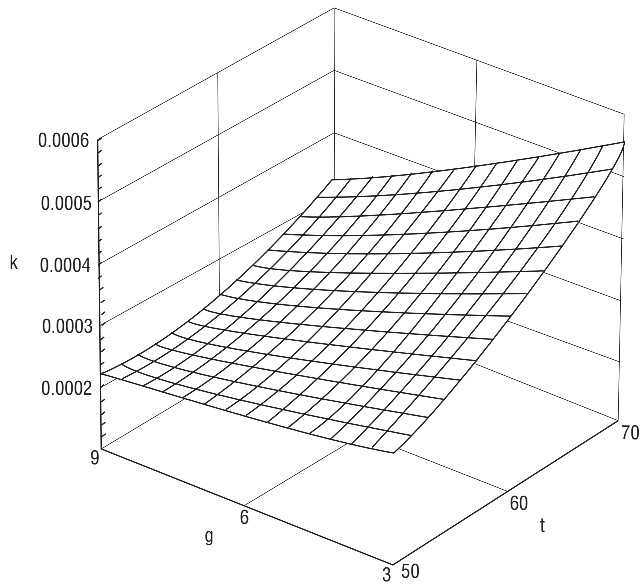

FIGURE 4. Initial drying rate for axial cylinder slices of parsley root as a function of slices thickness and drying temperature; k – initial drying rate, kg H_2O/(kg d.m.·s), g – thickness of slice, mm, t – temperature of drying air, °C.

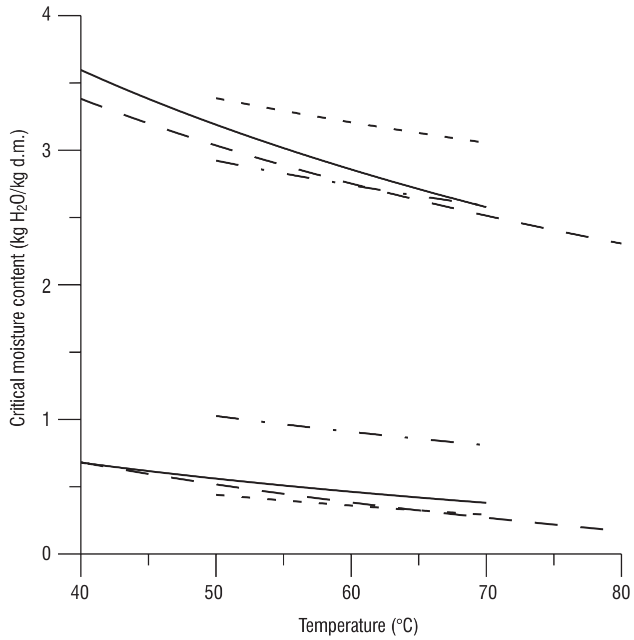

FIGURE 5. Critical moisture content for 3 mm thick (——) – crosswise cut slice, (- -) – axial cylinder slice, (— —) – lengthwise cut slice. (— · —) – ring of bark dried at different temperatures; thick lines – linear model (1), thinner lines – model with shrinkage (2).

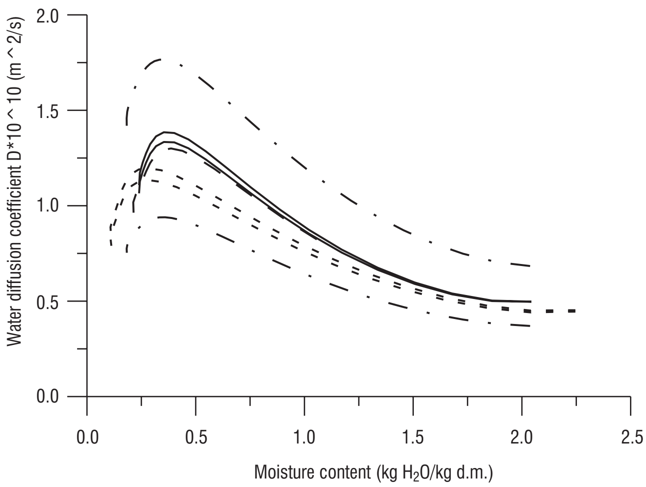

FIGURE 6. Water diffusion coefficient determined for 3 mm thick different parsley root particles approximated by different forms and dried at 60°C; (——) – crosswise cut slice (thick line – infinite plane, thinner line – finite cylinder), (- -) – axial cylinder slice (thick line – infinite plane, thinner line – finite cylinder), (— —) – lengthwise cut slice (infinite plane), (— · —) – ring of bark (thick line – finite plane, thinner line – infinite cylinder).

The values of water diffusion coefficient in the parsley root particles were determined in indirect way, that means, on the basis of mathematical model of drying in the second period. The coefficient depends on the temperature (of drying air and average temperature of particle), moisture content in the particle, kind of particle and also, by taking into account the shrinkage, on variable dimension of particle. Water diffusion coefficient increases with the increasing temperature of drying air. The following dependence of the discussed coefficient on the moisture content was obtained: for low moisture contents water diffusion coefficients increase with an increase in moisture content and after reaching the maximum the values of the coefficient decrease. Then when the moisture content approaches critical value, the water diffusion coefficient takes constant value. The dependence of the discussed coefficient on the kind of particle is presented in Figure 6. The above-discussed nature of changes of water diffusion coefficient with moisture content is caused by the fact that with a decrease in moisture content during drying, diffusion of water vapour begins to play a dominant part in water transport. Process of diffusion stops when moisture content in dried particle approaches zero. When the moisture content approaches critical value, the water diffusion coefficient takes constant value. That means that the process of diffusion takes place only in liquid phase.

The results of the modelling also point out the necessity of formulation of model of moisture content changes in dried parsley root particles for transition period in the subsequent research. Mechanisms of simultaneous external and internal mass transfer should be included in the model.

CONCLUSIONS

1. The obtained results of the research suggest that during the convective drying of the parsley root particles there is a period of time during which the conditions of external mass transfer determine course of the process. It is proved by the verified mathematical models of the first drying period:

– the linear model (1) with maximum relative error 1%,
– models with drying shrinkage (2) and (4) with maximum relative error 4%.

2. The results of the linear model (1) verification indicate that during the convective drying process of parsley root particles the period of constant drying rate takes place.

3. Verified models of the first drying period (2) and (4), taking into account drying shrinkage of parsley root particles, confirm that decreased drying rate during the first drying period could be caused by the shrinkage of drying

particles.

4. Model of infinite plane drying predicts well the course of drying curve in the second drying period for crosswise and lengthwise cut slices of parsley root and slices from the axial cylinder. Model of finite plane drying predicts well the course of drying curve in the second drying period for bark rings.

5. Results of modelling suggest the necessity of formulation of moisture content changes model in dried parsley root particles for transition period. Mechanisms of simultaneous external and internal mass transfer should be included in the model.

6. The results obtained allowed the statement that parsley root can be regarded as an anisotropic and heterogeneous body.

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PRZEWIDYWANIE PRZEBIEGU KRZYWEJ SUSZENIA CZĄSTEK KORZENI PIETRUSZKI W WARUNKACH KONWEKCJI NATURALNEJ

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Sformułowano matematyczny model opisujący przebieg krzywej suszenia pojedynczych cząstek korzeni pietruszki w warunkach konwekcji naturalnej, oparty na prawach ogólnej teorii wymiany ciepła i masy. Przebieg krzywej suszenia opisano w dwojaki sposób: modelem liniowym pierwszego okresu suszenia (bez uwzględnienia skurczu suszarniczego) a następnie modelami drugiego okresu suszenia, modelami pierwszego okresu suszenia uwzględniającymi skurcz suszarniczy a następnie modelami drugiego okresu suszenia. W modelach drugiego okresu suszenia przybliżano kształt suszonej cząstki następująco: nieograniczoną płytą (plaster krojony w poprzek i wzdłuż korzenia, plaster z walca osiowego), ograniczonym walcem (plaster krojony w poprzek korzenia, plaster z walca osiowego), ograniczoną w dwóch wymiarach płytą (pierścień z kory), nieograniczonym walcem (pierścień z kory). Na podstawie przeprowadzonej weryfikacji stwierdzono, że następujące matematyczne modele z zadowalającą dokładnością opisują przebieg krzywej suszenia pojedynczych cząstek korzeni pietruszki: dla plastrów poprzecznych i wzdłużnych oraz plastrów z walca osiowego – w pierwszym okresie suszenia model liniowy lub modele uwzględniające skurcz suszarniczy, w drugim okresie model suszenia płyty nieograniczonej, dla pierścieni z kory – w pierwszym okresie suszenia model liniowy lub modele uwzględniające skurcz suszarniczy, w drugim okresie model suszenia płyty ograniczonej (przykładowe rysunki 1 i 2). Błąd względny nie przekraczał: dla modelu liniowego 1%, dla modeli uwzględniających skurcz suszarniczy 4%, dla modelu suszenia płyty nieograniczonej i ograniczonej 29%. Zasugerowano, iż rezultaty modelowania wskazują na potrzebę sformułowania w dalszych badaniach modelu zmian zawartości wody w suszonych cząstkach korzeni pietruszki dla okresu przejściowego. Zależności uzyskane w wyniku matematycznego modelowania krzywych suszenia pojedynczych cząstek korzeni pietruszki w warunkach konwekcji naturalnej oraz modelowania skurczu suszarniczego tych cząstek przedstawiono na przykładowych rysunkach 3–6. Uzyskane wyniki dały podstawę do stwierdzenia, że korzeń pietruszki jest ciałem anizotropowym i heterogenicznym.