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COMPUTING THE ENERGY FOR WARMING UP THE PRISMS FOR VENEER PRODUCTION DURING AUTOCLAVE STEAMING WITH A LIMITED POWER OF THE HEAT GENERATOR

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ABSTRACT

An approach for computing the specific energy needed for warming up the wooden prisms for veneer production during their autoclave steaming with a limited power of the heat generator is suggested. The approach is based on the integration of the numerical solutions of the created and verified 2-dimensional mathematical model for the transient non-linear heat conduction and energy consumption in frozen and non-frozen prismatic wood materials. An application of the suggested approach is shown in the paper for the case of computing the specific energy for warming up non-frozen and frozen beech prisms with cross-sections of 0.3 × 0.3 m, 0.4 × 0.4 m, 0.5 × 0.5 m and moisture content of 0.6 $kg \cdot kg^{-1}$ during their autoclave steaming aimed at their plasticizing in the veneer production. The power of the steam generator is limited and equal to 500 kW. The obtained results can be used to create the systems for optimized energy saving model based automatic control of the steaming process of wood materials.

Key words: autoclave steaming, energy consumption, wood materials, heat generator, limited power, model based control.

INTRODUCTION

The steaming of wood materials with prismatic shape aimed at their plasticizing is an important part of the technological processes in the production of veneer and plywood (SHUBIN 1990, STEINHAGEN 1991, BURTIN *et al.* 2000, TREBULA – KLEMENT 2002, VIDELOV 2003, BEKHTA – NIEMZ 2003, PERVAN 2009, DELIISKI – DZURENDA 2010, DAGBRO *et al.* 2010, DELIISKI 2013b), etc.

The traditionally equipment and technologies used for steaming wood materials at atmospheric pressure of the processing medium are characterized by long durability (till some days) and low energy efficiency. During the last decades the utilization of intensive steaming of wood materials under increased pressure of the steam in autoclaves started (RIEHL *et al.* 2002, DELIISKI 2003, 2004, 2011a, VIDELOV 2003, DELIISKI – SOKOLOVSKI 2007, SOKOLOVSKI *et al.* 2007, DELIISKI *et al.* 2013a, 2013b).

In the specialized literature information about the energy consumption needed for warming up of wood materials during their autoclave steaming was given by DELIISKI (2003, 2009, 2013b), DELIISKI *et al.* (2010), DZURENDA – DELIISKI (2008, 2012), and DELIISKI –

DZURENDA (2010). The energy calculation in these publications were carried out for cases of unlimited generator power only.

The aim of the present work is to suggest an approach for the computation of the specific energy needed for warming up of wooden prisms for veneer production during their autoclave steaming with a limited power of the heat generator.

MATERIAL AND METHODS

Modelling of the 2D heat distribution in the wood prisms subjected to steaming

Mathematical models of 1D, 2D, and 3D heating processes of prismatic wood materials during their steaming at atmospheric and increased pressure of the processing medium have been created, solved and verified earlier by DELIISKI (2003, 2011b, 2013b, 2013c).

When the width of the wooden prisms does not exceed their thickness more than 3 times and simultaneously with this the length exceeds the thickness at least 5 times, then the heat transfer through the frontal sides of the prisms can be neglected, because it does not influence the change in temperature in the cross-section, which is equally distant from the frontal sides. In these cases for the calculation of the change in T in this section (i.e. only along the coordinates x and y) the following 2D model can be used:

$$\begin{aligned} & c_{\text{w-e}}\left(T,u,u_{\text{fsp}}\right)\cdot\rho_{\text{w}}(\rho_{\text{b}},u)\frac{\partial T(x,y,\tau)}{\partial\tau}= \\ & =\frac{\partial}{\partial x}\left[\lambda_{\text{w-cr}}\left(T,u,\rho_{\text{b}},u_{\text{fsp}}\right)\frac{\partial T(x,y,\tau)}{\partial x}\right]+\frac{\partial}{\partial y}\left[\lambda_{\text{w-cr}}\left(T,u,\rho_{\text{b}},u_{\text{fsp}}\right)\frac{\partial T(x,y,\tau)}{\partial y}\right] \end{aligned} \tag{1}$$

with an initial condition:

$$T_{\text{w}}(x,y,0)=T_{\text{w0}} \tag{2}$$

and the following boundary conditions:

$$T_{\text{w}}(0,y,\tau)=T_{\text{w}}(x,0,\tau)=T_{\text{m}}(\tau) \tag{3}$$

According to eq. (3), the temperature at the prisms' surfaces being in contact with the processing medium is equal to its temperature T_{m} due to the extremely high coefficient of heat transfer between the condensed saturated water steam on the wood materials during the whole regime of their thermal treatment processing (TTP).

Equations (1) to (3) represent a common form of a mathematical model of 2D heat distribution in prismatic wood materials subjected to steaming.

Mathematical description of the thermo-physical characteristics of the wood materials

For solving and practical usage of eq. (1) it is needed to have mathematical descriptions of the thermal conductivity cross sectional to the fibers of the non-frozen and frozen wood, $\lambda_{\text{w-cr}}$, of the effective specific heat capacity of the frozen and non-frozen wood, $c_{\text{w-e}}$, and of the wood density above the hygroscopic range (i.e. when $u > u_{\text{fsp}}$), ρ_{w}. For this purpose the description of $\lambda_{\text{w-cr}}$, $c_{\text{w-e}}$, and ρ_{w} given in (DELIISKI 2011b, 2013b) and in (DELIISKI – DZURENDA 2010) can be used.

Mathematical descriptions of the thermal conductivity of non-frozen and frozen wood, λ_{w}, and also of the specific heat capacity of the wood, c_{w}, have been suggested by DELIISKI (1990, 1994, 2003, 2013a) using the experimentally determined in the dissertations by KANTER (1955) and CHUDINOV (1966) data for their change as a function of t and u. This data for $\lambda_{\mathrm{w}}(t,u)$ and $c_{\mathrm{w}}(t,u)$ find a wide use in both the European (SHUBIN 1990, POŽGAJ *et al*. 1997, TREBULA – KLEMENT 2002, VIDELOV 2003, PERVAN 2009) and the American specialized literature (STEINHAGEN 1986, 1991, STEINHAGEN – LEE – LOEHNERTZ 1987, STEINHAGEN – LEE 1988, KHATTABI – STEINHAGEN 1992, 1993, 1995) when calculating various processes of the wood thermal treatment.

According to the mathematical description suggested in DELIISKI (1994, 2003, 2013a), the wood thermal conductivity during freezing of the wooden prisms can be calculated with the help of the following equations for $\lambda_{\mathrm{w}}(T,u,\rho_{\mathrm{b}},u_{\mathrm{fsp}})$ above the hygroscopic range:

$$\lambda_{\mathrm{w}} = \lambda_{\mathrm{w0}} \cdot \gamma[1+\beta(T-273.15)] \ @ \ u > u_{\mathrm{fsp}}^{272.15} \ \& \ 213.15 \ \mathrm{K} \le T \le 423.15 \ \mathrm{K} \tag{4}$$

$$\lambda_{\mathrm{w0}} = K_{\mathrm{ad}} \cdot \nu[0.165 + (1.39+3.8u)\cdot(3.3.10^{-7}\rho_{\mathrm{b}}^2 + 1.015.10^{-3}\rho_{\mathrm{b}})] \tag{5}$$

$$v = 0.1284 - 0.013u \tag{6}$$

In DELIISKI (2003, 2013b) the precise values of the coefficient K_{ad} in eq. (5) for different wood species have been determined. For the discussed in this paper beech wood the following value of $K_{\mathrm{ad\text{-}cr}} = K_{\mathrm{ad}} = 1.28$ has been obtained.

The coefficients γ and β in equation (1) are calculated using the following equations:

- For non-frozen wood when $u > u_{\mathrm{fsp}}^{272.15}$ and at the same time

$272.15 \ \mathrm{K} < T \le 423.15 \ \mathrm{K}$:

$$\gamma = 1.0 \tag{7}$$

$$\beta = 3.65\left(\frac{579}{\rho_{\mathrm{b}}} - 0.124\right)\cdot 10^{-3} \tag{8}$$

- For frozen wood when $u > u_{\mathrm{fsp}}^{272.15}$ and at the same time

$213.15 \ \mathrm{K} \le T \le 272.15 \ \mathrm{K}$:

$$\gamma = 1 + 0.34[1.15(u-u_{\mathrm{fsp}})] \tag{9}$$

$$\beta = 0.002(u-u_{\mathrm{fsp}}) - 0.0038\left(\frac{579}{\rho_{\mathrm{b}}} - 0.124\right) \tag{10}$$

where the fiber saturation point of the wood specie u_{fsp} is calculated according to the equation

$$u_{\mathrm{fsp}} = u_{\mathrm{fsp}}^{293.15} - 0.001(T-293.15) \tag{11}$$

and $u_{\mathrm{fsp}}^{272.15}$ is the fiber saturation point at T = 272.15 K (i.e. at t = –1 °C), kg·kg^{-1}. At this temperature the melting of the frozen bound water in the wood is fully completed and the melting of the free water in the wood starts, (DELIISKI – TUMBARKOVA 2016);

According to the suggested in DELIISKI (1990, 2011b, 2013b) mathematical description, the effective specific heat capacities the wood during TTP in an autoclave can be calculated with the help of the following equations for $c_{\mathrm{w\text{-}e}}(T,u,u_{\mathrm{fsp}})$ above the hygroscopic range:

- For non-frozen wood when $u > u_{\mathrm{fsp}}^{272.15}$ and at the same time the condition

$273.15 \ \mathrm{K} \le T \le 423.15 \ \mathrm{K}$ is fullfilld:

$$c_{\mathrm{w\text{-}e}} = c_{\mathrm{w-nfr}} \tag{12}$$

where

$$c_{\mathrm{w-nfr}} = \frac{2862u + 555}{1+u} + \frac{5.49u + 2.95}{1+u}T + \frac{0.0036}{1+u}T^2 \tag{13}$$

• For wood with frozen only free water in it when $u > u_{\mathrm{fsp}}^{272.15}$ and at the same time $272.15\ \mathrm{K} < T \le 273.15\ \mathrm{K}$:

$$c_{\mathrm{w\text{-}e}} = c_{\mathrm{w-nfr}} + c_{\mathrm{fw}} \tag{14}$$

where

$$c_{\mathrm{fw}} = 3.34 \cdot 10^5 \frac{u - u_{\mathrm{fsp}}^{272.15}}{1+u} \tag{15}$$

• For wood with frozen bound and free water in it when $u > u_{\mathrm{fsp}}^{272.15}$ and at the same time the condition $213.15\ \mathrm{K} \le T \le 272.15\ \mathrm{K}$ is fullfilld:

$$c_{\mathrm{w\text{-}e}} = c_{\mathrm{w-fr}} + c_{\mathrm{bwm}} \tag{16}$$

where

$$c_{\mathrm{w-fr}} = 1.06 + 0.04u + \frac{0.00075\,(T - 272.15)}{u_{\mathrm{fsp}}^{272.15}} \cdot \frac{526 + 2.95 + 0.0022\,T^2 + 2261u + 1976\,u_{\mathrm{fsp}}^{272.15}}{1+u}$$

(17)

where

$$c_{\mathrm{bwm}} = 1.8938 \cdot 10^4 \left(u_{\mathrm{fsp}}^{272.15} - 0.12\right) \cdot \frac{\exp\left[0.0567\,(T - 272.15)\right]}{1+u} \tag{18}$$

$$u_{\mathrm{fsp}}^{272.15} = u_{\mathrm{fsp}}^{293.15} + 0.021 \tag{19}$$

Eq. (19) is obtained from eq. (11) after substitution of T in it by T = 272.15 K.

The wood density ρ_{w}, which participate in eq. (1), is determined above the hygroscopic range according to the below equation (CHUDINOV 1968, PERVAN 2009, DELIISKI 2011, DELIISKI *et al*. 2015b, HRČKA 2017)

$$\rho_{\mathrm{w}} = \rho_{\mathrm{b}} \cdot (1+u) \tag{20}$$

Modelling of the heat energy needed for warming up of prisms during their steaming in an autoclave

It is known that the specific heat energy consumption, which is needed for the warming up of 1 m^3 of solid material, Q_{h}, with an initial mass temperature T_0 to a given average mass temperature T_{avg} is determined using the following equation (DELIISKI 2003, 2013b, DELIISKI – DZURENDA 2010):

$$Q_{\mathrm{h}} = \frac{c \cdot \rho}{3.6 \cdot 10^6} \cdot \left(T_{\mathrm{avg}} - T_0\right) \tag{21}$$

Based on eq. (21), the specific energy needed for warming up of prismatic wood materials during their steaming can be calculated according to the following equation

$$Q_{\mathrm{hw}}^{n} = \frac{\rho_{\mathrm{w}}}{3.6 \cdot 10^6 S_{\mathrm{w}}} \cdot \left\{ \iint_{S_{\mathrm{w}}} \frac{c_{\mathrm{w\text{-}e}} @ T_{i,k}^{n} + c_{\mathrm{w\text{-}e}} @ T_{\mathrm{w0}}}{2} \cdot (T_{i,j}^{n} - T_{\mathrm{w0}})\mathrm{d}S_{\mathrm{w}} \right\} \tag{22}$$

$$@\ \ T_{\mathrm{w0}} \le T_{i,k}^{n} \le T_{\mathrm{w-avg\text{-}end}}$$

where

$$T^n_{\mathrm{w-avg}} = \frac{1}{S_\mathrm{w}} \iint\limits_{S_\mathrm{w}} T^n_{i,k} \mathrm{d}S_\mathrm{w} \tag{23}$$

$$S_\mathrm{w} = \frac{d \cdot b}{4} \tag{24}$$

The multiplier $3.6 \cdot 10^6$ in the denominator of eq. (22) ensures that the values of Q_{hw} are obtained in kWh·m^{-3}, instead of in J·m^{-3}.

RESULTS AND DISCUSSION

For numerical solution of the above presented mathematical model aimed at computation of the energy needed for warming up of prisms for veneer production during their autoclave steaming with a limited power of the heat generator a software package was prepared, which was 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 2011b, 2013b).

With the help of the software package and of the approach suggested by the authors in DELIISKI *et al.* 2018, computations were made for the determination of T_m and also of the 2D non-stationary change of the temperature in 4 characteristic points of ¼ of the square cross section of beech prisms with thickness *d* and width *b* respectively, during their steaming in an autoclave with a diameter D = 2.4 m and length of its cylindrical part L = 9.0 m (DELIISKI – SOKOLOVSKI 2007, DELIISKI – DZURENDA 2010). The dimensions of the prisms' cross sections were equal to 0.3 × 0.3 m, 0.4 × 0.4 m, 0.5 × 0.5 m, and the coordinates of their characteristic points were, as follow: Point 1: d/8, b/8; Point 2: d/4, b/4; Point 3: d/2, b/4; and Point 4: d/2, b/2. During the solving of the models, the above presented mathematical descriptions of the thermo-physical characteristics of beech wood (*Fagus Sylvatica* L.) with basic density ρ_b = 560 kg·m^{-3} and fiber saturation point $u^{293.15}_{\mathrm{fsp}} = 0.31\ \mathrm{kg} \cdot \mathrm{kg}^{-1}$ (NIKOLOV – VIDELOV 1987, DELIISKI – DZURENDA 2010) were used. The initial temperature of the prisms was equal to 0 °C and –20 ºC and their moisture content was 0.6 kg·kg^{-1}.

The increase of t_m at the beginning of the 3-stage steaming regimes is calculated according to the approach given by the authors in DELIISKI *et al.* 2018 by taking in mind the available heat power of the generator that produces steam. During simulations the limited power of the generator q_{source} = 500 kW and loading level of the autoclave with filled in beech prisms for steaming ψ = 0.4 m^3·m^{-3} (i.e. ψ = 40%) were set.

Simultaneously with the solution of the model, computations of T_{avg} and Q_{hw} have been carried out, using the value of the wood density ρ_w = 896 kg.m^{-3}. This value of ρ_w is calculated according to eq. (20) for beech wood with u = 0.6 kg·kg^{-1} and ρ_b = 560 kg·m^{-3}.

During the numerical simulations 3-stage TTP regimes for autoclave steaming of the prisms (see Fig. 1 to 4 below) were used, which form was presented in (DELIISKI *et al.* 2018). As it was described in this source, during the first stage of the TTP regime input of water steam is accomplished in the autoclave, with situated inside wooden materials, until the temperature of the processing medium t_m = 130 °C is reached. After reaching t_m = 130 °C, this temperature is maintained unchanged by reducing the input of steam flux inside the autoclave until the calculated by the model average mass temperature of the wood, t_{avg}, reaches a value of 90 °C. After reaching t_{avg} = 90 °C the input of steam in the autoclave is terminated and the second stage of the steaming regime begins. During this stage, by using the accumulated heat in the autoclave, the further heating and plasticizing of the prisms is accomplished, thus resulting in gradual reduction of the temperature t_m for about 2 hours down to around 115 °C. Afterwards, the cranes directing the steam and condensed water out of the autoclave are opened, which initiates the third stage of the steaming regime. This stage ends after about one and half hour, when t_m reaches approximate value of around 80 °C.

The calculations of T_{avg} have been carried out during the whole TTP regimes but the computations of Q_{hw} have been conducted during only the first stages of these regimes, i.e. until reaching the set value of the average mass temperature of all studied prisms $t_{avg} = 90$ °C.

On Fig. 1 and Fig. 2 the calculated change in the temperature of the processing medium, t_m, and also in the temperature in 4 characteristic points of 2 beech prisms with cross-section dimensions $d \times b = 0.3 \times 0.3$ m, initial temperature $t_0 = 0$ °C and $t_0 = -20$ °C during their TTP in an autoclave with loading level $\gamma = 40$ % is presented. The coordinates of the separate characteristic points are given in the legend of the figures.

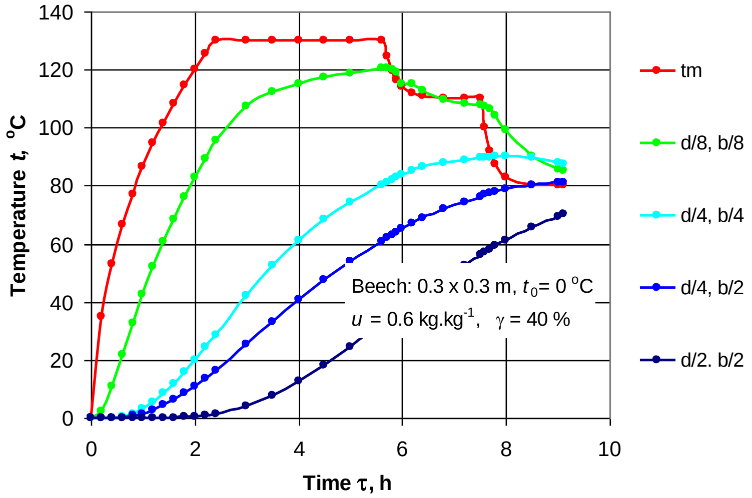

Fig. 1 Change in t_m and t in 4 characteristic points of beech prisms with cross-section dimensions $d \times b = 0.3 \times 0.3$ m and $t_0 = 0$ °C during their TTP in an autoclave at a loading of 40%.

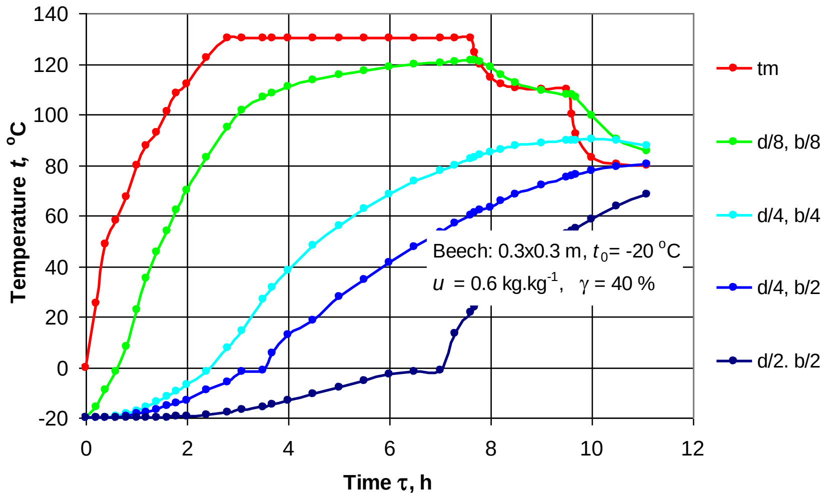

Fig. 2 Change in t_m and t in 4 characteristic points of beech prisms with cross-section dimensions $d \times b = 0.3 \times 0.3$ m and $t_0 = -20$ °C during their TTP in an autoclave at a loading of 40%.

Figures 3 and 4 present the calculated change of t_m in an autoclave and of t_{avg} during TTP of the studied beech prisms with t_0 = 0 °C and –20 °C respectively.

Figures 5 and 6 present the calculated change in t_m and Q_{hw} during the first stages of the TTP regimes for autoclave steaming with a limited power of the heat generator.

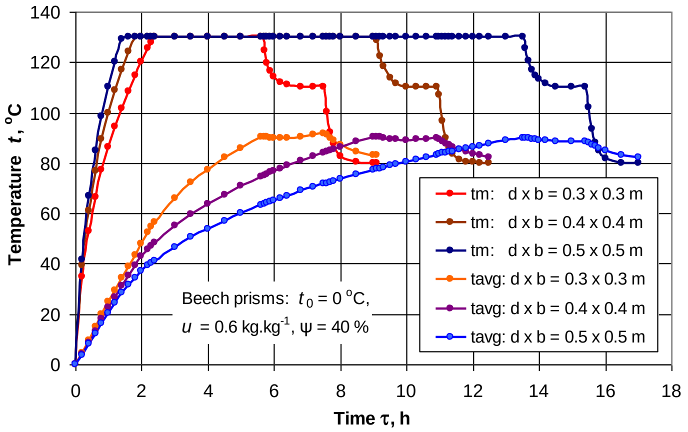

Fig. 3 Change in t_m and t_{avg} during the steaming of beech prisms with t_0 = 0 °C in an autoclave at γ = 40%, depending on their cross-section dimensions.

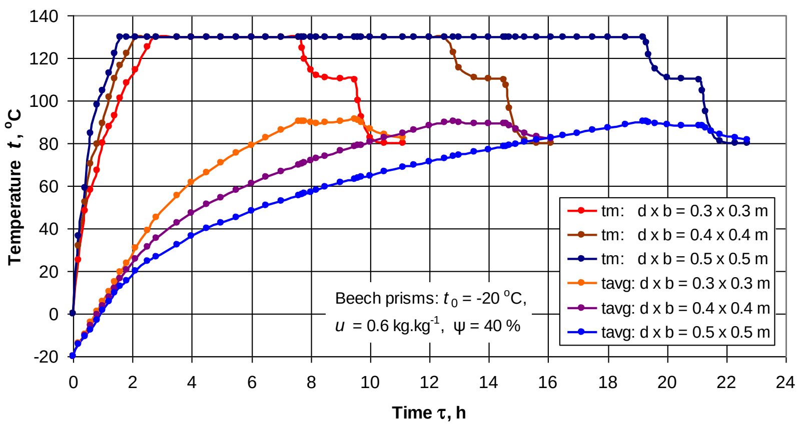

Fig. 4 Change in t_m and t_{avg} during the steaming of beech prisms with t_0 = –20 °C in an autoclave at γ = 40%, depending on their cross-section dimensions.

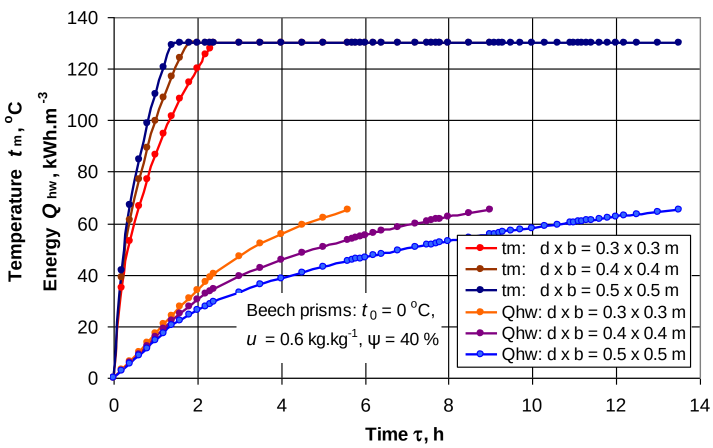

Fig. 5 Change in t_m and Q_{hw} during the steaming of beech prisms with t_0 = 0 °C in an autoclave at γ = 40%, depending on their cross-section dimensions.

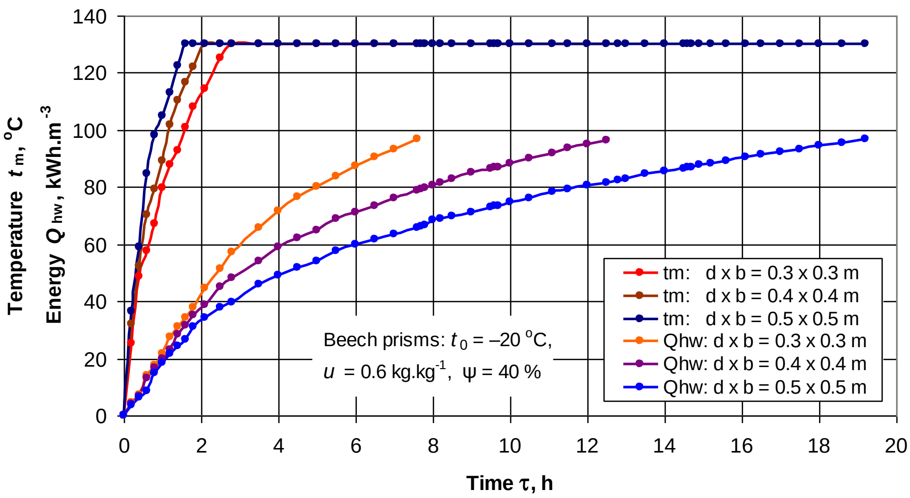

Fig. 6 Change in t_m and Q_{hw} during the steaming of beech prisms with t_0 = –20 °C in an autoclave at γ = 40%, depending on their cross-section dimensions.

The analysis of the obtained simulation results, part of which are presented on Fig. 1 to Fig. 6 lead to the following statements:

1. The non-stationary increasing of the temperature in the prisms' characteristic points goes on according to very complex curves during the steaming process (Fig. 1 and Fig. 2).

2. When the water in the prisms is fully in a liquid state (i.e. at $t_{w0} \geq 0$ °C), the increasing of t_m causes a smoothly increasing of t in the characteristic points. The smoothness of the increasing of t depends proportionally on the distance of the points from the both prisms' surfaces (Fig. 1).

3. When the subjected to steaming prisms are in frozen state, specific almost horizontal sections of retention of the temperature for a long period of time in the range from –1 °C to 0 °C can be seen, while in the points a complete melting of the frozen free water in the wood occurs (Fig. 2). As far the point is distanced from the prisms' surfaces that much these sections with temperature retention are more extended. The reason of such a long retention of the wood temperature is the very low temperature conductivity of the wood during melting of the frozen free water in it (DELIISKI *et al.* 2015).

4. The smoothness of the increasing of t_{avg} from $t_{avg} = t_{w0}$ to t_{avg} = 90 °C during the 1st stage of TTP regimes depends proportionally on the dimensions of the prisms' cross section. During the 2nd stage of the regimes t_{avg} remains practically unchanged and during the 3rd stage it decreases until reaching approximate value of around 82–83 °C (Fig. 3 and Fig. 4).

5. The increasing of the steaming time causes a smoothly increasing in the specific heat energy Q_{hw}, which character is analogous to that of t_{avg}. At the end of the 1st stage of TTP regimes, when t_{avg} = 90 °C is reached, this energy reaches values of 65.4 kWh.m^{-3} and 96.6 kWh.m^{-3} for prisms with t_{w0} = 0 °C and t_{w0} = –20 °C respectively (Fig. 5 and Fig. 6). The larger value of Q_{hw} at t_{w0} = –20 °C in comparison with that at t_{w0} = 0 °C is caused mainly by the participation in Q_{hw} of the energy, which is needed for the melting of the frozen free water in the wood in the range from –1 °C to 0 °C (DELIISKI – DZURENDA 2010, DELIISKI *et al.* 2013a).

CONCLUSIONS

The present paper describes the suggested approach for the computation of the specific heat energy Q_{hw}, which is needed for warming up of wooden prisms for veneer production during their steaming in an autoclave at limited heat power of the steam generator. The approach is based on the integration of the numerical solutions of personal 2D non-linear mathematical model of the steaming process of frozen and non-frozen prismatic wood materials, which are obtained using suggested by the authors in (DELIISKI *et al.* 2018) regimes for TTP with limited power of the heat generator.

For the solution of the model and practical application of the suggested approach for computation of Q_{hw}, a software program was prepared in the calculation environment of Visual Fortran Professional developed by Microsoft.

The paper shows and analyses, as an example, diagrams of the non-stationary change in 2D temperature distribution and in dependant on it change in t_{avg} and Q_{hw} of beech prisms with cross-section dimensions 0.3 × 0.3 m, 0.4 × 0.4 m, and 0.5 × 0.5 m, initial temperatures of 0 °C and –20 °C, basic density of 560 kg·m^{-3}, and moisture content of 0.6 kg·kg^{-1} during their steaming in an autoclave with a diameter of 2. 4 m, length of 9.0 m and loading with wood materials 40%, until reaching the average wood mass temperature of 90 °C at a limited heat power of the steam generator, equal to 500 kW. All diagrams are drawn using the results calculated by the model.

It has been determined, that the decrease of the cross-section dimensions of the prisms causes faster increase in t_{avg} and Q_{hw} during the 1st stage of the studied TTP regimes. At the end of this stage, i.e. at t_{avg} = 90 °C, the energy Q_{hw} reaches values of 65.4 kWh.m^{-3} and 96.6 kWh.m^{-3} for beech prisms with t_{w0} = 0 ^{o}C and t_{w0} = –20 ^{o}C respectively.

The obtained results can be used for science based computation of the energy saving optimized regimes for autoclave steaming of different wood materials at limited power of the steam generator. They will support the creation and improvement of systems for model based automatic realization of such regimes (DELIISKI 2003, 2011a, HADJISKI – DELIISKI 2016, HADJISKI *at al*. 2018).

Symbols

b = width (m)
c = specific heat capacity (J·kg^{-1}·K^{-1})
d = thickness (m)
Q = specific heat energy (kWh·m^{-3})
S = aria (m^2)
T = temperature (K)
t = temperature (^{o}C): $t = T - 273.15$
u = moisture content (kg·kg^{-1} = %/100)
x = coordinate on the thickness: $0 \le x \le d/2$ (m)
y = coordinate on the width: $0 \le y \le b/2$ (m)
β = coefficients in the equations for determining of λ
γ = coefficients in the equations for determining of λ
λ = thermal conductivity (W·m^{-1}·K^{-1})
ρ = density (kg·m^{-3})
τ = time (s)
ψ = loading level of the autoclave with filled in beech prisms for steaming (%)
Δτ = interval between time levels during the solving of the mathematical model (s)

Subscripts

ad = anatomical direction
avg = average (for mass temperature of the prisms)
b = basic (for density, based on dry mass divided to green volume)
bw = bound water
bwm = maximal possible amount of the bound water in the wood species
cr = cross sectional to the fibers
e = effective (for specific heat capacity)

end = end
fsp = fiber saturation point
fw = free water
h = heat
i = mesh point in the direction along the thickness for the prisms: 1, 2, 3, …, $(d/\Delta x)+1$
j = mesh point in the direction along the prisms' width: 1, 2, 3, …, $(b/\Delta x)+1$
m = medium
nfw = non-frozen water
0 = initial (for temperature) or at 0 °C (for λ)
p = process
w = wood
& = and simultaneously with this
@ = at

Superscripts

n = time level during the solving of the mathematical model: $n = 0, 1, 2, 3, \ldots, \tau_p/\Delta\tau$
272.15 = at 272.15 K, i.e. at –1 °C
293.15 = at 293.15 K, i.e. at 20 °C (for the standardized values of the wood fiber saturation point)

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