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COMPUTATION BY VISUAL FORTRAN OF POLINOMS, OBTAINED BY MEANS OF SOFTWARE PACKAGE TABLE CURVE 2D

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ABSTRACT

Polynomial equations, which describe the change in the processing air medium temperature T_m during freezing in a freezer and the subsequent defrosting of logs using a software package Table Curve 2D have been obtained. The equations are needed for computation of T_m in the boundary conditions of mathematical models of these processes in the calculation environment of Visual Fortran.

In the course of the work it was established that in the software of Visual Fortran there are constraints which cause a sharp deterioration of the accuracy of calculation of T_m when the polynomial equations contain members with a degree higher than 3.

Key words: temperature, processing air medium, freezing, defrosting, polynomial equation, Table Curve, Visual Fortran

1. INTRODUCTION

During the winter the logs prepared for veneer production are subjected to freezing and defrosting in natural air conditions.

It is known that the duration of thermal treatment of frozen logs aimed at their plasticizing, as well as the energy consumption needed for this treatment, depend on the degree of the logs' icing. It is also well known that the degree of the logs' icing depends on the changes in the temperature of the environmental air affecting them and on the duration of their stay in this environment (Sergovsky, 1975; Shubin, 1990; Trebula and Klement, 2002; Videlov, 2003; Deliiski, 2004, Hadjiski and Deliiski, 2016).

The degree of the logs' icing can be computed by means of mathematical models, which take into account a lot of peculiarities of the complex processes of freezing and defrosting of both free and bound water in the wood (Khattabi and Steinhagen, 1992, 1993, 1995; Deliiski, 2004, 2005, 2011; Deliiski and Dzurenda, 2010; Deliiski and Tumbarkova, 2018). In the boundary conditions of such models, equations for change in the temperature of the environmental air affecting the logs during these processes, $T_m = f(\tau)$ are applied.

The aim of this paper is to verify the accuracy of the solution (the answer) by Visual Fortran of the polynomial equations for $T_m = f(\tau)$, which are obtained by means of the software package Table Curve 2D.

2. EXPERIMENTAL RESEARCH OF CHANGE IN TEMPERATURE OF THE PROCESSING AIR MEDIUM DURING FREEZING AND DEFROSTING OF LOGS

Experimental research of beech logs' freezing in freezer and subsequent defrosting processes has been carried out. The logs subjected to such research were with a diameter of 240 mm and a length of

480 mm. Before the experiments, 4 holes with diameter of 6 mm and different length were drilled into each log.

Sensors with long cylindrical metal housings were positioned in these 4 holes for measuring the wood temperature during the experiments. The coordinates of the characteristic points of the logs were as follows (Deliiski and Tumbarkova, 2016):

Point 1: along the logs' radius r = 30 mm and along the log's length z = 120 mm;

Point 2: along the logs' radius r = 60 mm and along the log's length z = 120 mm;

Point 3: along the logs' radius r = 90 mm and along the log's length z = 180 mm;

Point 4: along the logs' radius r = 120 mm and along the log's length z = 240 mm.

For freezing of the logs a horizontal freezer was used with adjustable temperature range from –1 ^{o}C to –30 ^{o}C. Each log with temperature sensors in it was horizontally placed on a special stand in the open freezer at room temperature. After closing the freezer, it was switched on at full power and the temperature of the freezing air medium in it was lowered gradually until reaching approximately –30 ^{o}C.

The automatic measuring and recording of the temperature and humidity of the air processing medium in the freezer, t_m and φ_m respectively, as well as of the temperature t in the 4 characteristic points in logs during the experiments was carried out by means of Data Logger type HygroLog NT3 (Fig. 1–left) produced by the Swiss firm ROTRONIC AG (http:/www.rotronic.com). Recording of all data was performed automatically by Data Logger with intervals of 5 min. The Data Logger has software HW4 for graphical presentation of the measured data.

On the right-hand part of Fig. 1 is presented an example, the change in t_m, φ_m, and t in 4 characteristic points of a beech log with moisture content u = 0.55 kg·kg^{-1} during its 50 h freezing and 70 h subsequent defrosting.

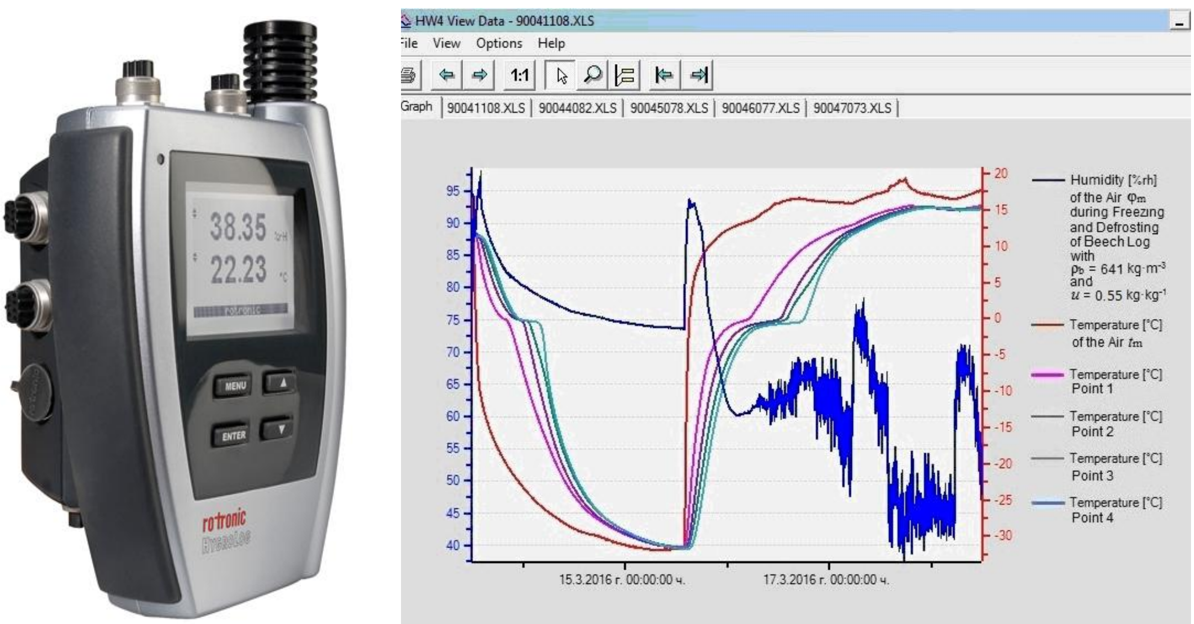

Figure 1. *Data Logger (left) and experimentally, with the Data Logger, determined change in t_m, φ_m, and t in 4 characteristic points of beech log with D = 0.24 m, L = 0.48 m, and u = 0.55 kg·kg^{-1} during 50 h freezing in a freezer and 70 h subsequent defrosting (right)*

3. USE OF SOFTWARE PACKAGE TABLE CURVE 2D FOR MATHEMATICAL DESCRIPTION OF T_m

For doing mathematical models of the logs' freezing and defrosting processes it is necessary to have a mathematical description of the change in the processing air medium temperatures during these processes, $T_{m\text{-}fr}$ and $T_{m\text{-}dfr}$, respectively. As it was pointed out above in the Introduction, in the boundary conditions of such models equations for $T_{m\text{-}fr} = f(\tau)$ and $T_{m\text{-}dfr} = f(\tau)$ are also used. Our research shows that the software package Table Curve 2D v.5.01 is particularly suitable for precise mathematical description (approximation) of experimentally determined complex curves of $T_{\text{m-fr}}$ and $T_{\text{m-dfr}}$ during the logs' freezing and defrosting.

The approximation process in this package is fully automated and it can be realized only in a single operation. Over 3600 equations are introduced in this package, which give the user the possibility quickly to find the most precise approximation for its 2D data.

The package (http://www.sigmaplot.co.uk/products/tablecurve2d/tablecurve2d.php) allows to select an equation which provides the best match between the calculated and experimentally established data. It calculates and draws a curve which most approximates the 2D experimental data.

4. RESULTS AND DISCUSSION

Equations for the change in $T_{\text{m-fr}}$ and $T_{\text{m-dfr}}$, obtained by Table Curve 2D

By means of Table Curve 2D, approximating equations for the change in $T_{\text{m-fr}}$ and $T_{\text{m-dfr}}$ during 50 h freezing in a freezer and subsequent 70 h defrosting of the beech logs were selected. The software suggested the following equations, which provide the best match between the calculated and experimentally established values of $T_{\text{m-fr}}$ and in $T_{\text{m-dfr}}$:

• for calculation of $T_{\text{m-fr}}$ for the studied (see Figure 1 – right) beech log:

$$T_{\text{m-fr}} = \frac{a_{\text{fr}} + c_{\text{fr}}\tau^{0.5}}{1 + b_{\text{fr}}\tau^{0.5} + d_{\text{fr}}\tau}, \qquad (1)$$

• for calculation of $T_{\text{m-dfr}}$ for the studied beech log:

$$T_{\text{m-dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\tau^{0.5} + c_{\text{dfr}}\tau + d_{\text{dfr}}\tau^{1.5} + e_{\text{dfr}}\tau^{2} + f_{\text{dfr}}\tau^{2.5} + g_{\text{dfr}}\tau^{3} + h_{\text{dfr}}\tau^{3.5} + i_{\text{dfr}}\tau^{4} + j_{\text{dfr}}\tau^{4.5} + k_{\text{dfr}}\tau^{5}. \qquad (2)$$

The cross-correlation coefficients between calculated and experimentally determined values, *r*, for $T_{\text{m-fr}}$ and for $T_{\text{m-dfr}}$ are very high and equal to 0.992 and 0.973 respectively. The Root Squared Mean Error, σ, for $T_{\text{m-fr}}$ and for $T_{\text{m-dfr}}$ is equal to 0.948 ^{o}C and 1.073 ^{o}C respectively.

Solving the obtained equations for $T_{\text{m-fr}}$ and $T_{\text{m-dfr}}$ by means of Visual FORTRAN

By means of a software program prepared by us, computations were carried out in the calculation environment of Visual Fortran for solving and verifying the 2D mathematical model of the logs' freezing and defrosting processes (Deliiski and Tumbarkova 2018). Equations (1) and (2) were included in the boundary conditions of the model.

There was no problem to calculate the boundary conditions of the model with participation of eq. (1) in them during freezing of the studied beech log. Unfortunately, our attempt for calculation of the boundary conditions of the model with participation in them of eq. (2) during defrosting of the same log after its freezing was unsuccessful.

The computations were broken automatically immediately after the outset of the calculations of $T_{\text{m-dfr}}$ and the software gave a message "Overfilled registers". With the purpose of overcoming this impediment, new calculations by means of Table Curve 2D were carried out aimed at obtaining simpler equations for $T_{\text{m-dfr}}$ in comparison to eq. (2), which could be solved by Visual Fortran.

In Table 1 the obtained polynomial equations for $T_{\text{m-dfr}}$ with 2.5, 3.0, 3.5, and 5.0$^{\text{th}}$ degree and the values of their *r* and σ are given. In row 4 of Table 1 equation (2) is given, which could not be solved by Visual Fortran. It can be seen from Table 1 that the decrement in the degree of the polynomial equation causes a decrease in *r* and an increase in σ.

Table 1. *Change in r and σ depending on the degree of the equations $T_{m\text{-}dfr} = f(\tau)$ at τ in s*

№	Kind of equation that describes the dependence $T_{\text{m-dfr}} = f(\tau)$	*r*	σ, K
1.	$T_{\text{m-dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\tau^{0.5} + c_{\text{dfr}}\tau + d_{\text{dfr}}\tau^{1.5} + e_{\text{dfr}}\tau^{2} + f_{\text{dfr}}\tau^{2.5}$	0.928	1.743
2.	$T_{\text{m-dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\tau^{0.5} + c_{\text{dfr}}\tau + d_{\text{dfr}}\tau^{1.5} + e_{\text{dfr}}\tau^{2} + f_{\text{dfr}}\tau^{2.5} + g_{\text{dfr}}\tau^{3}$	0.938	1.625
3.	$T_{\text{m-dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\tau^{0.5} + c_{\text{dfr}}\tau + d_{\text{dfr}}\tau^{1.5} + e_{\text{dfr}}\tau^{2} + f_{\text{dfr}}\tau^{2.5} + g_{\text{dfr}}\tau^{3} + h_{\text{dfr}}\tau^{3.5}$	0.971	1.123
4.	$T_{\text{m-dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\tau^{0.5} + c_{\text{dfr}}\tau + d_{\text{dfr}}\tau^{1.5} + e_{\text{dfr}}\tau^{2} + f_{\text{dfr}}\tau^{2.5} + g_{\text{dfr}}\tau^{3} + h_{\text{dfr}}\tau^{3.5} + i_{\text{dfr}}\tau^{4} + j_{\text{dfr}}\tau^{4.5} + k_{\text{dfr}}\tau^{5}$	0.973	1.073

Our further research showed that the boundary conditions of the model could be solved by Visual Fortran only with polynomial equation for $T_{\text{m-dfr}}$, whose degree is not higher than 3.

In Fig. 2 the experimentally established and calculated curves of $T_{\text{m-dfr}}$ according to equation $T_{\text{m-dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\tau^{0.5} + c_{\text{dfr}}\tau + d_{\text{dfr}}\tau^{1.5} + e_{\text{dfr}}\tau^{2} + f_{\text{dfr}}\tau^{2.5} + g_{\text{dfr}}\tau^{3}$ for the studied beech log are presented. In the figure the values of the coefficients of this equation are shown.

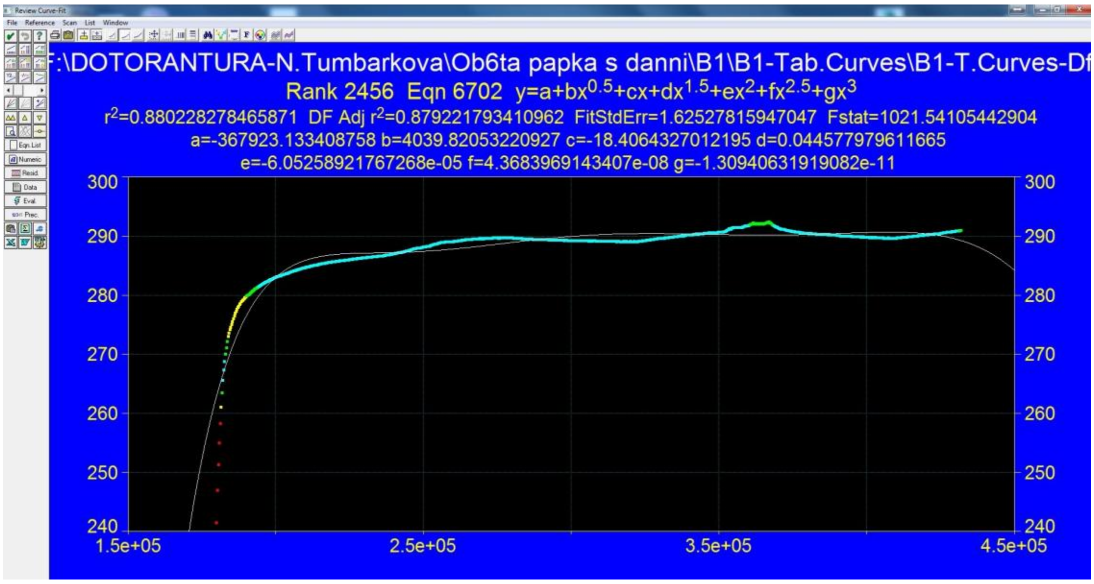

Figure 2. *Experimentally established (thick line) and calculated with an equation of 3rd degree (thin line) change in $T_{m\text{-}dfr} = f(\tau)$ when τ on the abscissa is expressed in seconds*

We tried to overcome the occurred problem related to the impossibility to solve by Visual Fortran equations which degree is higher than 3. For this purpose new polynomial equations for $T_{\text{m-dfr}} = f(\tau)$ by means of Table Curve were obtained, in which the time τ on the abscissa is expressed not in seconds, but in hours (Table 2) or in h/10 (Table 3).

In Figure 3 the experimentally established and the calculated curves of $T_{\text{m-dfr}}$ according to equation $T_{\text{m-dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{0.5} + c_{\text{dfr}}\left(\frac{\tau}{3600}\right) + d_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{1.5} + e_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2} + f_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2.5} + g_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{3}$ for the studied beech log are presented.

Table 2. *Change in r and σ depending on the degree of the equations $T_{m\text{-}dfr} = f(\tau)$ at τ in h*

№	Kind of equation that describes the dependence $T_{\text{m-dfr}} = f(\tau)$	r	σ, K
1.	$T_{\text{m}-\text{dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{0.5} + c_{\text{dfr}}\left(\frac{\tau}{3600}\right) + d_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{1.5} + e_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2} + f_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2.5}$	0.928	1.743
2.	$T_{\text{m}-\text{dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{0.5} + c_{\text{dfr}}\left(\frac{\tau}{3600}\right) + d_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{1.5} + e_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2} + f_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2.5} + g_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{3}$	0.938	1.625
3.	$T_{\text{m}-\text{dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{0.5} + c_{\text{dfr}}\left(\frac{\tau}{3600}\right) + d_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{1.5} + e_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2} + f_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2.5} + g_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{3} + h_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{3.5}$	0.968	1.181
4.	$T_{\text{m}-\text{dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{0.5} + c_{\text{dfr}}\left(\frac{\tau}{3600}\right) + d_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{1.5} + e_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2} + f_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{2.5} + g_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{3} + h_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{3.5} + i_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{4} + j_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{4.5} + k_{\text{dfr}}\left(\frac{\tau}{3600}\right)^{5}$	0.977	0.997

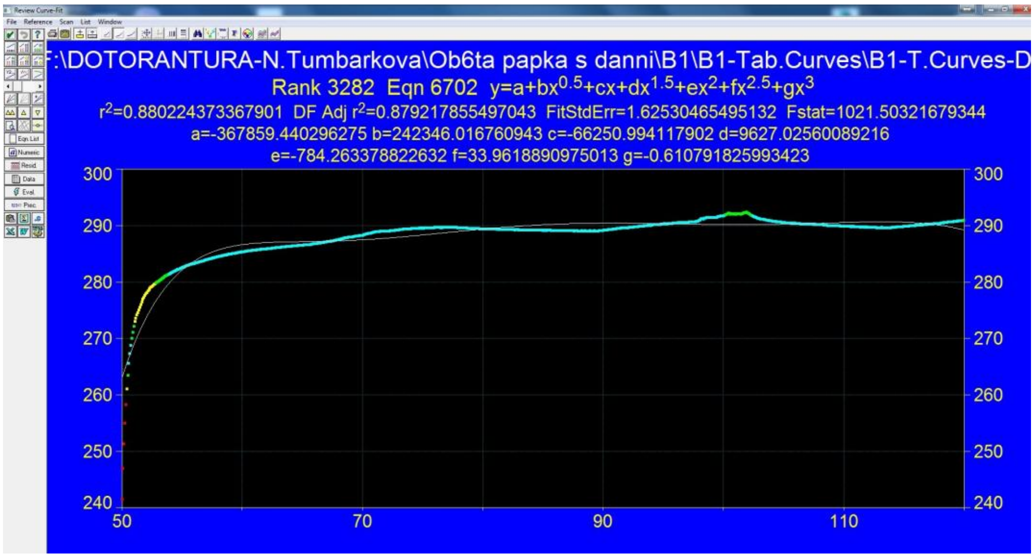

Figure 3. *Experimentally established (thick line) and calculated with an equation of 3rd degree (thin line) change in $T_{m\text{-}dfr} = f(\tau)$ when τ on the abscissa is expressed in hours*

In Figure 4 the experimentally established and the calculated curves of $T_{\text{m-dfr}}$ according to $T_{\text{m}-\text{dfr}} = a_{\text{dfr}} + b_{\text{dfr}}\left(\frac{\tau}{36000}\right)^{0.5} + c_{\text{dfr}}\left(\frac{\tau}{36000}\right) + d_{\text{dfr}}\left(\frac{\tau}{36000}\right)^{1.5} + e_{\text{dfr}}\left(\frac{\tau}{36000}\right)^{2} + f_{\text{dfr}}\left(\frac{\tau}{36000}\right)^{2.5} + g_{\text{dfr}}\left(\frac{\tau}{36000}\right)^{3}$ for the studied beech log are presented.

Table 3. *Change in r and σ depending on the degree of the equations $T_{m\text{-}dfr} = f(\tau)$ at τ in h/10*

№	Kind of equation that describes the dependence $T_{m\text{-}dfr} = f(\tau)$	*r*	σ, °C
1.	$T_{m-dfr} = a_{dfr} + b_{dfr}\left(\frac{\tau}{36000}\right)^{0.5} + c_{dfr}\left(\frac{\tau}{36000}\right) + d_{dfr}\left(\frac{\tau}{36000}\right)^{1.5} + e_{dfr}\left(\frac{\tau}{36000}\right)^{2} + f_{dfr}\left(\frac{\tau}{36000}\right)^{2.5}$	0.928	1.743
2.	$T_{m-dfr} = a_{dfr} + b_{dfr}\left(\frac{\tau}{36000}\right)^{0.5} + c_{dfr}\left(\frac{\tau}{36000}\right) + d_{dfr}\left(\frac{\tau}{36000}\right)^{1.5} + e_{dfr}\left(\frac{\tau}{36000}\right)^{2} + f_{dfr}\left(\frac{\tau}{36000}\right)^{2.5} + g_{dfr}\left(\frac{\tau}{36000}\right)^{3}$	0.938	1.625
3.	$T_{m-dfr} = a_{dfr} + b_{dfr}\left(\frac{\tau}{36000}\right)^{0.5} + c_{dfr}\left(\frac{\tau}{36000}\right) + d_{dfr}\left(\frac{\tau}{36000}\right)^{1.5} + e_{dfr}\left(\frac{\tau}{36000}\right)^{2} + f_{dfr}\left(\frac{\tau}{36000}\right)^{2.5} + g_{dfr}\left(\frac{\tau}{36000}\right)^{3} + h_{dfr}\left(\frac{\tau}{36000}\right)^{3.5}$	0.968	1.183
4.	$T_{m-dfr} = a_{dfr} + b_{dfr}\left(\frac{\tau}{36000}\right)^{0.5} + c_{dfr}\left(\frac{\tau}{36000}\right) + d_{dfr}\left(\frac{\tau}{36000}\right)^{1.5} + e_{dfr}\left(\frac{\tau}{36000}\right)^{2} + f_{dfr}\left(\frac{\tau}{36000}\right)^{2.5} + g_{dfr}\left(\frac{\tau}{36000}\right)^{3} + h_{dfr}\left(\frac{\tau}{36000}\right)^{3.5} + i_{dfr}\left(\frac{\tau}{36000}\right)^{4} + j_{dfr}\left(\frac{\tau}{36000}\right)^{4.5} + k_{dfr}\left(\frac{\tau}{36000}\right)^{5}$	0.978	0.995

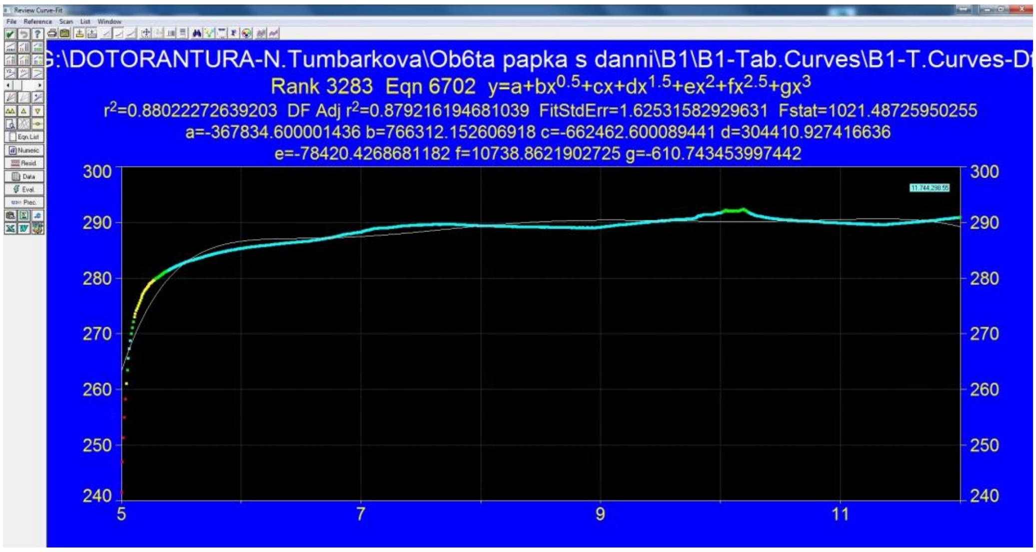

Figure. 4. *Experimentally established (thick line) and calculated with an equation of 3rd degree (thin line) change in $T_{m\text{-}dfr} = f(\tau)$ when τ on the abscissa is expressed in h/10*

It can be seen from Table 1, Table 2, and Table 3 that the chosen by Table Curve 2D polynomial equations of 3rd degree, whose coefficients are given in the upper part of Figure 2, Figure 3, and Figure 4 respectively, provide good enough match (r = 0.938 and σ = 1.625 °C) between the calculated and experimentally established data for $T_{\text{m-dfr}}$. The possibility that these equations can be successfully solved in the calculation environment of Visual Fortran allows using them in boundary conditions of the mathematical model of logs' defrosting process, whose 2D solution is obtained in this environment.

5. CONCLUSIONS

This paper addresses application of the software package Table Curve 2D v.5.01 for approximation (mathematical description) of change in temperature of the processing air medium temperature during freezing in a freezer and subsequent defrosting of logs. This package allows for the selection of equations, which provide the best similarity between the values calculated with them and the respective experimentally established 2D data.

By means of Table Curve 2D one polynomial equation for mathematical description of the experimentally established decreasing of the temperature $T_{\text{m-fr}}$ in the range from about 15 ^{o}C to about –30 ^{o}C during 50 h freezing in a freezer of a beech log with diameter of 240 mm, length of 480 mm, and moisture content of 35 % was selected, and its coefficients were determined. This equation is of 1st degree and it has r = 0.992 and σ = 0.948 ^{o}C. It was successfully solved by Visual Fortran as part of the boundary conditions of an own 2D model of logs' freezing process.

By means of the same software package of Table Curve 2D one polynomial equation for approximation of the experimentally established increasing of the temperature $T_{\text{m-dfr}}$ in the range from about –30 ^{o}C to about 20 ^{o}C during subsequent 70 h defrosting of the frozen beech log was selected and its coefficients were determined. This equation is of 5th degree and it has r = 0.938 and σ = 1.073 ^{o}C.

Because of existing constraints in the software of Visual Fortran, this equation could not be solved as part of the boundary conditions of an own 2D model of the logs' defrosting process. Trying to overcome the occurred problem, with impossibility to solve it by Visual Fortran equation of 5th degree, we established that by means of Visual Fortran it is possible to solve only polynomial equations whose degree is not higher than 3.

The equation of 3rd degree, obtained by Table Curve 2D, for approximation of the experimentally established change in $T_{\text{m-dfr}}$ has r = 0.973 and σ = 1.625 ^{o}C. This equation can be successfully solved in the calculation environment of Visual Fortran as part of the boundary conditions of the mathematical model of logs' defrosting process, whose 2D solution is obtained in this environment.

Symbols

D	-	diameter (m)
L	-	length (m)
r	-	radial coordinate ($0 \le r \le R$) or correlation coefficient
t	-	temperature (^{o}C): $t = T - 273.15$
T	-	temperature (K): $T = t + 273.15$
u	-	wood moisture content (kg·kg^{-1}): $u = W/100$
W	-	moisture content (%): $W = 100u$
z	-	longitudinal coordinate
σ	-	Root Squared Mean Error (K or ^{o}C)
ρ	-	density (kg·m^{-3})
τ	-	time (s)

Subscripts and superscripts:

b	-	basic (for wood density, based on dry mass divided by green volume)
dfr	-	defrosting
fr	-	freezing

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