3D VISUALIZATION OF THE DEFROSTING PROCESS OF BEECH PRISMS IN THE VENEER PRODUCTION

Nencho Deliiski, Radoslav Miltchev, Veselin Brezin, Ivan Hristov
University of Forestry, 10 Kliment Ohridski blvd, 1756 Sofia, Bulgaria
e-mail: deliiski@netbg.com, e-mail: rmilchev@ltu.bg, e-mail: brezin@abv.bg, e-mail: hristov_ivan@hotmail.com

ABSTRACT

The paper presents a new approach for the 3D colour visualization of the obtained with the help of own mathematical model calculated results about the non-stationary temperature distribution in the volume of frozen wood materials with prismatic shape during their defrosting. An example for the application of the approach for visualization of the temperature distribution in frozen beech prisms with thickness 0,4 m, width 0,4 m, length 0,8 m, initial temperature -40 ^{o}C, and moisture content 0,3 kg.kg^{-1} (wood with ice from the bounded water in it) and 0,6 kg.kg^{-1} (wood with ice from both the bounded and the free water in it) during their defrosting at temperature of the processing medium 80 ^{o}C has been given. The results from the studies can be used for the creation of an optimal energy saved thermal treatment of prismatic wood materials during their defrosting with an aim of following plasticizing in the veneer production.

Key words: frozen wood, beech prisms, defrosting, 3D visualization, temperature distribution

INTRODUCTION

For the optimization of the control of the heating process of wood materials in veneer and plywood mills, it is required that the distribution of the temperature field in them at every moment of the process are known (Shubin 1990, Trebula and Klement 2003, Pervan 2009).

This paper presents solutions of 3-dimensional mathematical model of the transient non-linear heat conduction in frozen and non-frozen wood materials with prismatic shape, which have been suggested earlier by the first co-author (Deliiski 2003, 2011). The paper also presents and visualizes the results from simulative investigation of the impact of the ice in the materials, formed in the wood only from the bounded, and from both the bounded and free water as well on 3D temperature distribution in the volume of beech prisms with dimensions 0,4 x 0,4 x 0,8 m during their defrosting at temperature of the processing medium of 80 ^{o}C.

The visualization process of the results received from the application of numerical methods to solve three-dimensional field problems is an essential problem. Utilization of proper methods for visualization can assist in better analysis of studied phenomena or processes.

Some of the main approaches for three-dimensional visualization of the results received from different numerical methods have been investigated in (Miltchev and Deliiski 2012). The present paper considers visualization approach based on the use of plane views that contain cross sections of studied three-dimensional temperature fields in subjected to defrosting wood prisms and especially planes of interest which reflect the veneer production.

1. 3D MATHEMATICAL MODEL OF THE DEFROSTING PROCESS OF PRISMATIC WOOD MATERIALS

The defrosting process of prismatic wood materials during their thermal treatment can be described by a non-linear differential equation of the thermo-conductivity, which takes the following form in Cartesian coordinates (Deliiski 2003):

$$c_e(T,u)\rho(T,u)\frac{\partial T(x,y,z,\tau)}{\partial \tau}=\frac{\partial}{\partial x}\left[\lambda_x(T,u)\frac{\partial T(x,y,z,\tau)}{\partial x}\right]+ +\frac{\partial}{\partial y}\left[\lambda_y(T,u)\frac{\partial T(x,y,z,\tau)}{\partial y}\right]+\frac{\partial}{\partial z}\left[\lambda_z(T,u)\frac{\partial T(x,y,z,\tau)}{\partial z}\right], \quad \textbf{(1)}$$

Where c_e is the effective specific heat capacity of the frozen wood, W.kg^{-1}.K^{-1};

ρ – the density of the wood, kg.m^{-3};

u – the wood moisture content, kg.kg^{-1} = %/100;

T – temperature, K;

λ_x, λ_y and λ_z – the thermal conductivity of the wood in the anatomical directions of the prismatic materials, which coincide with the coordinate axes x, y, and z, W.m^{-1}.K^{-1};

x – coordinate on the thickness d of subjected to defrosting materials: $0 \le x \le d/2$, m;

y – coordinate on the width b of subjected to defrosting materials: $0 \le y \le b/2$, m;

z – coordinate on the length L of subjected to defrosting materials: $0 \le z \le L/2$, m;

τ – time, s.

The initial and the boundary conditions to the equation (1) have been given in (Deliiski 2011) in the following form:

- the initial condition:

$$T(x,y,z,0)=T_0 \quad \textbf{(2)}$$

- the boundary condition:

$$T(0,y,z,\tau)=T(x,0,z,\tau)=T(x,y,0,\tau)=T_m(\tau), \quad \textbf{(3)}$$

where T_0 is the initial temperature of the frozen wood materials, K;

T_m – the processing medium temperature during thermal treatment of the wood, K.

The transformation of the non-linear differential equation with partial derivatives (1) in its discrete analogue with the help of the explicit form of the finite-difference method (Deliiski 2011) is carried out using the shown on Fig. 1 coordinate system for the positioning of the knots of the calculation mesh, in which the distribution of the temperature in a subjected to thermal processing frozen prism is computed.

For the solution of the system of equations (1) ÷ (3), a mathematical description of the participant in them thermo-physical characteristics of the wood, c_e, λ_r, λ_t, λ_z, and of its density, ρ, is needed. Equations in (Deliiski 2011) present a mathematical description of the effective specific heat capacity coefficient, c_e, of the frozen wood as a sum of the capacities of the wood itself, c, and the created in it ice from the freezing of the free water, c_{fw}, and of the hygroscopically bound water, c_{bw}. Equations in (Deliiski 2003) present also a mathematical description of the density of the wood, ρ, and of its thermal conductivity λ in different anatomical directions.

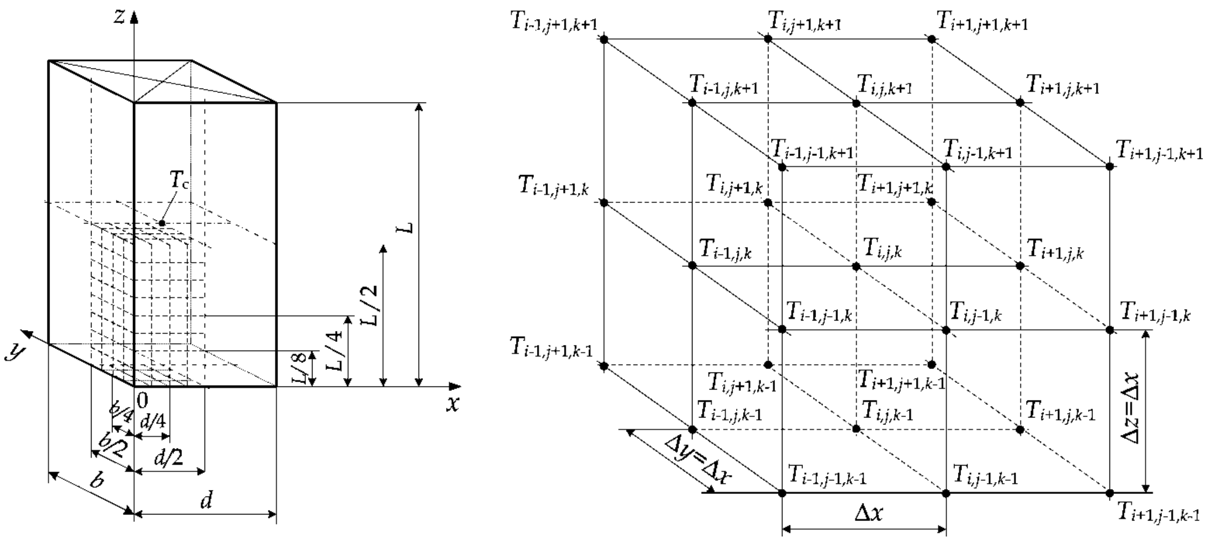


Figure 1: Positioning of the knots in the calculation mesh on 1/8 of the volume of a subjected to thermal treatment frozen wooden prism

2. RESULTS AND DISCUSSION

For the numerical solution of the above presented model a software package has been prepared in FORTRAN, which has been input in the developed by Microsoft calculation environment of Visual Fortran Professional (Deliiski 2011).

With the help of the program the 3D change in t in the volume of frozen beech prisms with initial temperature t_0 = -40 $^{\mathrm{o}}$C, thickness 0,4 m, width 0,4 m, length 0,8 m, basic density $\rho_{\mathrm{b}} = 560$ kg.kg^{-1}, fiber saturation point at 20 $^{\mathrm{o}}$C $u_{\mathrm{fsp}}^{20} = 0{,}31$ kg.kg^{-1} (Videlov 2003), and two values of the wood moisture content: u = 0,3 kg.kg^{-1} and u = 0,6 kg.kg^{-1} has been calculated during the time of thermal processing during 20 hours at a prescribed surface temperature $t_{\mathrm{m}} = 80$ ^{o}C.

On Fig. 1 and Fig. 2 the computed change in the surface temperature of the prisms, which is equal to t_{m}, and also in the temperature in 6 characteristic points in the 1/8 of the volume of prisms (because of its symmetry to the rest 7/8 of the volume) with $u = 0{,}3$ kg.kg^{-1} containing ice only from bounded water and with $u = 0{,}6$ kg.kg^{-1} containing ice both from bounded and free water is shown. The coordinates of the characteristic points are given in the legend of the graphs.

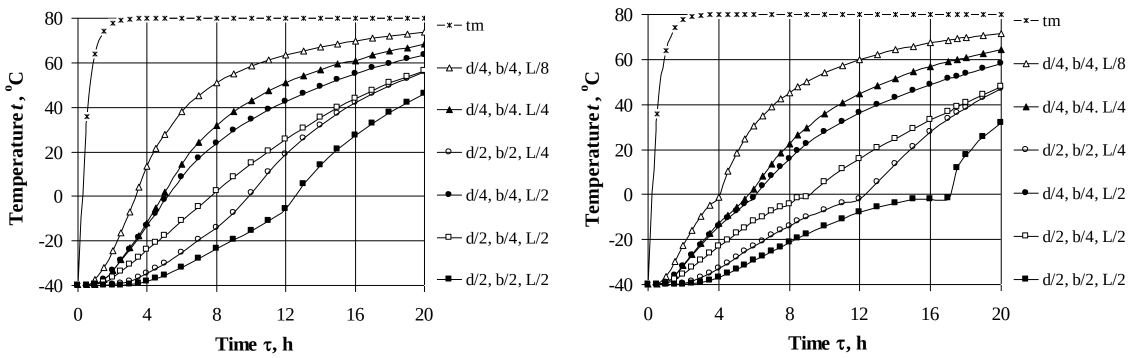


Figure 2: 3D defrosting at $t_{\mathrm{m}} = 80$ $^{\mathrm{o}}$C of beech prisms with dimensions 0,4 x 0,4 x 0,8 m, $t_0 - 40$ $^{\mathrm{o}}$C, $\rho_{\mathrm{b}} = 560$ kg.kg^{-1}, $u_{\mathrm{fsp}}^{20} = 0{,}31$ kg.kg^{-1}, $u = 0{,}3$ kg.kg^{-1} (left), and $u = 0{,}6$ kg.kg^{-1} (right) depending on τ

On the curves on Fig. 2 (right) in situated on the prism's inner layers characteristic points the specific almost horizontal sections of retention of the temperature for a long period of time in the range from -2 °C to -1 °C can be seen, while in these points a complete melting of the ice from the free water in the wood occurs (Chudinov 1988, Deliiski 2011). However much a given characteristic point is distant from the prism's surfaces, this much its retention of the temperature in this range is longer.

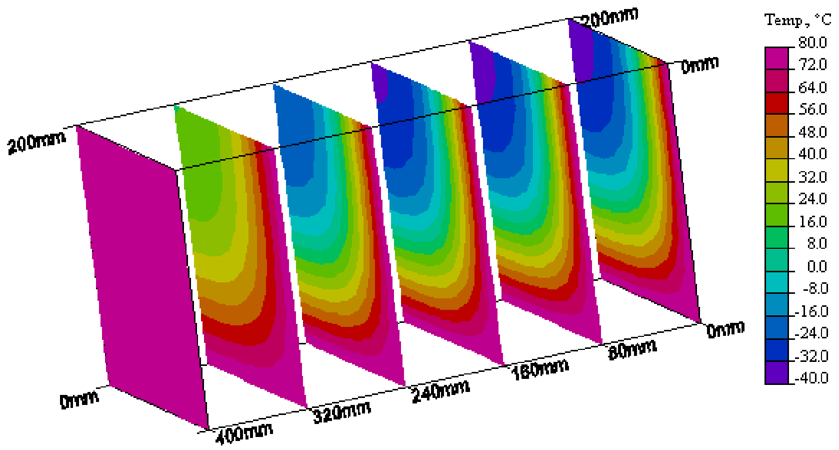
Analogically, the almost horizontal sections in the change of the wood temperature are absent during defrosting of the ice, formed only by bounded water in the prism.

3. VISUALIZATION OF 3D NON-STATIONARY TEMPERATURE DISTRIBUTION IN FROZEN WOODEN PRISMS

An original software has been prepared by us for computer processing and following visualization of the obtained results in the calculation environment of Visual Fortran for the temperature distribution in the volume of the subjected to defrosting wooden prisms.

The prepared graphs by this software are exhibited on Fig. 3 and Fig. 4, showing the change of the temperature in 6 equally distant from each other longitudinal sections in 1/8 of the volume of the prisms after corresponding duration of 5 h and 10 h of the defrosting of the wood during its thermal treatment.

On the graphs of Fig. 3 and Fig. 4 it can be seen that during the defrosting of the prism with u = 0,6 kg.kg^{-1}, which contains ice from the free water, the usual smoothness of the border between adjacent temperature zones in the legend of this figure is disturbed only in the temperature zones from -8 °C to 0 °C and from 0 °C to 8 °C. A reason for this is the shown in the analysis of Fig. 2 above retention of the temperature into the central points of the material for a too long period of time in the range from -2 °C to -1 °C, while the ice in them, formed from the freezing of the free water in the wood, is completely thawed. While the points with not completely thawed ice are still located in the colour area from -8 °C to 0 °C, their adjacent points from the calculation mesh after the complete thawing of the ice go into the zone from 0 °C to 8 °C. This explains the deformation of the smoothness of the border between these zones of color plots at τ = 5 h and τ = 10 h.



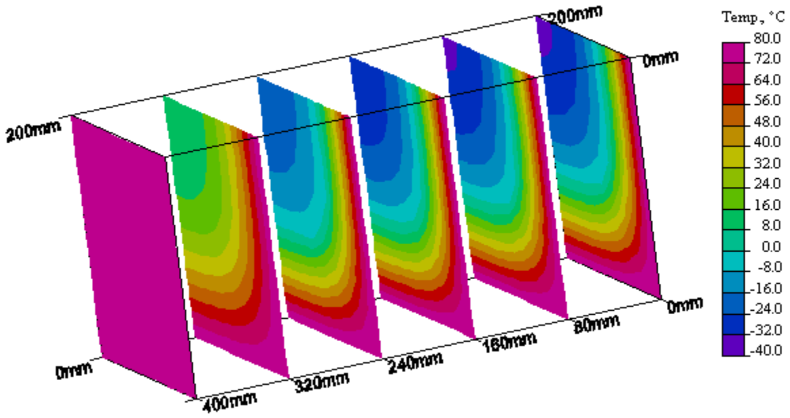


Figure 3: 3D graphics for the temperature distribution in 1/8 of the volume of the subjected to defrosting beech prisms with t_0= -40 °C, u=0,3 kg.kg^{-1} (above) and u=0,6 kg.kg^{-1} (below) after 5 h thermal treatment at t_m= 80 °C

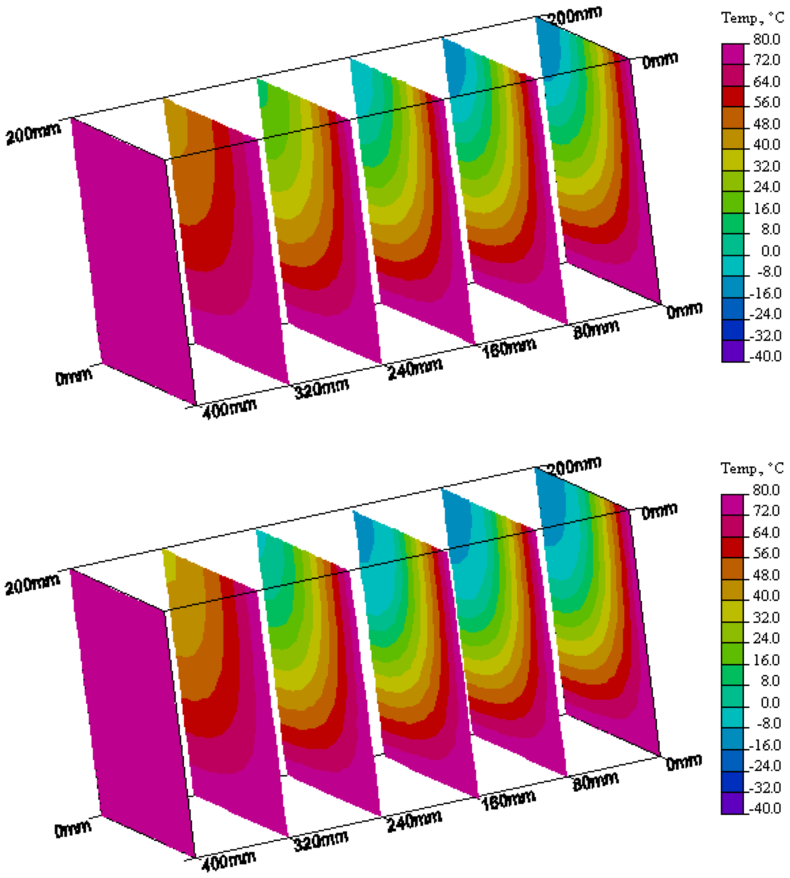


Figure 4: 3D graphics for the temperature distribution in 1/8 of the volume of the subjected to defrosting beech prisms with t_0= -40 °C, u=0,3 kg.kg^{-1} (above) and u=0,6 kg.kg^{-1} (below) after 10 h thermal treatment at t_m= 80 °C

4. CONCLUSIONS

All 3D graphs in this paper were plotted for the first time with the help of own software, which has a good visualization effect for the model output. The 3D contour graphs can be displayed not only individually at each time step of the defrosting process for detailed examination, but also they can be displayed together as an animation for the overall trend observation, which will be very helpful for the industry operators to easily foresee the overall changes of the process (Deliiski, Brezin, Dzurenda and Miltchev, 2012).

The 3D graphs for temperature profiles are powerful graphical tools that provide a better understanding of the relative change and changing patterns. However, it is difficult to analyze the details of the change and compare the heat transfer in the three directions. For such analyses the computational results can be used from the solving of the mathematical model (1) ÷ (3) for the transient non-linear heat conduction in frozen wooden prisms.

The cross section use in the suggested approach for visualization can include the inner planes of symmetry of the studied model or cross sections parallel of the major axes of the model. The proposed approach is suitable in both cases of more or less complex geometry of the model because of its opportunity for visualization of the inner space of the objects.

A possible disadvantage of the proposed approach can be observed when the cross sections containing results are too close to each other. The concentration of cross sections is necessary in the boundary areas with changing boundary conditions or material properties. In this particular case visualization could be improved partly by changing point of view in the three-dimensional space and proper rotation of the studied model. The best conditions for analysis and visualization could be achieved by use of special self-developed software as it shown in (Miltchev and Deliiski 2012). The main features of such approach are high level of interactivity and speed up visualization of the results, but it also needs significant preliminary computational work.

The results from the studies can be used for creation of optimal energy saved thermal treatment of prismatic wood materials during their defrosting with an aim of following plasticizing in the veneer production.

ACKNOWLEDGMENT

This paper was prepared as a part of the solution of the joined between University of Forestry in Sofia and TU in Zvolen project „Modelling and visualization of the wood defrosting processes in the technologies for wood thermal treatment”, which is supported by the Scientific Research Sector in the University of Forestry (project 114/2011).

REFERENCES

1. Chudinov, B. S., 1968. Theory of the thermal treatment of wood. Publishing Company „Nauka”, Moscow, USSR
2. Deliiski, N., 2003. Modelling and technologies for steaming wood materials in autoclaves. Dissertation for D.Sc., University of Forestry, Sofia
3. Deliiski, N., 2011. Transient heat conduction in capillary porous bodies. In Ahsan A (ed) Convection and conduction heat transfer. InTech Publishing House, Rieka: 149–176
4. Deliiski, N., V. Brezin, L. Dzurenda, R. Miltchev, 2012. 3D visualization of the temperature fields in subjected to defrosting poplar logs. 8-th international science conference “Chip- and chipless woodworking processes”. Zvolen, Slovakia, c.409–414, 163–168, ISBN 978-80-228-2385-2.
5. Miltchev R., N. Deliiski, 2012. Approaches for postprocessor visualization in numerical analysis of problems in the woodworking. International scientific conference “Automation & Information’2012, Sofia (in print).
6. Pervan, S. 2009: Technology for Treatment of Wood with Water Steam. University in Zagreb
7. Shubin, G. S., 1990: Drying and Thermal Treatment of Wood. Publisher “Lesnaya promyshlennost”, Moskow, URSS
8. Trebula, P., Klement, I., 2002: Drying and hydrothermal treatment of wood. TU Zvolen, Slovakia
9. Videlov, H. 2003: Drying and Thermal Treatment of Wood. Publishing House of the University of Forestry, Sofia