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Modeling and Energy Consumption of the One Sided Heating Process of Flat Wood Details before Bending

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Key Words: *Wood details; one sided heating; modeling; plasticizing; bending; specific energy consumption.*

Abstract. *A methodology for mathematical modeling and research of two mutually connected problems: temperature distribution along the thickness of subjected to one sided heating flat wood details and energy consumption of this process has been suggested. For the realization of the methodology, a 1-dimensional mathematical model has been created and solved for the transient non-linear heat conduction in flat wood details during their one sided heating. Based on the integration of the model's solutions, a numerical approach for the computation of the total specific (for 1 m2) energy consumption needed for the heating of the details aimed at their plasticizing before bending in the production of curved details for different applications in the furniture industry has been suggested. The total energy consists of two components: energy for warming up of the wood itself and energy for covering of the emission from the non-heated side of the details in the surrounding environment during the heating.*

1. Introduction

An important mandatory component of the technologies for production of curved wood details is their plasticizing up to the stage that allows their faultless bending [1,13,16].

The one sided heating is used for plasticizing of wood in the production of curved details for the back parts of chairs or curved outside parts for the corpses of string music instruments (violins, violoncellos, guitars, mandolins). The technologies for plasticizing of such details are most often carried out in the specific equipment used for bending.

The curved details for the back parts of chairs, which are produced through this method of plasticizing, have a relatively small thickness h_w, a large radius R of the curvature, and a relationship of $R/h_w = 20 \div 25$ [13,14,15]. For such heating of details with thicknesses between 10 and 25 mm and moisture content from 12% to 20% in the production of chairs, hot hydraulic presses in the range from 80ºC to 120ºC with appropriately bent surfaces or electrically heated tube are usually used (*figure 1*).

Plasticizing with relatively low wood moisture content ensures considerable decreasing of the duration of the following drying of the bent details aimed at lasting stabilization of their form [17,18].

The duration of the heating process and the energy consumption for one sided heating of wood details aimed at their plasticizing before bending depends on many factors: wood specie, thickness and moisture content of the details, temperatures of the heating medium and of the surrounding air, desired degree of plasticizing, etc. [1,5,8,17].

Figure 1. Overview of an electrically heated tube for one sided heatng and bending of flat wood details (BAS)

In the specialized literature information about the energy consumption needed for the one sided heating of flat wood details was given only by the authors concerning the production of bent parts for the corpses of string music instruments [6,7]. The calculation of the energy consumption in these publications was carried out using a suggested by the authors linear model for the heat distribution in subjected to one sided heating flat wood details [4].

The aim of the present work is to suggest a numerical approach for the computation of the total specific energy consumption of the one sided heating process, which has to be based on the integration of the solutions of more complicated and precise non-linear model for the calculation of the non-stationary 1D temperature distribution along the thickness of subjected to such heating flat wood details.

2. Mechanism of the Heat Distribution in Flat Wood Details Subjected to One Sided Heating

The mechanism of the heat distribution in wood details during their one sided conductive heating can be described by the equation of the heat conduction [2,3,5]. When the width and length of the wood details exceed their thickness by at least 3 and 5 times respectively, then the calculation of the change in the temperature only along the thickness of the details in the center of their flat side during the one sided heating (i.e. along the coordinate x, which coincides with the details' thickness h_w) can be carried out with the help of the following non-linear 1D mathematical model:

$$c_w(T,u)\rho_w(\rho_b,u,u_{fsp},S_v)\frac{\partial T_w(x,\tau)}{\partial \tau} = \lambda_w(T,u,\rho_b)\frac{\partial^2 T_w(x,\tau)}{\partial x^2} + \frac{\partial \lambda_w(T,u,\rho_b)}{\partial T}\left(\frac{\partial T_w}{\partial x}\right)^2 \quad (1)$$

with an initial condition

$$T_w(x,0) = T_{w0} \quad (2)$$

and following boundary conditions:

• from the side of the details' heating – at prescribed surface temperature, which is equal to the temperature of the metal heating body t_m (see *figure 2* below):

$$T_w(0,\tau) = T_m(\tau), \quad (3)$$

• from the opposite non-heated side of the details – at convective heat exchange between the details' surface and the surrounding air environment

$$\frac{dT_w(X,\tau)}{dx} = -\frac{\alpha_w(\tau)}{\lambda_{ws}(\tau)}\left[T_a(\tau) - T_{ws}(\tau)\right]. \quad (4)$$

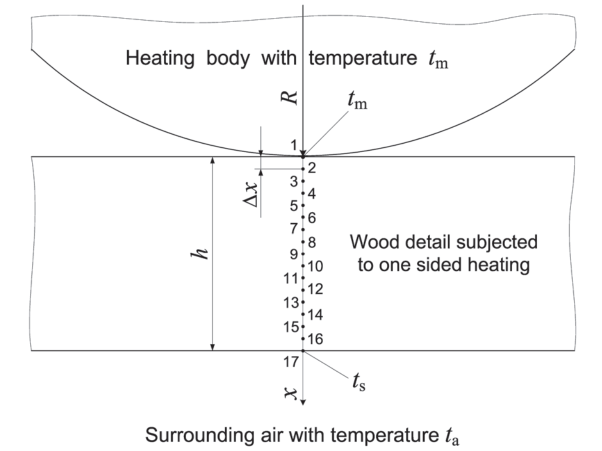

Figure 2. Positioning of the nodes of the 1D calculation mesh along the thickness of the wood detail subjected to one side heating

According to eq. (3), the temperature at the details surface being in contact with the heating body (i.e. the point with *x-coordinate* = 0 m) is equal to its temperature T_m due to the extremely high coefficient of heat transfer between the body and the wood during their very close contact.

According to eq. (4), the temperature of the non-heated surface of the details depends on the current value of the difference between it and the temperature of the surrounding air and also on the current values of the thermo-physical characteristics of the wood λ_{ws} and α_w during the one sided heating.

3. Mathematical Description of the Thermo-Physical Characteristics of the Wood c_w, λ_w, and α_w

For the usage of the equations (1) and (4) it is needed to have a mathematical description of the specific heat capacity of the wood, c_w, of the wood's thermal conductivity, λ_w, and of the heat transfer coefficient α_w.

The following equations for the calculation of c_w and λ_w of non-frozen wood in the hygroscopic range (i.e. when $u < u_{fsp}$) have been suggested in [2]:

$$c_w = \frac{2097u + 826}{1+u} + \frac{9.92u + 2.55}{1+u}T + \frac{0.0002}{1+u}T^2, \quad (5)$$

$$\lambda_w = \lambda_{w0}\left[1 + \beta(T - 273.15)\right], \quad (6)$$

where

$$\lambda_{w0} = K_{ad}\nu \cdot [0.165 + (1.39 + 3.8u) \cdot (3.3 \cdot 10^{-7}\rho_b^2 + 1.015 \cdot 10^{-3}\rho_b)], \quad (7)$$

$$\nu = 0.15 - 0.07u, \quad (8)$$

$$\beta = (2.05 + 4u) \cdot \left(\frac{579}{\rho_b} - 0.124\right) \cdot 10^{-3}. \quad (9)$$

Equations (5)÷(9) are part of the mathematical description of the thermo-physical characteristics of wood, which has been done earlier in [2] using many experimental data derived by different scientists.

It is pointed and shown in [2,3], that this data finds a wide use in both European and the American specialized literature when calculating various processes of thermal treatment of wood. This fact ensures good adequacy of the suggested in this paper non-linear mathematical model to the real process of warming up of wood details during their one sided heating before bending.

The calculation of the heat transfer coefficient α_w can be carried out with the help of the following equation, which is valid for the cases of cooling or heating of horizontally situated wood plates in atmospheric conditions of free convection in the hygroscopic range [6,7]:

$$\alpha_w = 3.256\left[T_{ws}(\tau) - T_a(\tau)\right]^{0.25}. \quad (10)$$

4. An Approach for Computing the Energy Needed for One Sided Heating of Wood Details

The total specific energy consumption for unilateral heating of wood details, Q_{total}, consists of two components:

• energy needed for warming up of the wood itself, Q_w;

• energy needed for covering of the heat emission from the non-heated side of the wood details, Q_e.

This means that the energy Q_{total} can be calculated according to the following equation:

$$Q_{\text{total}} = Q_{\text{w}} + Q_{\text{e}} . \quad (11)$$

It is known that the specific energy consumption for the heating of 1 m^3 of solid materials, Q, with an initial mass temperature T_0 to a given average mass temperature T_{avg} is determined using the following equation [3,5]:

$$Q = \frac{c \cdot \rho \cdot \left(T_{\text{avg}} - T_0\right)}{3.6 \cdot 10^6} . \quad (12)$$

After multiplying the right part of eq. (12) with the detail's thickness h_w the following equation for the determination of the specific mass energy consumption needed for the warming up of 1 m^2 of the subjected to one sided heating flat wood details, Q_w, is obtained:

$$Q_{\text{w}} = \frac{c_{\text{w}} \cdot \rho_{\text{w}} \cdot h_{\text{w}} \cdot \left(T_{\text{w-avg}} - T_{\text{w0}}\right)}{3.6 \cdot 10^6} , \quad (13)$$

where

$$T_{\text{w-avg}} = \frac{1}{h_{\text{w}}} \int_{(h)} T_{\text{w}}(x, \tau) \text{d}x \quad (14)$$

and according to [2,3]

$$\rho_{\text{w}} = \rho_{\text{b}} \frac{1 + u}{1 - \frac{S_{\text{v}}}{100}\left(u_{\text{fsp}}^{293.15} - u\right)} \quad @ \quad u \le u_{\text{fsp}}. \quad (15)$$

The multiplier $3.6 \cdot 10^6$ in the denominator of eq. (13) ensures that the values of Q_w are obtained in kWh·m^{-2}, instead of in J·m^{-2}.

The change in the specific energy consumption ΔQ_e, which is needed for covering of the heat emission from 1 m^2 of the non-heated details' surface into the surrounding air environment during time of $\Delta\tau$, can be calculated according to the equation [3,5]

$$\Delta Q_{\text{e}} = \frac{\alpha_{\text{w}}(\tau) \cdot \Delta\tau}{3.6 \cdot 10^6} \left[T_{\text{ws}}(\tau) - T_{\text{a}}\right]. \quad (16)$$

The specific energy consumption Q, needed for the covering of the emission from 1 m^2 surface of the details during their one sided heating with duration of the whole heating process $\tau_p = N \cdot \Delta\tau$ is equal to

$$Q_{\text{e}} = \sum_{j=1}^{N} \Delta Q_{j\text{e}} . \quad (17)$$

5. Transformation of the Model to a Form Suitable for Programming

The presenting of the mathematical model (1)÷(4) through its discrete analogue suitable for programming corresponds to the shown setting of the coordinate system and the positioning of the nodes in the mesh shown on *figure 2*, in which the 1D distribution of the temperature along the thickness of flat wood details subjected to one sided heating is calculated.

The following system of equations has been derived by passing to final increases in eqs. (1)÷(4) with the usage of the same, as well as by the described in [2,3,5] explicit form of the finite-difference method:

$$T_i^0 = T_{\text{w0}} \quad @ \quad 1 \le i \le 17 , \quad (18)$$

$$T_1^{n+1} = T_{\text{m}} \quad @ \quad 1 \le i \le 17 , \quad (19)$$

$$T_i^{n+1} = T_i^n + \frac{\lambda_{\text{w0c}} \cdot \Delta\tau}{c_{i\text{w}}^n \cdot \rho_{\text{w}} \cdot \Delta x^2} \cdot \left\{ \begin{array}{l} \left[1 + \beta \cdot \left(T_i^n - 273.15\right)\right] \cdot \\ \cdot \left(T_{i+1}^n + T_{i-1}^n - 2T_i^n\right) + \beta \cdot \left(T_i^n - T_{i-1}^n\right)^2 \end{array} \right\} , \quad @ \quad 2 \le i \le 16 \quad (20)$$

$$T_{17}^{n+1} = \frac{T_{16}^n + \alpha_{\text{w}}^n \cdot T_{\text{a}} \cdot \Delta x}{1 + \frac{\alpha_{\text{w}}^n \cdot \Delta x}{\lambda_{\text{w0c}} \cdot [1 + \beta \cdot (T_{17}^n - 273.15)]}} , \quad (21)$$

where

$$\lambda_{\text{w0c}} = K_{\text{adc}}(0.15 - 0.07u) \cdot [0.165 + \left(1.39 + 3.8u\right) \cdot (3.3 \cdot 10^{-7} \rho_{\text{b}}^2 + 1.015 \cdot 10^{-3} \rho_{\text{b}})] , \quad (22)$$

$$c_{i\text{w}}^n = \frac{2097u + 826}{1 + u} + \frac{9.92u + 2.55}{1 + u} T_i^n + \frac{0.0002}{1 + u} (T_i^n)^2 \quad @ \quad 1 \le i \le 17 , \quad (23)$$

$$\alpha_{\text{w}}^n = 3.256 \left(T_{17}^n - T_{\text{a}}\right)^{0.25} . \quad (24)$$

The values of the wood density ρ_w and of the coefficient β in eq. (20) during the solving of the model are calculated according to eqs. (15) and (9) respectively.

The equations (13), (14), (16), and (17) for the computation of the specific energy consumption needed for one sided heating of wood details results in the following suitable for programming form:

$$Q_{\text{w}}^n = \frac{c_{\text{w-avg}}^n \cdot \rho_{\text{w}} \cdot h_{\text{w}}}{3.6 \cdot 10^6} \left(T_{\text{w-avg}}^n - T_{\text{w0}}\right), \quad (25)$$

$$T_{\text{w-avg}}^n = \frac{1}{h_{\text{w}}} \int_{(h)} T[x, n \cdot \Delta\tau] \text{d}x , \quad (26)$$

$$\Delta Q_{\text{e}}^{n} = \frac{\alpha_{\text{w}}^{n}(\tau)\cdot\Delta\tau}{3.6\cdot 10^{6}}\left(T_{17}^{n} - T_{\text{a}}\right), \tag{27}$$

$$Q_{\text{e}}^{n} = \sum_{j=1}^{N} \Delta Q_{je}^{n}\,, \tag{28}$$

where

$$c_{\text{w-avg}}^{n} = \frac{2097u + 826}{1+u} + \frac{9.92u + 2.55}{1+u} T_{\text{w-avg}}^{n} + \frac{0.0002}{1+u}(T_{\text{w-avg}}^{n})^{2}. \tag{29}$$

For the achieving of the highest precision of the energy computations the Simpson's method [5] instead of trapezoidal method or of Gregory's method is used for the integration in eq. (26) of the temperature field along the detail's thickness according to the following equation:

$$T_{\text{w-avg}}^{n} = \frac{\Delta x}{3h_{\text{w}}}\left(\begin{array}{l} T_1^n + 4T_2^n + 2T_3^n + 4T_4^n + \\ + 2T_5^n + + 4T_6^n + 2T_7^n + \\ + 4T_8^n + 2T_9^n + 4T_{10}^n + \\ + 2T_{11}^n + 4T_{12}^n + 2T_{13}^n + \\ + 4T_{14}^n + + 2T_{15}^n + 4T_{16}^n + T_{17}^n \end{array} \right). \tag{30}$$

6. Results and Discussion

For the numerical solution of the discrete analogue of the mathematical model and for the applying of the suggested approach a software program has been prepared in FORTRAN, which was input in the calculation environment of Visual Fortran Professional developed by Microsoft.

Using the program, computations have been made for the determination of the 1D change of the temperature in flat oak details with thicknesses h_w=0.012 m, h_w=0.016 m, h_w=0.020 m, initial temperature t_{w0}=20ºC, basic density ρ_b=670 kg·m$^{-3,}$ coefficient in eq. (22) K_{adc} = 1.13, volume shrinkage S_v=11.9 %, moisture contents u= .15 kg·kg^{-1}, and $u_{fsp}^{293.15}$= 0.29 kg·kg^{-1} [5] during their 30 min one sided heating with t_m=80ºC, t_m = 100ºC, and t_m=120ºC, and at t_a=20ºC.

With the help of the software program, computations have been carried out also for the determination of the change in the details' average mass temperature and in the specific energy, which is needed for realization of the studied heating process.

Figure 3, *Figure 4*, and *Figure 5* present the change of the temperature t_w, calculated by the model in 4 equidistant from one another points along the thicknesses of oak details with h_w = 16 mm during its one sided heating at t_m=80ºC, t_m=100ºC, and t_m= 120ºC respectively. The coordinates of those points are shown in the legends of the figure.

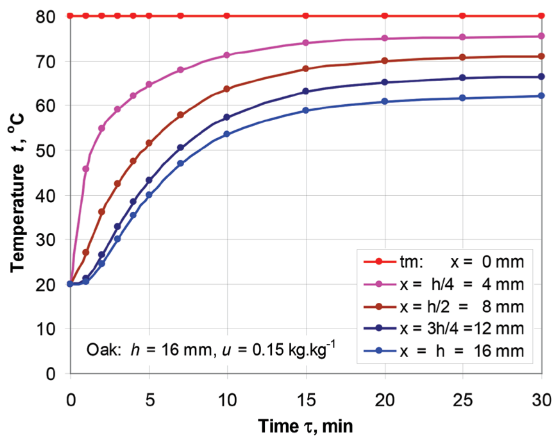

Figure 3. Change in t_w along the thickness of oak detail with h_w=16 mm during its one sided heating at t_m = 80ºC

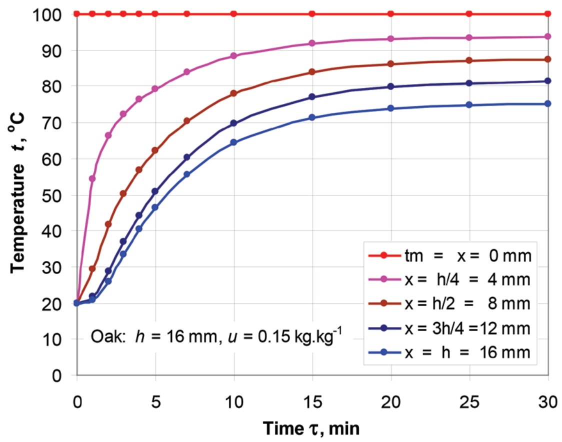

Figure 4. Change in t_w along the thickness of oak detail with h_w=16 mm during its one sided heating at t_m=100ºC

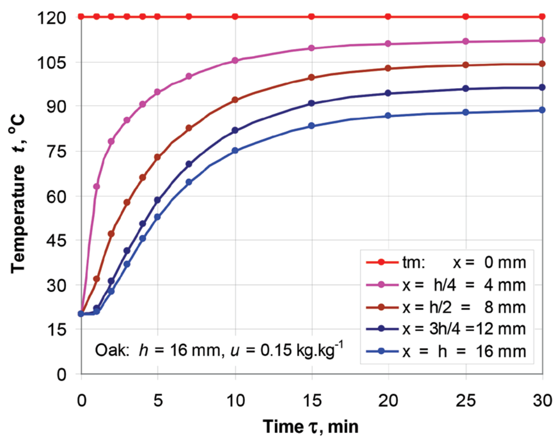

Figure 5. Change in t_w along the thickness of oak detail with h_w=16 mm during its one sided heating at t_m=120ºC

Figure 6 shows the calculated at t_m=120ºC change in the convective heat transfer coefficients of the non-heated details' surface, α_w, depending on h_w.

Figure 7 presents the calculated change of the average mass temperature $t_{w\text{-avg}}$ during the one sided heating at t_m=120ºC of the studied oak details, depending on h_w.

Figure 8, *Figure 9*, and *Figure 10* present the calculated change of the specific energies Q_w, Q_e, and Q_{total} during the one sided heating at t_m=120ºC of the studied oak details respectively, depending on their thicknesses h_w.

The obtained results show that during the unilateral heating of the details the change of all studied parameters of the process takes place according to complex curves.

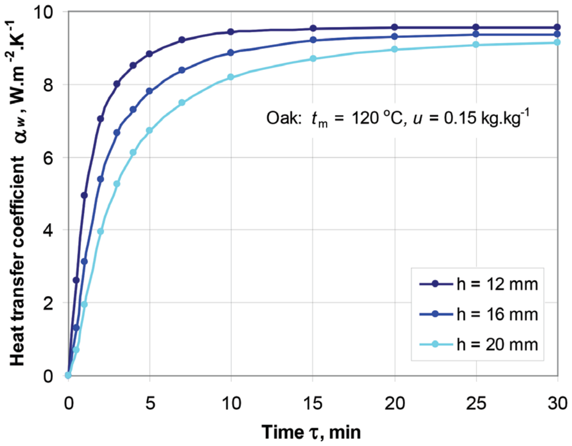

Figure 6. Change in α_{w-} of the oak details during their one sided heating at t_m = 120ºC, depending on h_w

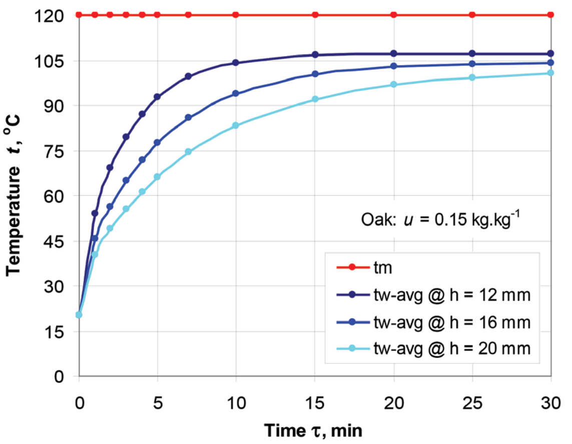

Figure 7. Change in t_{w-avg} of oak details subjected to one sided heating at t_m = 120ºC, depending on h_w

By increasing the heating time τ, the curves of t_w gradually approach asymptotically their largest values, decreasingly dependent on the remoteness of the characteristic points from the heated surface of the details. Analogously, the curves of the change in t_{w-avg}, α_w, and Q_w approach asymptotically their largest values, increasingly dependent on t_m and decreasingly dependent on h_w.

The largest values of t_w, t_{w-avg}, α_w, and Q_w are achieved when a stationary temperature distribution occurs along the details' thickness.

At t_m = 120ºC the most slowly changing temperature of the details surface, t_{ws}, that is in contact with the outside air environment reaches temperatures of 50ºC, 60ºC, and 70ºC [5], which are necessary for the start of the bending of the details with different radii R after a duration of the one sided heating, equal respectively to (*figure 5*):

- 2.5 min, 3.3 min, and 4.4 min at h_w = 12 mm;
- 4.6 min, 6.2 min, and 8.4 min at h_w = 16 mm;
- 7.4 min, 10.1 min, and 14.3 min at h_w = 20 mm.

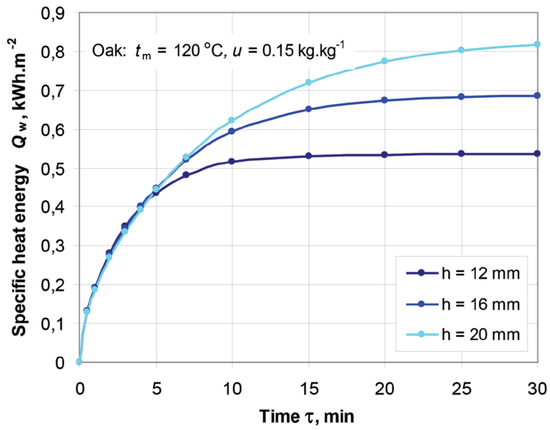

Figure 8. Change in Q_w of oak details subjected to one sided heating at t_m = 120ºC, depending on h_w

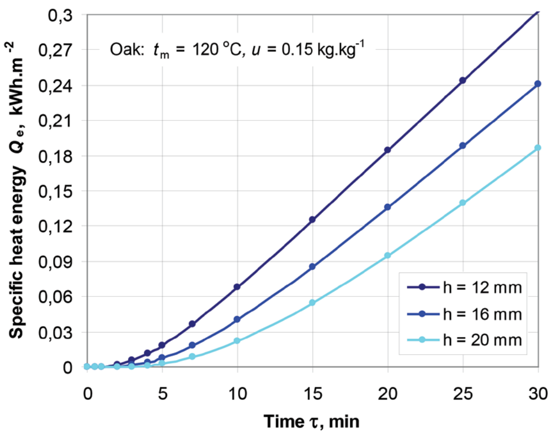

Figure 9. Change in Q_e of oak details subjected to one sided heating at t_m = 120ºC, depending on h_w

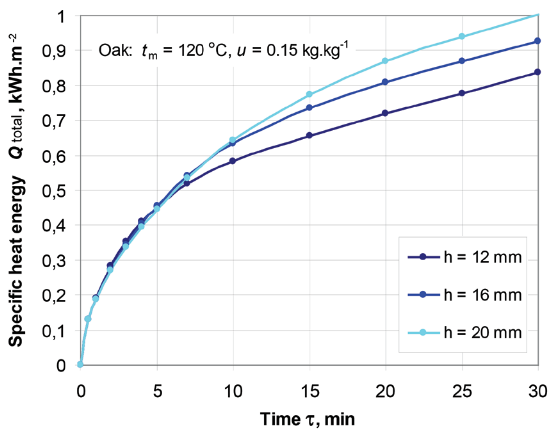

Figure 10. Change in Q_{total} of oak details subjected to one sided heating at t_m = 120ºC, depending on h_w

By increasing the heating time τ, the specific energy consumptions Q_e and Q_{total} increase according to curvilinear dependences, which change into linear after the reaching of stationary distribution of tw along the details' thickness. The slopes of the linear sections of the dependences $Q_e = f(\tau)$ and $Q_{total} = f(\tau)$ are proportional to t_m.

The values of Q_{total} are increasingly dependent on t_m and decreasingly dependent on h_w. For example, after 15 min duration of the unilateral heating, Q_{total} reaches the following values:

- for details with h_w = 12 mm: Q_{total} = 0.372 kWh·m^{-2} at t_m = 80ºC, Q_{total} = 0.511 kWh·m^{-2} at t_m = 100ºC, and Q_{total} = 0.657 kWh·m^{-2} at t_m = 120ºC;
- for details with h_w = 16 mm: Q_{total} = 0.420 kWh·m^{-2} at t_m = 80ºC, Q^{total} = 0.575 kWh·m^{-2} at t_m = 100ºC, and Q_{total} = 0.736 kWh·m^{-2} at t_m = 120 oC;
- for details with h_w = 20 mm: Q_{total} = 0.445 kWh·m^{-2} at t_m = 80ºC, Q_{total} = 0.607 kWh·m^{-2} at t_m = 100ºC, and Q_{total} = 0.775 kWh·m^{-2} at t_m = 120ºC.

Using the values of Q_{total}, the minimum necessary power of the heating metal body (refer to *figure 2*) can be determined depending on the desired duration of the one sided details' heating at given values for t_m, h_w and R/h_w.

7. Conclusions

The article presents a methodology for mathematical modeling and research of two mutually connected problems: temperature distribution in subjected to one sided heating flat wood details and energy consumption of this process. It describes a non-linear mathematical model and a numerical approach for the computation of the specific energy consumption, which is needed for realization of the one sided heating of flat wood details aimed at their plasticizing before bending.

The approach is based on the integration of the solutions of a non-linear model for calculation of the transient 1D temperature distribution along the thickness of flat wood details during their one sided heating. Heat distribution along the thickness of the subjected to such heating wood details from any wood species is described by 1D partial differential equation of heat conduction. For the solution of the model without any simplifications, an explicit form of the finite-difference method is used.

For the numerical solution of the mathematical model, a software program was prepared in FORTRAN in the calculation environment of Visual Fortran Professional developed by Microsoft.

The novel point in this paper is the creation and precise solution of a non-linear mathematical model of the considered heating process of wood details and its energy consumption at conductive and convective boundary conditions from the heated and non-heated side of the details respectively.

The article shows and analyzes diagrams of a 1D non-stationary and stationary distribution of the temperature along the thickness of flat oak details subjected to one sided heating in order to be plasticized before their bending for the production of bent back parts of chairs. It shows and analyzes also the change of the total specific energy consumption, Q_{total}, and its components, needed for the one sided heating of the details.

All diagrams are drawn using the results calculated by the model.

The 1D distribution of the temperature and the change of Q_{total} and of its components for flat oak details with thicknesses of 12 mm, 16 mm, and 20 mm, initial wood temperature of 20ºC, and moisture content of 0.15 kg.kg^{-1} during their one sided heating for a period of 30 min at a temperatures of the heating metal body t_m = 80ºC, t_m = 100ºC, t_m = 120ºC, and temperature of the air near the non-heated side of the details t_a = 20ºC is calculated, visualized and analyzed using the model.

The suggested methodology and algorithm for its realization, and also the obtained results from the computer solutions of the model could be used for the following purposes:

- Visualization and technological analysis of the temperature change along the thickness of details from different wood species with different thickness, initial temperature and moisture content during their one sided heating before bending accomplished by a heating body with different temperatures.
- Determination of the time of details' heating, which is necessary for achieving the minimum required plasticity of the details at given t_m before their bending with a specified radius R and relationship R/h_w [13]. This will allow in each particular case the heating process to be realized with minimal energy consumption.
- Computation of the non-stationary change in the energy consumption of the details at each moment of their one sided heating.
- Scientifically based dimensioning of the heating metal body depending on the desired duration of the one sided details' heating at given values for tm, hw, and R/h_w [14].
- Creation of a scientifically derived model-based automatic control of the one sided heating process.

It can be noted that the databases of the wood plasticizing technologies contain many empirically established data about the minimal average mass temperature, which is necessary for the start of the bending of details with different radii R, depending on the wood species, h_w and R/h_w. Taking into account these data, the mathematical model could be input into the software of programmable controllers for optimized model based automatic control [9, 10, 11, 12] of the one sided heating of wood details in the production of curved details for different applications in the furniture industry.

The methodology that was suggested for the creation and solution of the model could be further applied in the development of analogous models, for example, for the calculation of the change in the temperature and the energy consumption in flat details used for different purposes or in equipment walls made of various materials.

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Symbols

c = Specific heat capacity ($J \cdot kg^{-1} \cdot K^{-1}$)
h = Thickness (m)
N = Number of the steps on the τ-coordinate using which the model was solved
Q = Specific energy consumption ($kWh \cdot m^{-2}$)
R = Radius of bending of the heated and plasticized wood details (m)
S = Wood shrinkage (%)
t = Temperature (ºC): t = T – 273.15
T = Temperature (K): T = t + 273.15
u = Moisture content ($kg \cdot kg^{-1}$)
x = Coordinate along the thickness of the details subjected to heating: $0 \le x \le X = h_w$ (m)
α = Heat transfer coefficient ($W \cdot m^{-2} \cdot K^{-1}$)
λ = Thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$)
ρ = Density ($kg \cdot m^{-3}$)
τ = Time (s)
Δ*x* = Step on the x-coordinate of the model, which coincides with the thickness of the subjected to heating wood detail (m)
Δ*τ* = Step on the τ-coordinate for solving of the model, i.e. interval between time levels (s)
Δ*Q* = Change of *Q* for time equal to Δτ ($kWh \cdot m^{-2}$)
@ = At

Subscripts and Superscripts

a = Air
ad = Anatomical direction of the wood
adc = Anatomical direction cross sectional to the wood fibers
avg = Average (for mass temperature of the wood details at given moment of their heating)
b = Basic (for wood density, based on dry mass divided to green volume)
c = Cross-sectional to the fibers
e = Emission (for energy needed for covering of the heat emission from the non-heated surface of the details in the surrounding air)
fsp = Fiber saturation point
i = Nodal point of the calculation mesh along detail's thickness: i = 1, 2, 3, …….., 15, 16, 17
j = Nodal point of the calculation mesh along time coordinate: j = 0, 1, 2,…….., N-2, N-1, N
m = Medium (for the temperature of the heating metal body used for unilateral heating)
p = Process (for the duration of whole process of the one sided heating)
total = Total (for the energy needed both for heating of the wood itself and for the covering of the heat emission from the details)
v = Volume (for the wood shrinkage)
n = Time level during the solving of the mathematical model: n = 0, 1, 2, 3, …,τp /Δτ
s = Surface (for non-heated surface of the subjected to heating wood details)
w = Wood
0 = Initial (for average mass temperature of the details in the beginning of their heating or for time level in the beginning of the calculations)
293.15 = At 293.15 K, i.e. at 20ºC (for the standardized values of the wood fiber saturation point)

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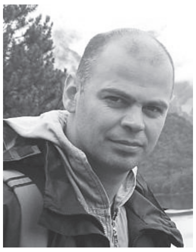

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