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RESEARCH ON THE SIMULTANEOUS STEAMING IN AN AUTOCLAVE OF NON-FROZEN BEECH PRISMS WITH DIFFERENT THICKNESSES INTENDED FOR PRODUCTION OF VENEER

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ABSTRACT

An approach to mathematical modeling and research on the 2D non-stationary temperature distribution in non-frozen wooden prisms with different thicknesses during their simultaneous autoclave steaming at limited heat power of the steam generator and during the subsequent air conditioning before the cutting of veneer is described in the paper. Mathematical descriptions of the changing processing medium temperature in an autoclave and near the steamed prisms out of the autoclave were introduced as boundary conditions in our own 2D non-linear mathematical model of the 2D temperature distribution in non-frozen prisms during their heating and cooling. Numerical solutions of the model in the calculation environment of Visual FORTRAN Professional are given as an application of the suggested approach. Simulative investigation of 2D non-stationary temperature distribution in non-frozen beech (*Fagus Sylvatica* L.) prisms with an initial temperature of 0 °C, cross-section dimensions of 0.3 × 0.3 m, 0.4 × 0.4 m, and 0.5 × 0.5 m, moisture content of 0.4, 0.6, and 0.8 $kg{\cdot}kg^{-1}$, during their autoclave steaming and subsequent conditioning was carried out. The simultaneous steaming of all prisms was simulated according to regimes for prisms with cross-section dimensions of 0.5 × 0.5 m in an autoclave with a diameter of 2.4 m, length of 9.0 m and loading levels of 40, 50, and 60% at a limited heat power of the steam generator, equal to 500 kW. It was found that good quality veneer could be obtained after simultaneous steaming of prisms of the same wood species with differences between their thicknesses up to 100 mm. It is necessary to carry out the steaming according to the regime that applies to the prisms with the largest thickness in a given batch. Then the effect of the wood moisture content and loading level of the autoclave on the plasticization degree of the prisms and the veneer quality is practically negligible. The suggested approach can be used for the computation and model based automatic realization of energy-efficient optimized regimes for autoclave steaming of different wood materials.

Key words: simultaneous steaming in autoclave, beech prisms, thickness of prisms, moisture content, loading level of autoclave

INTRODUCTION

For plasticizing the prismatic wood materials in the production of veneer and plywood, the materials are usually subjected to steaming in different types of equipment that can operate at atmospheric or increased pressure (CHUDINOV 1966, KOLLMANN and CÔTÉ 1984, SHUBIN 1990, TREBULA and KLEMENT 2002, VIDELOV 2003, PERVAN 2009, DELIISKI and DZURENDA 2010, DELIISKI 2013), etc.

The steaming of wood materials under increased pressure of the processing medium in autoclaves is used in many applications due to its higher energy efficiency and lower duration in comparison with the steaming at atmospheric pressure (BURTIN *et al.* 2000, RIEHL *et al.* 2002, BEKHTA and NIEMZ 2003, DELIISKI 2003, 2004, 2011a, DAGBRO *et al.* 2010, VIDELOV 2003, DELIISKI and SOKOLOVSKI 2007, SOKOLOVSKI *et al.* 2007, DELIISKI and DZURENDA 2010, DELIISKI *et al.* 2020, 2021).

The information about the duration of regimes for steaming the wood materials only with certain thicknesses in atmospheric or increased pressure for the cases of unlimited generator power has been given in CHUDINOV (1968), SHUBIN (1990), TREBULA and KLEMENT 2002, VIDELOV (2003), DELIISKI (2003, 2004, 2011b, 2013), PERVAN (2009), DELIISKI and DZURENDA (2010), DZURENDA and DELIISKI (2011), etc.

Because of the production of veneers, small and medium-sized enterprises are significantly interested in steaming regimes for simultaneous heat treatment of wood materials with different thicknesses at limited heat power of the steam generator.

In DELIISKI *et al.* (2018) an approach and an algorithm to compute the processing medium temperature during steaming of wooden prisms for veneer production in an autoclave at limited heat power of the steam generator was described.

The aim of the present work is to suggest an approach to mathematical modelling and research on the 2D temperature distribution in non-frozen wooden prisms with different cross section dimensions and wood moisture content during simultaneous steaming in an autoclave at different loading level and limited heat power of the steam generator and during their subsequent air conditioning before the cutting of veneers.

MATERIAL AND METHODS

Modelling of the 2D temperature distribution in non-frozen wooden prisms subjected to steaming and subsequent conditioning in an air environment

When the length of the prisms, *l*, is larger than their thickness, *d*, at least more than 4 ÷ 5 times, and simultaneously the width, *b*, does not exceed the thickness more than 3 times, the following 2D mathematical model can be used for the calculation of the change in the temperature in the prism cross section, which is equally distant from the frontal sides (i.e. along the coordinates *x* and *y* of this section) during heating and cooling in steaming or air medium (DELIISKI 2003, 2011b):

$$c(T,u)\cdot\rho(\rho_{\mathrm{b}},u)\frac{\partial T(x,y,\tau)}{\partial\tau}=\frac{\partial}{\partial x}\left[\lambda_{\mathrm{r}}(T,u,\rho_{\mathrm{b}})\frac{\partial T(x,y,\tau)}{\partial x}\right]+\frac{\partial}{\partial y}\left[\lambda_{\mathrm{t}}(T,u,\rho_{\mathrm{b}})\frac{\partial T(x,y,\tau)}{\partial y}\right],\quad (1)$$

under an initial condition:

$$T(x,y,0)=T_0 \quad (2)$$

and the following boundary conditions:

▪ During the steaming process:

$$T(x,0,\tau)=T(0,y,\tau)=T_{\mathrm{m}}(\tau) \quad (3)$$

▪ During the conditioning process of the steamed prisms in an air environment:

$$\frac{\partial T(x,0,\tau)}{\partial y} = -\frac{\alpha_t(x,0,\tau)}{\lambda_t(x,0,\tau)}\left[T(x,0,\tau) - T_{\text{m-cond}}(\tau)\right] \quad (4)$$

$$\frac{\partial T(0,y,\tau)}{\partial x} = -\frac{\alpha_r(0,y,\tau)}{\lambda_r(0,y,\tau)}\left[T(0,y,\tau) - T_{\text{m-cond}}(\tau)\right] \quad (5)$$

where c is the specific heat capacity of the non-frozen wood during its heating and cooling, $J \cdot kg^{-1} \cdot K^{-1}$; λ_r and λ_t – thermal conductivities of the non-frozen wood in radial and tangential directions respectively, $W \cdot m^{-1} \cdot K^{-1}$; ρ – wood density, $kg \cdot m^{-3}$; x – coordinate along the prism thickness of the separate points of the calculation mesh for numerical solving of the model: $0 \leq x \leq d$, m; d – thickness of the prism, m; y – coordinate along the prism width of the separate points of the calculation mesh: $0 \leq y \leq b/2$, m; b – width of the prism, m; τ – time, s; T – temperature, K; T_0 – initial average mass temperature of the subjected to steaming prism, K; $T(x,y,0)$ – temperature of all points in the prism volume at the beginning of the steaming process, K; $T(x,0,\tau)$ and $T(0,y,\tau)$ – temperature of all points on the surfaces of the prism parallel to its thickness and width, respectively, during the steaming and conditioning processes, K; T_m – temperature of the processing medium during the steaming process, K; $T_{\text{m-cond}}$ – temperature of the ambient air environment near the steamed prism during the conditioning, K; α_r and α_t – convective heat transfer coefficients between the prism's surfaces and ambient air environment in radial and tangential directions, respectively, during the conditioning process, $W \cdot m^{-2} \cdot K^{-1}$.

Mathematical descriptions of the specific heat capacity of the non-frozen wood during its heating and cooling and also of the thermal conductivities of the wood in different anatomical directions have been suggested in DELIISKI (1990, 1994, 2003, 2004, 2011b, 2013) based on the experiments determined in the dissertations of CHUDINOV (1966) and KANTER (1955) equations describing the change in c and λ of non-frozen wood as a function of t and u.

These equations are used in both the European (CHUDINOV 1968, SHUBIN 1990, POŽGAJ *et al.* 1997, TREBULA and KLEMENT 2002, VIDELOV 2003, PERVAN 2009, DELIISKI and DZURENDA 2010, HRČKA and BABIAK 2017) and the American scientific literature (STEINHAGEN 1977, 1986, 1991, STEINHAGEN and LEE 1988, KHATTABI and STEINHAGEN 1992, 1993, 1995) when calculating various processes of wood thermal treatment.

Mathematical descriptions of wood density above the hygroscopic range, ρ, and of the convective heat transfer coefficients between steamed wood materials and ambient air environment, were given in (CHUDINOV 1968, DELIISKI and DZURENDA 2010).

During the solving of the model, mathematical descriptions of the thermo-physical properties of beech wood (*Fagus Sylvatica* L.) with basic density $\rho_b = 560$ $kg \cdot m^{-3}$ and fibre saturation point $u_{fsp} = 0.31$ $kg \cdot kg^{-1}$ (DELIISKI and DZURENDA 2010) were used. Using the well-known equation $\rho = \rho_b(1+ u)$ (CHUDINOV 1968, KOLLMANN and CÔTÉ 1984, TREBULA and KLEMENT 2002, HRČKA and BABIAK 2017, NIEMZ and SONDEREGGER 2017), the following values of the wood density were applied: $\rho = 784$ $kg.m^{-3}$ for $u = 0.4$ $kg \cdot kg^{-1}$, $\rho = 896$ $kg.m^{-3}$ for $u = 0.6$ $kg \cdot kg^{-1}$, and $\rho = 1008$ $kg.m^{-3}$ for $u = 0.8$ $kg \cdot kg^{-1}$.

Temperature time profile of regimes for autoclave steaming and subsequent air conditioning of wooden prisms

The typical temperature time profile of the processing medium temperature T_m in a steaming autoclave and of the air medium for the subsequent conditioning of the heated prisms, which was used for the numerical simulations below, is shown in Fig. 1.

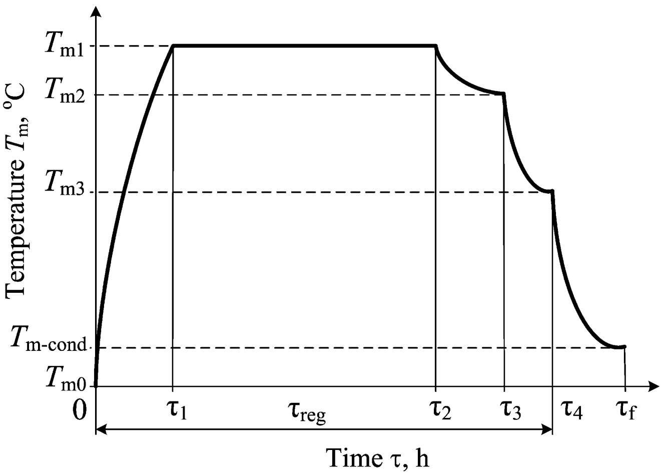

Fig. 1 Typical temperature time profile for change in T_m during steaming of prisms in an autoclave and during their subsequent conditioning in an air environment.

This temperature time profile includes the following 5 stages:

▪ An intensive increase in T_m during the time $0 – \tau_1$ caused by the opening the valve directing the water steam in the autoclave. The duration τ_1 depends on many factors, whose impact separately is briefly considered below;

▪ Constant T_m of the steaming medium during $\tau_1 – \tau_2$ caused by dosed introduction of steam in the autoclave;

▪ A decrease in T_m of the steaming medium during $\tau_2 – \tau_3$ caused by using the already accumulated heat in the hermetized autoclave;

▪ A decrease in T_m of the steaming medium during $\tau_3 – \tau_4$, which is caused by the opening the valves directing the steam and condensed water out of the autoclave;

▪ A decrease in T_m of the air temperature near the steamed prisms out of the autoclave during $\tau_4 – \tau_f$.

The time from 0 to τ_4 represents the duration of the regime for autoclave steaming of the prisms, τ_{reg}.

RESULTS AND DISCUSSION

For numerical solving of the above presented mathematical model (1) ÷ (5) aimed at computation of 2D temperature distribution in the central cross section of wooden prisms intended for production of veneer during their autoclave steaming at limited heat power of the steam generator a software package was prepared. It was an input in the calculation environment of Visual FORTRAN Professional developed by Microsoft. For transformation of the model in a form suitable for programming, an explicit form of the finite-difference method has been used (DELIISKI 2003, 2011b, 2013, DELIISKI and DZURENDA 2010).

An increase in T_m at the very beginning of the steaming regimes during the time $0 – \tau_1$ (see Fig. 1) is calculated according to the approach given in DELIISKI *et al.* (2018) by taking in mind the available heat power of the steam generator, which influences the change of T_m at the beginning of the steaming regimes.

Using the software package computations made for the determination of T_m and also for the 2D non-stationary change of the temperature in 4 characteristic points of ¼ of the square cross section of beech prisms with the thickness *d* and width *b* respectively, during their steaming in an autoclave with industrial dimensions: diameter D = 2.4 m and length of its cylindrical part L = 9.0 m (DELIISKI and SOKOLOVSKI 2007, DELIISKI and DZURENDA

2010). The coordinates of the characteristic points of the prisms, in which the change of the temperature was recorded, were equal, as follow: t_1 in Point 1: d/8, b/8; t_2 in Point 2: d/4, b/4; t_3 in Point 3: d/2, b/4; and t_4 in Point 4: d/2, b/2 (centre of the prisms).

During the simulations, a limited heat power of the steam generator q_{source} = 500 kW and the following values of the factors influencing the first stage of T_m (Fig. 1) and also 2D temperature distribution in the prisms and the duration of the steaming regimes were set:

▪ Dimensions of the square cross section of beech prisms with thickness *d* and width *b*: 0.3 × 0.3 m, 0.4 × 0.4 m, and 0.5 × 0.5 m;

▪ Moisture content *u* of the prisms subjected to autoclave steaming: 0.4 $kg{\cdot}kg^{-1}$, 0.6 $kg{\cdot}kg^{-1}$, and 0.8 $kg{\cdot}kg^{-1}$;

▪ Initial temperature of the subjected to steaming prisms: t_0 = 0 °C;

▪ Initial temperature of the processing medium in the steaming autoclave: t_{m0} = 0 °C;

▪ A decrease in the steaming medium temperature: t_{m1} = 130 °C;

▪ Loading level, γ, of the autoclave with filled in prisms for steaming: 0.4 $m^3{\cdot}m^{-3}$, 0.5 $m^3{\cdot}m^{-3}$, and 0.6 $m^3{\cdot}m^{-3}$ (i.e. γ = 40%, γ = 50%, and γ = 60% respectively).

In Fig. 2 the calculated change in the surface temperature, t_s, average mass temperature, t_{avg}, and *t* of 2 characteristic points (t_1 in Point 1 and t_4 in Point 4) of the prisms with the largest dimensions *d* × *b* = 0.5 × 0.5 m, moisture content *u* = 0.4, 0.6, 0.8 $kg{\cdot}kg^{-1}$, and loading level of the autoclave γ = 50% during their autoclave steaming and subsequent conditioning at $T_{m\text{-}cond}$ = 293.15 K (i.e. $t_{m\text{-}cond}$ = 20 °C) is presented.

In the mentioned and in Figures 3, 4, and 5 the minimum and maximum values of the temperature, $t_{opt\text{-}min}$ = 62 °C and $t_{opt\text{-}max}$ = 90 °C, respectively are also shown. For obtaining the quality veneer from plasticized beech wood it is needed that the temperature of all characteristic points of the prisms during the veneer cutting process stays between these optimum values of the temperature (MÖRATH 1949, DELIISKI 2003, DELIISKI and DZURENDA 2010). The computation of the temperature distribution in the prisms was done in interconnection of the processes of their steaming in an autoclave and the subsequent conditioning in an air environment. Based on the calculations, it can be determined when the moment of reaching in the entire volume of the heated prisms occurred for the necessary optimal temperatures (between $t_{opt\text{-}min}$ and $t_{opt\text{-}max}$) needed for cutting the quality veneer.

It is known that the individual wooden prisms in each batch loaded for steaming have different cross-sectional dimensions. In order to ensure that all prisms reach the required optimal temperatures, in practice the steaming of each batch is carried out according to the regime corresponding to the prisms with the largest thickness in it.

Therefore, the study of simultaneous steaming in an autoclave of prisms with cross sections *d* × *b* = 0.5 × 0.5 m, *d* × *b* = 0.4 × 0.4 m, and *d* × *b* = 0.3 × 0.3 m was performed by computing the change in t_s, t_{avg}, t_1, and t_4 of the prisms with *d* × *b* = 0.4 × 0.4 m and *d* × *b* = 0.3 × 0.3 m for the cases of their steaming according to regimes with *d* × *b* = 0.5 × 0.5 m, which are shown in Fig. 2 for the different 3 values of the wood moisture content *u*. The obtained calculated results for prisms with *d* × *b* = 0.4 × 0.4 m and *d* × *b* = 0.3 × 0.3 m are graphically presented in Fig. 3 and Fig. 4 respectively.

Figure 5 shows the change in t_s, t_{avg}, t_1, and t_4 for the case of simultaneous autoclave steaming and subsequent air conditioning of prisms with *d* × *b* = 0.3 × 0.3 m, *d* × *b* = 0.4 × 0.4 m, and *d* × *b* = 0.5 × 0.5 m according to the regime with *d* × *b* = 0.5 × 0.5 m at the intermediate studied values of *u* = 0.6 $kg.kg^{-1}$ and γ = 50%.

In Table 1 the change in the duration of the stages 0 – τ_2, 0 – τ_3 and 0 – τ_4 = τ_{reg} (see Fig. 2), the temperatures t_1 and t_4 at τ_2 and at τ_4, and also after 1 h of the conditioning of the steamed prisms (at τ_4+1h) and after 2 h of their conditioning (at τ_4+2h) is given.

The obtained results allow for making the following statements about the change in the duration of the regimes for steaming of beech prisms with *d* × *b* = 0.5 × 0.5 m, τ_{reg}, in an autoclave with D = 2.4 m and L = 9.0 m at t_{m1} = 130 °C, t_{m2} = 110 °C, t_{m3} = 80 °C depending on the studied influencing factors:

1. An increase in the loading level of the autoclave from 40 to 60% at given values of u causes slight linear increase in τ_{reg}. When u = 0.6 kg·kg^{-1} the duration τ_{reg} at the studied values of t_{m1} = 130 °C, t_{m2} = 110 °C, t_{m3} = 80 °C and q_{source} = 500 kW obtains the following values: 19.3 h for γ =40%, 19.4 h for γ = 50%, and 19.5 h for γ = 60% (Table 1).

2. An increase in the prism moisture content from 0.4 to 0.8 kg·kg^{-1} at given value of the loading level γ causes insignificant practically linear increase in τ_{reg}. When γ = 50% the duration τ_{reg} at the studied values of t_{m1}, t_{m2}, t_{m3}, and q_{source} is equal as follows: 18.9 h for u = 0.4 kg·kg^{-1}, 19.4 h for u = 0.6 kg·kg^{-1}, and 19.9 h for u = 0.8 kg·kg^{-1}.

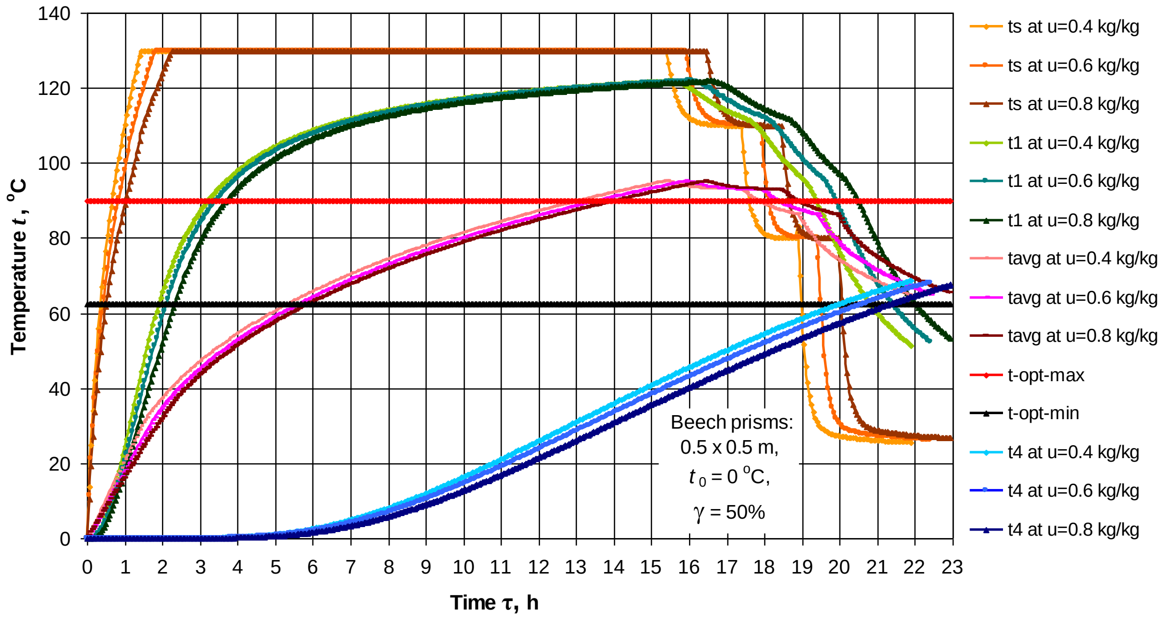

Fig. 2 Change in t_s, t_{avg}, and t in 2 characteristic points t_1 and t_4 of the prisms with $d \times b$ = 0.5 × 0.5 m during their steaming in an autoclave at γ = 50% and subsequent conditioning, depending on u.

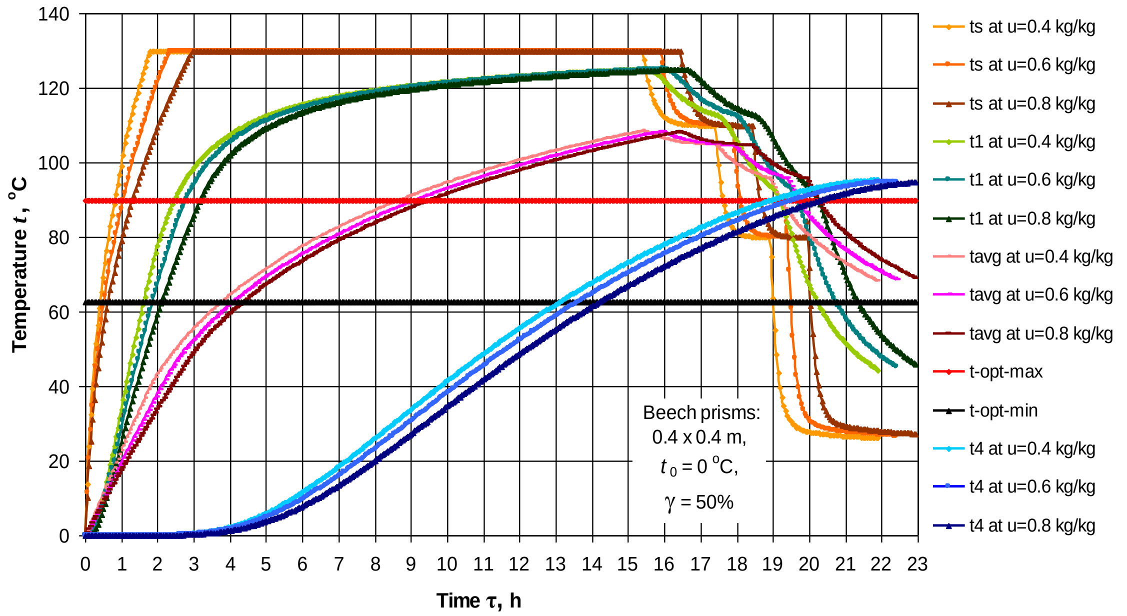

Fig. 3 Change in t_s, t_{avg}, t_1, and t_4 of the prisms with $d \times b$ = 0.4 × 0.4 m during their steaming in an autoclave at γ = 50% according to regime for prisms with $d \times b$ = 0.5 × 0.5 m, depending on u.

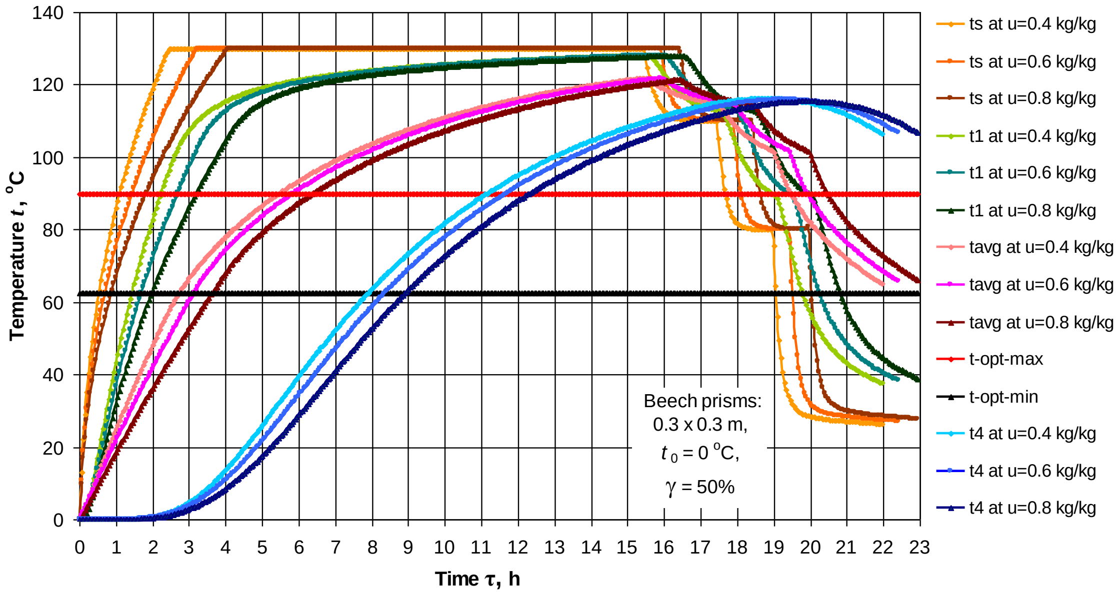

Fig. 4 Change in t_s, t_{avg}, t_1, and t_4 of the prisms with $d \times b = 0.3 \times 0.3$ m during their steaming in an autoclave at $\gamma = 50\%$ according to regimes for prisms with $d \times b = 0.5 \times 0.5$ m, depending on u.

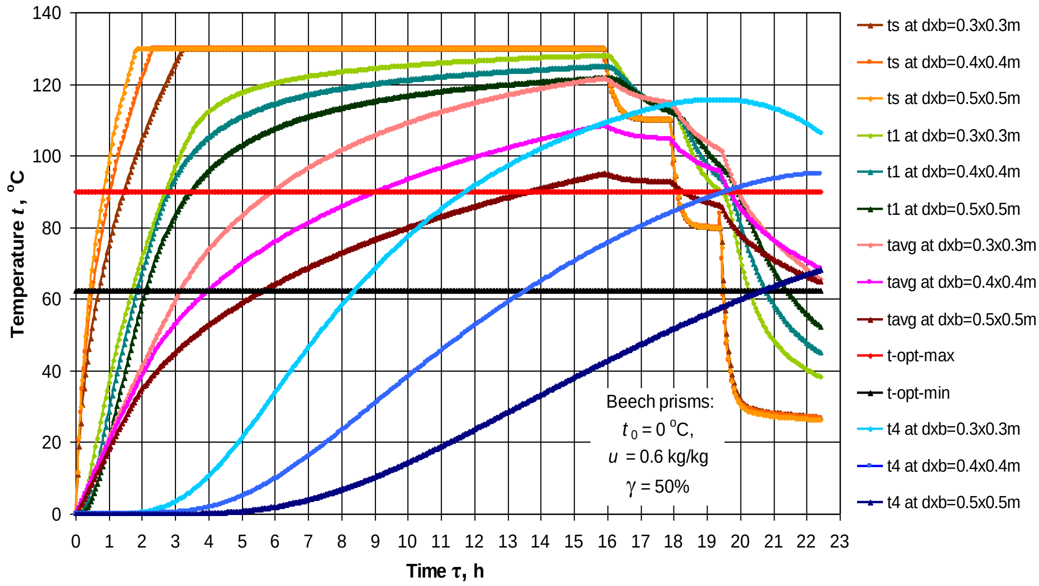

Fig. 5 Change in t_s, t_{avg}, t_1, and t_4 of the prisms with $u = 0.6$ kg·kg^{-1} during their steaming in an autoclave at $\gamma = 50\%$ according to regimes for prisms with $d \times b = 0.5 \times 0.5$ m, depending on $d \times b$.

3. An increase in the wood moisture content u caused practically linear increase in the duration of the first stage of the regimes for autoclave steaming, $0 - \tau_1$. When $d \times b = 0.5 \times 0.5$ m, $u = 0.6$ kg·kg^{-1}, $\gamma = 50\%$, and $q_{source} = 500$ kW, the duration τ_1 is equal as follows: 1.4 h for $u = 0.4$ kg·kg^{-1}, 1.8 h for $u = 0.6$ kg·kg^{-1}, and 2.2 h for $u = 0.8$ kg·kg^{-1}.

The reason for this influence of u on τ_1 is that the larger wood moisture content is the more heat capacity of the wet wood is present in the autoclave (CHUDINOV 1968, DELIISKI and DZURENDA 2010, HRČKA and BABIAK 2017). Because of this, the larger part of the limited $q_{source} = 500$ kW constant flux of the water steam at the beginning of the steaming regime is needed for warming up ~~of~~ the prisms with larger u, while the remaining smaller part from this flux leads to a smaller (i.e., slower) increase in t_m during any next step $\Delta\tau$ when solving the mathematical model.

Tab 1 Change in τ_{reg} and t of beech prisms with t_0 = 0 °C during their steaming in an autoclave at t_{m1}=130 °C, t_{m2}=110 °C, t_{m3}=80 °C according to regimes for prisms with $d \times b$ = 0.5 × 0.5 m, depending on dimensions of the cross section $d \times b$, wood moisture content u and loading level of the autoclave γ.

u, kg.kg^{-1}	γ, %	τ_2, h	τ_3, h	$\tau_4 = \tau_{reg}$, h	t_1 at τ_2, °C	t_4 at τ_2, °C	t_1 at τ_4, °C	t_4 at τ_4 °C	t_1 at τ_4+1h, °C	t_4 at τ_4+1h, °C	t_1 at τ_4+2h, °C	t_4 at τ_4+2h, °C
Prisms with $d \times b$ = 0.5 × 0.5 m												
0.4	40	15.3	17.3	18.8	121.8	42.7	97.0	58.3	78.6	62.2	61.5	65.7
0.4	50	15.4	17.4	18.9	121.8	42.8	96.9	58.3	78.2	62.2	61.3	65.7
0.4	60	15.5	17.5	19.0	121.8	42.8	97.2	58.3	78.9	62.2	61.7	65.7
0.6	40	15.8	17.8	19.3	121.9	42.6	97.1	57.9	78.9	61.7	62.2	65.2
0.6	50	15.9	17.9	19.4	121.8	42.5	97.3	57.7	79.3	61.5	62.4	65.0
0.6	60	16.0	18.0	19.5	121.8	42.2	97.7	57.4	80.3	61.3	63.3	64.8
0.8	40	16.3	18.3	19.8	121.9	42.4	98.6	57.4	79.7	61.2	63.5	64.7
0.8	50	16.4	18.4	19.9	121.8	42.2	98.0	57.1	81.1	60.9	64.0	64.4
0.8	60	16.5	18.5	20.0	121.7	41.6	97.6	56.6	80.3	60.4	63.1	63.9
Prisms with $d \times b$ = 0.4 × 0.4 m												
0.4	40	15.3	17.3	18.8	125.0	75.5	94.2	90.0	70.9	92.8	53.3	94.7
0.4	50	15.4	17.4	18.9	125.1	75.3	93.8	89.9	70.6	92.6	52.7	94.5
0.4	60	15.5	17.5	19.0	125.0	75.3	94.0	89.6	70.4	92.4	53.0	94.4
0.6	40	15.8	17.8	19.3	125.1	75.3	94.0	89.6	70.4	92.4	53.6	94.4
0.6	50	15.9	17.9	19.4	125.0	74.8	93.8	89.3	70.0	92.1	53.4	94.1
0.6	60	16.0	18.0	19.5	125.0	74.8	93.9	88.8	70.4	91.7	53.5	93.7
0.8	40	16.3	18.3	19.8	125.1	75.2	94.7	89.3	70.5	92.1	55.1	94.1
0.8	50	16.4	18.4	19.9	125.0	74.3	93.9	88.7	72.0	91.6	54.8	93.6
0.8	60	16.5	18.5	20.0	124.9	73.3	94.0	87.9	72.7	90.8	54.1	92.9
Prisms with $d \times b$ = 0.3× 0.3 m												
0.4	40	15.3	17.3	18.8	128.1	110.0	90.2	116.4	58.7	115.3	43.9	112.2
0.4	50	15.4	17.4	18.9	128.1	109.7	90.3	116.2	59.1	115.2	44.0	112.2
0.4	60	15.5	17.5	19.0	128.1	109.2	90.0	115.8	57.8	114.7	43.5	111.7
0.6	40	15.8	17.8	19.3	128.1	109.8	90.3	116.3	59.2	115.2	44.6	112.2
0.6	50	15.9	17.9	19.4	128.1	109.2	90.1	115.8	58.8	114.8	44.4	111.9
0.6	60	16.0	18.0	19.5	128.0	108.4	90.4	115.4	60.0	114.6	44.8	111.8
0.8	40	16.3	18.3	19.8	128.1	109.7	90.3	116.1	59.7	115.2	45.3	112.4
0.8	50	16.4	18.4	19.9	128.0	108.7	90.4	115.5	60.1	114.7	45.4	112.0
0.8	60	16.5	18.5	20.0	127.9	107.4	90.3	114.8	60.0	114.0	45.5	111.4

4. A decrease in the prisms dimensions at given values of u and γ causes non-linear increase of τ_1. For example, when u = 0.6 kg·kg^{-1}, γ = 50%, and q_{source} = 500 kW the duration τ_1 obtains the following values:

- at $d \times b$ = 0.4 × 0.4 m: 1.8 h for u = 0.4 kg·kg^{-1}, 2.4 h for u = 0.6 kg·kg^{-1}, and 3.0 h for u = 0.8 kg·kg^{-1}.
- at $d \times b$ = 0.3 × 0.3 m: 2.4 h for u = 0.4 kg·kg^{-1}, 3.3 h for u = 0.6 kg·kg^{-1}, and 4.0 h for u = 0.8 kg·kg^{-1}.

The reason of this influence of the dimensions $d \times b$ on τ_1 is that the heating of the prisms with smaller cross section dimensions is done faster in comparison with the heating of the prisms with larger dimensions, which means that the smaller prisms have a larger heat capacity. Because of this, a larger part of the limited by q_{source} = 500 kW constant flux of the water steam introduced into the autoclave at the beginning of the regime for the heating of the prisms with smaller dimensions is needed and as a consequence, a less part from this flux remains for the formation of a smaller (i.e., slower) increase in t_m during any next step Δτ when solving the mathematical model.

5. The temperatures of the studied characteristic points near the prisms surfaces (t_1) and in the prisms centre (t_4) are within the following ranges after 1 h and 2 h conditioning of the steamed prisms in an air environment at $t_{m\text{-}cond}$ = 20 °C (refer to Table 1):

- after 1 h conditioning: from 60.4 °C to 80.3 °C for prism with $d \times b$ = 0.5 × 0.5 m, from 70.0 °C to 92.8 °C for prism with $d \times b$ = 0.4 × 0.4 m, and from 57.8 °C to 115.3 °C for prism with $d \times b$ = 0.3 ×× 0.3 m;

- after 2 h conditioning: from 61.3 °C to 65.7 °C for prism with $d \times b$ = 0.5 × 0.5 m, from 52.7 °C to 94.7 °C for prism with $d \times b$ = 0.4 × 0.4 m, and from 43.5 °C to 112.4 °C for prism with $d \times b$ = 0.3 × 0.3 m.

These data show that 2D temperature fields of the prisms with $d \times b$ = 0.5 × 0.5 m and $d \times b$ = 0.4 × 0.4 m enter between $t_{opt\text{-}min}$ = 62 °C and $t_{opt\text{-}max}$ = 90 °C (or are very close to these values of t_{opt}) after their simultaneous steaming according to regimes with $d \times b$ = 0.5 × 0.5 m and after subsequent conditioning for 1 h and 2 h. This means that these prisms are well plasticized enough to produce high quality veneer.

The temperatures on the surface and in the centre of the prisms with $d \times b$ = 0.3 × 0.3 m turn out to be more than 20 °C outside the limits $t_{opt\text{-}min}$ = 62 °C and $t_{opt\text{-}max}$ = 90 °C both at the end of their autoclave steaming according to regimes with $d \times b$ = 0.5 × 0.5 m and after their subsequent 1 h and 2 h air conditioning. This means that good quality veneer cannot be produced from such prisms, i.e., from the layers of prisms having a significantly lower temperature than $t_{opt\text{-}min}$, in the veneer cracks would appear, and from the layers with a significantly higher temperature than $t_{opt\text{-}max}$, in the surface of the veneer it would have torn fibres and deteriorated smoothness.

Consequently, to obtain quality veneer from wooden prisms steamed simultaneously in an autoclave, they must have thicknesses with differences between them in the range up to 100 mm. It is necessary to carry out the autoclave steaming according to the regime that applies to the prisms with the largest thickness in a given batch. Then the influence of the wood moisture content and loading level of the autoclave on the plasticization degree of the prisms and on the veneer quality is practically negligible.

CONCLUSIONS

An approach to mathematical modeling and research on 2D temperature distribution in non-frozen wooden prisms with different cross section dimensions, $d \times b$, and wood moisture content, u, during simultaneous steaming in an autoclave at different loading level, γ, and limited heat power of the steam generator, q_{source}, and also during the subsequent air conditioning in the production of veneer is presented in the paper.

For numerical solving of the 2D model and carrying out the numerous computer simulations with it, a software program was prepared in the calculation environment of Visual FORTRAN Professional developed by Microsoft.

Tables and diagrams of the non-stationary change in 2D temperature distribution of beech prisms with cross-section dimensions 0.3 × 0.3 m, 0.4 × 0.4 m, and 0.5 × 0.5 m, initial temperature of 0 °C, basic density of 560 $kg \cdot m^{-3}$, moisture content of 0.4, 0.6, and 0.8 $kg \cdot kg^{-1}$, during their simultaneous steaming in an autoclave according to regimes with $d \times b$ = 0.5 × 0.5 m are presented and analysed in the paper. An autoclave with industrial dimensions: diameter of 2. 4 m, length of 9.0 m and loading level of 40, 50, 60% and a limited heat power of the steam generator q_{source} = 500 kW were used during the simulations.

It was found that veneer of good quality in accordance with the standard can be obtained after simultaneous steaming of prisms of the same wood species with differences between their thicknesses up to 100 mm. It is necessary to carry out the steaming according to the regime that applies to the prisms with the largest thickness in a given batch. Then the influence of the wood moisture content and loading level of the autoclave on the plasticization degree of the prisms and on the veneer quality is practically negligible.

The suggested approach and the obtained results can be used for the computation and model based automatic realization of energy efficient optimized regimes for autoclave steaming of different wood materials at limited power of the steam generator (HADJISKI and DELIISKI 2016, HADJISKI *at al*. 2019).

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