



COMPUTATION OF THE TEMPERATURE FIELD IN BEECH LOGS SUBJECTED TO DEFROSTING USING THE SOFTWARE PACKAGE ANSYS WORKBENCH 16.0

Natalia Tumbarkova – Nencho Deliiski

Abstract

An approach for the computation of the temperature field in subjected to defrosting logs with the help of software package ANSYS Workbench 16.0 has been suggested. The sequence of actions and commands for the simulation of the logs' defrosting process in the working environment of this package are given.

The first results from ANSYS' calculation of the non-stationary temperature distribution in 4 characteristic points of the longitudinal section of a beech log with a diameter of 0.24 m, length of 0.48 m, moisture content of 0.63 kg·kg⁻¹, and initial temperature –28.8 °C during its 50 h defrosting at room temperature are graphically presented and analyzed. The root square mean error between the calculated and experimentally established temperature field of the studied log has been determined.

Key words: *beech logs, defrosting, ANSYS, computation, temperature field*

INTRODUCTION

The abbreviation ANSYS comes from the expression “Analysis SYStem” (<https://en.wikipedia.org/wiki/Ansys>). It presents a software package for the analysis based on the method of finite elements, developed by the firm “Ansys Inc.” (USA). The software package ANSYS is used mainly for the solution of linear and non-linear equations from the mechanics of solid bodies, mechanics of fluids, acoustics, thermodynamics, and problems connected to the electromagnetic and piezoelectric properties of the materials and others.

When studying the processes of thermal treatment of wood materials, it is necessary to determine the change in the temperature of materials depending on the temperature of the influencing medium and on the duration of staying in this medium. Our comprehensive study shows that the software package ANSYS so far has not been used for the simulation of processes of freezing or/and defrosting of any kind of wood materials, including logs.

The aim of the present work is to suggest an approach for use of ANSYS Workbench 16.0 for the computation of the temperature field in subjected to defrosting logs.

MATERIAL AND METHODS

Commands in ANSYS for preparation of simulations of defrosting process

The preparation of the simulation for the logs' defrosting process in the calculation environment of ANSYS consists of the following sequence of actions and commands:

- a. Creation of a working file in ANSYS and input of a suitable for the aim name:

File ⇒ **New**;

- b. Choice of the type of the subjected to studying process – in this case unsteady thermal conductivity: **Toolbox** ⇒ **Transient Thermal**. This is carried out by dragging in the neighboring right window or by double clicking on the type of studied process in the right dialogue window;

- c. By double clicking on the option **Engineering Data** a new window is opened, in which the type and main properties of the studied process are input. In our case we input **Wood** and after that in the tables under this input the thermo-physical characteristics of the studied process are input: **Density**, **Thermal conductivity**, and **Specific heat capacity**. The dimensions of all variables are input into the system SI. The values of the thermal conductivity and the specific heat capacity of the materials are input separately for the separate temperature ranges of the logs' freezing process.

- d. After inputting of the main thermo-physical characteristics of the material, it is necessary to return to the main window by double clicking on the third position **Geometry** in the main menu. There a 3D graph of the model, which is being studied, is created (*Figure 3*). In our case this is $\frac{1}{4}$ of the longitudinal section of the log because of the circumstance that this $\frac{1}{4}$ is mirror symmetrical towards the remaining $\frac{3}{4}$ of the same section.

- e. The next step is a creation of the calculation mesh on the log using the command **Model** ⇒ **Mesh** in the main menu. In the window, which appeared, the type of mesh and the size of its separate components are input. In our case the change of the temperature in the longitudinal section of beech logs with a diameter of 0.24 m and length of 0.48 m is studied. That is why a rectangular mesh with a step $\Delta x = 15$ mm along the space coordinates is input. The number of knots of the mesh along the radial coordinate is equal to 9, and along the longitudinal coordinate it is equal to 17, i.e. the total amount of the knots of the used calculation mesh is equal to $N_{\text{total}} = 9 \times 17 = 153$.

- f. Using the command **Setup** in the main menu, the following parameters of the studied log are input: initial temperature of the log, duration of the freezing process, time interval by which the freezing process has been monitored during experimental research (using this interval, the change in temperature in the characteristic points of the log will be calculated), dimensions (diameter and length) of the log, heat transfer coefficients in the radial α_{wr} and longitudinal α_{wp} directions of the wood fibers, and values of the temperature of the freezing air medium t_m at each moment of the process divisible by the input time interval. Input of the values of α_{wr} , α_{wp} and t_m is carried out by filling in their values in the table, which is situated in the lower right corner of the program menu of ANSYS.

- g. After completing the described steps above, using the command **Solution**, the calculation of the temperature distribution in the longitudinal section of the subjected to freezing log is started. For this aim, in the opened dialogue window, the command **Solve** is selected and this way the calculation begins.

- h. After the program finishes the calculations, by clicking on each of the points **Temperature T1**, **T2**, **T3**, and **T4** (see *Fig. 3*) data are obtained about the values of the temperature in each of the 4 characteristic points of the longitudinal section of the log during the simulation of its defrosting. Taking the calculated data with the aim of its

subsequent graphical presentation in MS Excel is carried out by pressing the right button of the mouse and selecting the command **Export**, following which the type, name and place for saving the file need to be given.

Experimental research of the temperature distribution in subjected to defrosting logs

For the assessment of the solutions, which are obtained in the calculation environment of ANSYS, we needed experimentally obtained data about the change of the temperature field in logs during their defrosting. That is why we carried out such experiments. The logs subjected to experimental research were with a diameter $D = 240$ mm, length $L = 480$ mm, and moisture content u above the hygroscopic range. They were produced from a freshly felled beech trunk. Before the experiments, 4 holes with diameters of 6 mm and different lengths were drilled into each log. Sensors with long metal casings were positioned in these 4 holes for the measurement of the wood temperature during the experiments. The coordinates of the characteristic points of the logs are, as follows: Point 1: along the radius $r = 30$ mm and along the length $z = 120$ mm; Point 2: with $r = 60$ mm and $z = 120$ mm; Point 3: with $r = 90$ mm and $z = 180$ mm and Point 4: with $r = 120$ mm and $z = 240$ mm (center of the log). These coordinates of the points allow to cover the impact of the heat fluxes simultaneously in the radial and longitudinal directions on the temperature distribution in logs during their freezing and subsequent defrosting (Deliiski – Tumbarkova 2016). Each log with temperature sensors in it was horizontally situated on a special stand in the open freezer at room temperature. After the closing of the freezer it was switched on at full power and the temperature of the freezing air medium in it was lowered gradually during 50 h until reaching approximately -30 °C. After that the freezer was opened and the studied by us 50 h defrosting process of the frozen log at room temperature started.

The automatic measurement and record of the temperature and humidity of the air processing medium and also of the temperature in the 4 points in logs during the experiments was carried out with the help of Data Logger type HygroLog NT3 produced by the Swiss firm ROTRONIC AG (<http://www.rotronic.com>). On Fig. 1, as an example, the change in the temperature of the defrosting air medium, t_m and in its humidity, φ_m , and also in the temperature in the 4 characteristic points of beech log with moisture content $u = 0.63$ kg·kg⁻¹ and basic density $\rho_b = 684$ kg·m⁻³ during its 50 h defrosting, is presented.

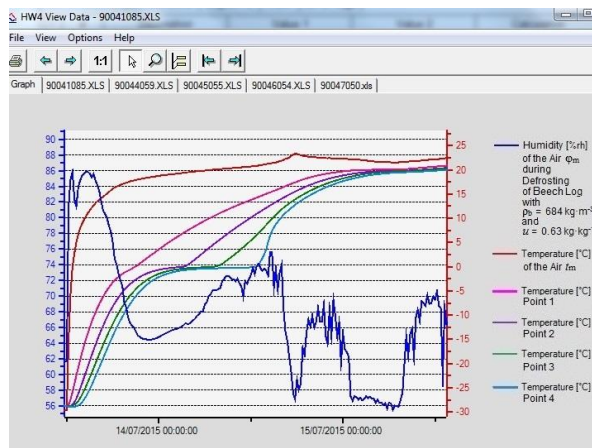


Fig. 1. Experimentally determined change in t_m , φ_m , and t in 4 points of the studied beech log during its 50 h defrosting

Determination of the values of the thermo-physical characteristics of logs needed for computations with ANSYS

On Fig. 2 the three temperature ranges are shown, at which the process of the logs' defrosting above the hygroscopic range can be defragmented. There also the thermo-physical characteristics of the wood and of the frozen water in it have been shown. The values of these characteristics are needed for the computation with ANSYS of the temperature field in subjected to defrosting logs.

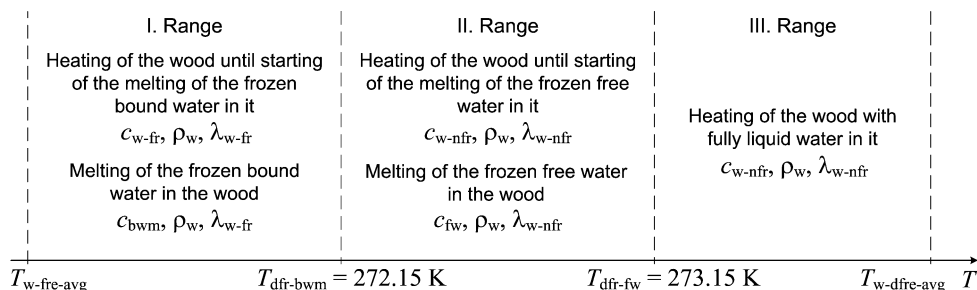


Fig. 2. Temperature ranges of the logs' defrosting process above the hygroscopic range and thermo-physical characteristics of the wood and the frozen water in it

During the first range from the average mass temperature of the log at the end of its freezing, $T_{w-fre-avg}$, to the temperature $T_{dfr-bwm} = 272.15 \text{ K}$ heating of the frozen wood occurs until reaching of its state needed for starting of the melting of the frozen bound water in it. In this range also the phase transition of this water into liquid state is carried out.

During the second range from $T_{dfr-bwm}$ to $T_{dfr-fw} = 273.15 \text{ K}$ a further heating of the log occurs until reaching of the state needed for starting of the melting of the frozen free water in it. In this range also the phase transition of this water into liquid state is performed.

During the third range from T_{dfr-fw} to the average mass temperature of the log at the end of its defrosting, $T_{w-dfre-avg}$, a heating of the log with fully liquid water in it occurs.

For the computation of the temperature field in subjected to defrosting logs using ANSYS it is needed to have average values of their thermal conductivity, λ_w , effective specific heat capacity, c_{we} , density, ρ_w , and of the heat transfer coefficients of the logs' surfaces, α_r and α_p . Such values can be obtained with the help of mathematical descriptions of the mentioned variables for the separate ranges of the logs' defrosting process. The values of λ_w , c_{we} , α_r , and α_p of the studied log have been determined using their mathematical descriptions given in (Deliiski 2011). The change of these variables during the 50 h log's defrosting has been calculated using software in Visual Fortran synchronously with the solving of an own non-linear mathematical model of the logs' defrosting process at the same initial and convective boundary conditions, as those during the experiment.

Average values of the thermal conductivities of the studied beech log

A mathematical description of the thermal conductivity, λ_w , of non-frozen and frozen wood has been suggested in (Deliiski 2013) using an experimentally obtained dissertations' data from other authors for the change of this conductivity as a function of t and u . Using the data calculated with Visual Fortran, the following average values of λ_{wr} and λ_{wp} for the separate ranges of the log's defrosting process have been determined:

- I. range: $\lambda_{wr1} = 0.646 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, $\lambda_{wp1} = 1.151 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$;
- II. range: $\lambda_{wr2} = 0.548 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, $\lambda_{wp2} = 0.975 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$;
- III. range: $\lambda_{wr3} = 0.559 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$, $\lambda_{wp3} = 0.996 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$.

Average values of the effective specific heat capacities of the studied beech log

The effective specific heat capacities of the logs' wood, c_{we} , during the shown on Fig. 2 three ranges of the defrosting process above the hygroscopic range are equal to:

$$c_{we1} = c_{w-fr} + c_{bwm} \text{ during the I. temperature range of the defrosting,} \quad (1)$$

$$c_{we2} = c_{w-nfr} + c_{fw} \text{ during the II. temperature range of the defrosting,} \quad (2)$$

$$c_{we3} = c_{w-nfr} \text{ during the III. temperature range of the defrosting.} \quad (3)$$

Using the mathematical descriptions of the separate specific heat capacities, which participate in the right parts of eqs. (1), (2), and (3), given in (Deliiski 2011, 2013) the following summarized expressions for c_{we1} , c_{we2} , and c_{we3} have been obtained:

- I. range: $c_{we1} = 2086 + 747 = 2833 \text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$;
- II. range: $c_{we2} = 2684 + 61267 = 63951 \text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$;
- III. range: $c_{we3} = 2738 \text{ J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$.

Average values of the heat transfer coefficients of the studied beech log

Our study has shown that for the calculation of the convective boundary conditions of the logs' defrosting process the following equations for the computation of the heat transfer coefficients of the logs are most suitable (Telegin *et al.* 2002):

- in the radial direction on the cylindrical surface of the horizontally situated logs:

$$\alpha_{wr} = 2.56[T(0, z, \tau) - T_{m-fr}(\tau)]^{E_{dfr}}, \quad (4)$$

- in the longitudinal direction on the frontal surface of the logs:

$$\alpha_{wp} = 1.123[T(r, 0, \tau) - T_{m-fr}(\tau)]^{E_{dfr}}, \quad (5)$$

where E_{dfr} is an exponent, whose values are determined during the solving and validation of our non-linear mathematical model of the logs' defrosting process through minimization of the root square mean error (*RSME*) between the calculated by the model and experimentally obtained results about the change of the temperature fields in subjected to defrosting logs.

For the computation of the temperature field in subjected to defrosting beech log with ANSYS, calculated in Visual Fortran values of α_{wr} and α_{wp} have been used as input data. These values have been calculated with an interval of 60 s synchronously with the solving of an own mathematical model of the logs' defrosting process.

Value of the wood density of the studied beech log

The wood density of the logs, ρ_w , is determined above the hygroscopic range according to the equation (Chudinov 1966, Shubin 1990, Trebula – Klement 2002, Videlov 2003, Deliiski – Dzurenda 2010, Steinhagen 1991):

$$\rho_w = \rho_b \cdot (1 + u). \quad (6)$$

Using eq. (6), the wood density of the studied beech log with basic density $\rho_b = 684 \text{ kg}\cdot\text{m}^{-3}$ and moisture content $u = 0.63 \text{ kg}\cdot\text{kg}^{-1}$ turned out to be equal to $1115 \text{ kg}\cdot\text{m}^{-3}$.

Values of the temperature of the air medium near the log during its defrosting

The curvilinear change in the shown on Fig. 1 defrosting air medium temperature, T_m , with high accuracy (correlation of 0.99 and $RSME$ of 1.49 °C has been approximated with the help of the software package Table Curve 2D (<http://www.sigmaplot.co.uk/products/tablecurve2d/tablecurve2d.php>) by the following equation:

$$T_m = \frac{a_{dfr} + c_{dfr}\tau^{0.5}}{1 + b_{dfr}\tau^{0.5}}, \quad (7)$$

whose coefficients are equal to: $a_{dfr} = 297.1420433$, $b_{dfr} = -0.00237763$, $c_{dfr} = -0.70526837$.

The calculated values of T_m according to eq. (7) with time step $\Delta\tau = 60$ s have been used as input data in the boundary condition for the computation of the temperature field in subjected to defrosting beech log using ANSYS.

RESULTS AND DISCUSSION

The above described approach was used for the calculation of the non-stationary temperature field in subjected to defrosting beech log using ANSYS. On Fig. 3 the calculation mesh on $\frac{1}{4}$ of the longitudinal section of the subjected to defrosting log and also the positioning of the 4 characteristic points T1, T2, T3, and T4 in it is presented.

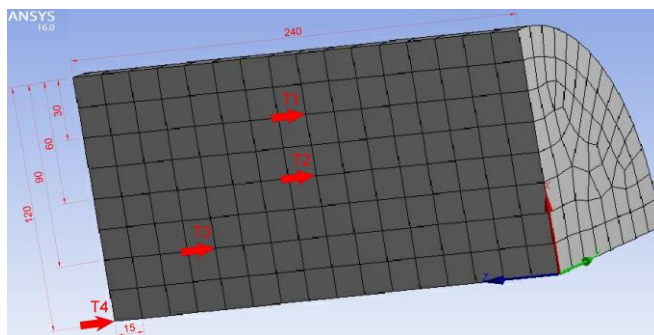


Fig. 3. Calculation mesh on $\frac{1}{4}$ of the longitudinal section of the subjected to defrosting log

Using this mesh, we have carried out some simulations in ANSYS aimed at computation of the temperature distribution in the longitudinal section of the studied beech log during its 50 h defrosting applying different combinations of the input data.

The first simulation has been made with the following combination of the input data:

- average constant values of the thermal conductivities and of the specific heat capacities of the log, which have been determined above for the separate 3 temperature ranges of the defrosting process (refer to Fig. 2);
- constant value of the wood density of $1115 \text{ kg}\cdot\text{m}^{-3}$;
- current variable values of the heat transfer coefficients, which have been calculated with an interval of 60 s according to eqs. (4) and (5) using an exponent $E_{dfr} = 0.32$ in them;
- current variable values of the defrosting air medium temperature, which has been calculated according to eq. (7) with an interval of 60 s.

The change of the temperature, which has been computed with this input data, turned out to be much slower than the experimentally determined change, which is shown on Fig. 1. Because of this, the calculated value of $RSME$ was unacceptably large and equal to 15.88 °C. Our study has shown that the main reason for such a large value of $RSME$ are the relatively small values of the heat transfer coefficients of the log during its defrosting, especially during the second and third temperature ranges. That is why we tried to simulate the studied defrosting process using obtained with Visual Fortran maximal values of the log's heat transfer coefficients $\alpha_{wr} = 6.62 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ and $\alpha_{wp} = 2.98 \text{ W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$ during the entire process and leaving unchanged the other input data.

On Fig. 4 the calculated in this simulation and the experimentally established temperature fields in subjected to defrosting beech log, and also the change of the log's surface temperature, t_s , and air defrosting medium temperature, t_m , are given.

The comparison to each other of the analogical curves on Fig. 4 show good enough qualitative and quantitative conformity between the calculated and experimentally determined changes in the very complicated temperature field of the log during its defrosting. This is proven by the relatively small value of $RSME$, equal of 2.64 °C.

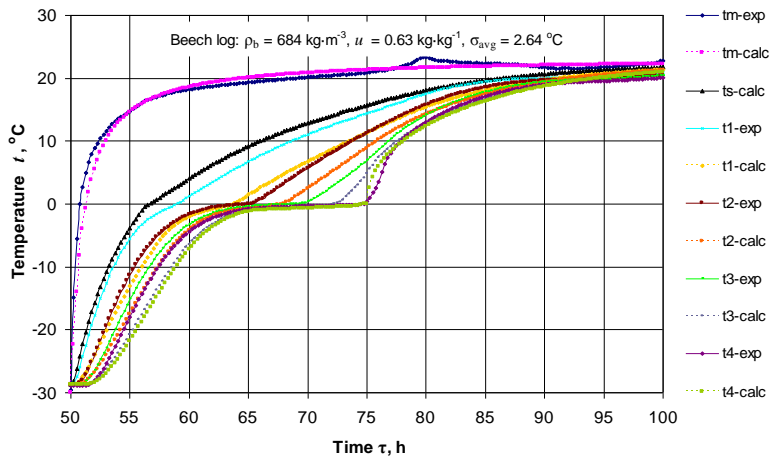


Fig. 4. Experimentally determined and calculated temperature field with average values of the log's thermo-physical characteristics and with maximal values of the log's heat transfer coefficients

CONCLUSIONS

This paper describes an approach for the computation of the temperature field in subjected to defrosting logs with the help of software package ANSYS Workbench 16.0.

The first results from ANSYS' calculation of the non-stationary temperature distribution in 4 characteristic points of the longitudinal section of frozen beech log with a diameter of 0.24 m, length of 0.48 m, initial temperature of -28.8 °C , and moisture content of $0.63 \text{ kg}\cdot\text{kg}^{-1}$ (above the hygroscopic range) during its 50 h defrosting at room temperature are graphically presented and analyzed.

The aim of the simulations was to assess the degree of the qualitative and quantitative compliance between the experimentally determined and calculated temperature field in the log's longitudinal section during the defrosting using ANSYS. As a criterion for the degree

of compliance between the compared temperature distributions in the log's section the average value of *RSME* total for the 4 characteristic points has been used.

During all simulations with ANSYS the average constant values of the thermal conductivities and the specific heat capacities of the log separately for each of the three temperature ranges of the defrosting process and variable values of the room air defrosting temperature, t_m , have been used. The values of t_m have been obtained after approximation of the experimentally established values of the temperature near the log from its initial value of -29.6 °C to its final value of 22.8 °C using software package Table Curve 2D.

Using this input data and also the maximal values of the heat transfer coefficient of the subjected to defrosting log, a relatively good qualitative and quantitative compliance (*RSME* = 2.64 °C) between the experimentally determined and calculated with ANSYS Workbench 16.0 temperature field in the log's longitudinal section has been obtained.

REFERENCES

1. CHUDINOV, B. S., 1966: Theoretical research of thermo physical properties and thermal treatment of wood. Dissertation, SibLTI, Krasnoyarsk, USSR (in Russian).
2. DELIISKI, N., 2011: Transient heat conduction in capillary porous bodies. In: Convection and Conduction Heat Transfer. InTech Publishing House, Rieka: 149-176.
3. DELIISKI, N., 2013: Computation of the wood thermal conductivity during defrosting of the wood. Wood research, 58 (4): 637-650.
4. DELIISKI, N., DZURENDA, L., 2010: Modelling of the thermal processes in the technologies for wood thermal treatment. TU Zvolen, Slovakia (in Russian).
5. DELIISKI, N., TUMBARKOVA, N. 2016. A methodology for experimental research of the freezing process of logs. Acta Silvatica et Lignaria Hungarica, Vol. 12, № 2: 145-156, <http://dx.doi.org/10.1515/aslh-2016-0013>
6. SHUBIN, G. S., 1990: Drying and thermal treatment of wood. Lesnaya promyshlennost, Moscow, URSS, 337 p., 1990 (in Russian).
7. STEINHAGEN, H. P., 1991: Heat transfer computation for a long, frozen log heated in agitated water or steam – A Practical Recipe. Holz als Roh- und Werkstoff, 49(7-8): 287-290, <http://dx.doi.org/10.1007/BF02663790>
8. TELEGIN, A. S., SHVIDKIY, B. S., YAROSHENKO U. G., 2002: Heat- and mass transfer. Akademkniga, Moscow, 454 p. (in Russian).
9. TREBULA, P., KLEMENT, I., 2002: Drying and hydrothermal treatment of wood, TU in Zvolen, Slovakia (in Slovak).
10. VIDELOV, H., 2003: Drying and thermal treatment of wood, University of Forestry in Sofia, Bulgaria (in Bulgarian).
11. <http://www.rotronic.com/humidity-measurement-feuchtemessung-temperaturmessung-data-loggers-datenlogger/hygrolog-hl-nt3.html>
12. <http://www.sigmaplot.co.uk/products/tablecurve2d/tablecurve2d.php>