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Modeling of the Energy Consumption for Warming up of Furniture Elements during their Unilateral Convective Heating before Lacquering

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Key Words: *Flat furniture elements; convective heating; temperature distribution; energy consumption; lacquering.*

Abstract. *A mathematical model and a numerical approach for the computation of the specific energy consumption, which is needed for warming up of flat furniture elements before their lacquering, have been suggested. The approach is based on the integration of the solutions of a non-linear model for the calculation of the non-stationary 1D temperature distribution along the thickness of subjected to unilateral convective heating furniture elements. With the help of a self-prepared software program, computations have been carried out for the determination of the change in the specific energy, which is consumed by oak furniture elements with an initial temperature of 20 °C, moisture content of 8 %, thickness of 16 mm, and length of 0.6 m, 1.2 m, and 1.8 m, during their 10 min unilateral convective heating by hot air with temperature of 100 °C and velocity of 5 m·s^{-1}.*

1. Introduction

The pre-heating of subjected to lacquering furniture details is done with the aim to speed up the hardening of thin coatings of lacquering systems with organic solvents. During the application of the lacquer coatings onto the heated surface of the wood, the evaporation of the solvents is speeded up and the air is removed from the pores of the wood [5,11,12].

Unilateral convective heating used prior to lacquering is mostly applied on flat wooden furniture elements with thickness from 4 to 35 mm and moisture content of 8ч10%. [10]. The equipment for preliminary heating of the furniture elements is formed usually as a tunnel section (*figure 1*), which can be part of an assembly line for protective and decorative film application [10,12].

In the specialized literature there is very limited information about the temperature distribution in wood details during their unilateral convective heating [3,4] and there is no information et all about the energy consumption needed for the realizing of such heating. That is why each research in this aria has both a scientific and a practical interest.

The aim of the present work is to suggest a mathematical model and a numerical approach for the computation of the specific energy consumption, which is needed for warming up of flat wooden furniture elements during their unilateral heating before lacquering. The approach has to be based on the integration of the solutions of a non-linear model for the calculation of the transient 1D temperature distribution along the thickness of subjected to unilateral heating flat wooden furniture elements.

2. Mechanism of the Heat Distribution in Subjected to Unilateral Convective Heating Wooden Furniture Elements

The mechanism of the heat distribution in wooden furniture elements during their unilateral convective heating can be described by the equation of the heat conduction [1,2].

When the width and length of the furniture elements exceed their thickness by at least three and five times re-



Figure 1. General view of equipment for unilateral convective heating of wooden furniture elements and for their subsequent lacquering

spectively, then the calculation of the change in the temperature only along the thickness of the elements in the center of their flat side during the unilateral convective heating (i.e. along the coordinate x, which coincides with the elements' thickness h_w) can be carried out with the help of the following non-linear 1D mathematical model [1,2,3]:

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

with an initial condition

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

and following boundary conditions:

• from the side of the elements' heating – at conditions of forced convective heat exchange between the upper surface of the elements and the circulated hot air with temperature T_{ha} and velocity v_{ha} (see *figure 2*)

$$\frac{dT_{w-hs}(\tau)}{dx} = -\frac{\alpha_{w\text{-}hs}(\tau)}{\lambda_{w\text{-}hs}(T,u,\rho_b,\tau)}\left[T_{w-hs}(\tau) - T_{ha}(\tau)\right]; \quad (3)$$

• from the opposite non-heated surface of the elements – at temperature, which is equal to the temperature $T_{B\text{-}hs}$ of the upper (heated) side of the carrying rubber band, on which the non-heated surface of the elements lies (see *figure 2*):

$$T_{w-nhs}(\tau) = T_{B-hs}(\tau). \quad (4)$$

Because of the tight contact between the elements and the thin carrying rubber band on which they lie during the heating process, the temperature of the non-heated lower surface of the elements is assumed in eq. (4) to be equal to the temperature of the band's upper surface.

3. Mechanism of the Heat Distribution in the Carrying Rubber Band during Unilateral Convective Heating of the Furniture Elements

The change in the temperature along the thickness of the carrying rubber band, on which the non-heated surface of the furniture elements lies during the elements' heating (i.e. along the coordinate x, which coincides with the thicknesses of the elements and of the band – see *figure 2*), can be computed using the following 1D mathematical model [3,4]:

$$\frac{\partial T_B(x,\tau)}{\partial \tau} = a_B(T)\frac{\partial^2 T_B(x,\tau)}{\partial x^2} \quad (5)$$

with an initial condition

$$T_B(x,0) = T_{B0} \quad (6)$$

and following boundary conditions:

• from the upper (heated by the furniture elements) surface of the band – at temperature, which is equal to the temperature of the bottom (non-heated) side of the elements

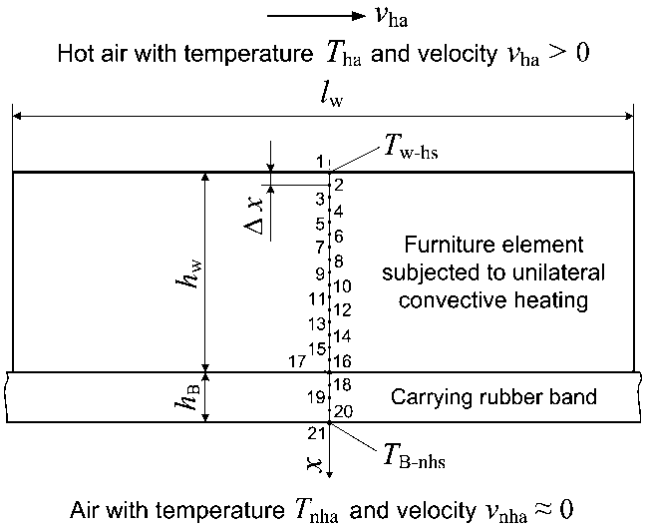

Figure 2. Positioning of the nodes of the 1D calculation mesh along the thicknesses of the wooden furniture element and carrying rubber band

$$T_{B-hs}(\tau) = T_{w-nhs}(\tau); \quad (7)$$

• from the bottom (non-heated) surface of the band – at conditions of free convective heat exchange between the band and the surrounding air environment

$$\frac{dT_{B-nhs}(\tau)}{dx} = -\frac{\alpha_{B\text{-}nhs}(\tau)}{\lambda_{B\text{-}nhs}}\left[T_{B\text{-}nhs}(\tau) - T_{nha}(\tau)\right]. \quad (8)$$

4. Mathematical Description of the Thermo-Physical Characteristics of the Wood c_w and λ_w

For the usage of the equations (1) and (3) it is needed to have a mathematical description of the specific heat capacity of the wood, c_w, and of the wood's thermal conductivity, λ_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 [1]:

$$c_w = \frac{2097u + 826}{1+u} + \frac{9.92u + 2.55}{1+u}T + \frac{0.0002}{1+u}T^2, \quad (9)$$

$$\lambda_w = \lambda_{w0}\left[1 + \beta(T - 273.15)\right], \quad (10)$$

where

$$\lambda_{w0} = K_{ad}\nu[0.165 + (1.39 + 3.8u)\cdot (3.3\cdot 10^{-7}\rho_b^2 + 1.015\cdot 10^{-3}\rho_b)], \quad (11)$$

$$\nu = 0.15 - 0.07u, \quad (12)$$

$$\beta = (2.05 + 4u)\left(\frac{579}{\rho_b} - 0.124\right)\cdot 10^{-3}. \quad (13)$$

Equations (9)ч(13) are part of the mathematical description of the thermo-physical characteristics of wood species, which has been developed earlier by us using

many experimental data derived by different scientists. The full description is given in [1].

It is pointed and shown in [1], 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 mathematical model to the real process of warming up of wooden furniture elements during their unilateral convective heating before lacquering.

5. Mathematical Description of the Temperature Conductivity of the Transport Rubber Band a_B

The following equation for the calculation of a_B in eq. (5) along the thickness of the carrying rubber band reinforced by textile fibers, on which the non-heated surfaces of the subjected to unilateral heating furniture elements lie, have been suggested in [9]:

$$a_B = 1.4409 \cdot 10^{-7} - 4.14765 \cdot 10^{-10} T + 1.0791 \cdot 10^{-12} T^2 . \quad (14)$$

6. Mathematical Description of the Heat Transfer Coefficient $a_{w\text{-}hs}$

The calculation of the convective heat transfer coefficient $б_{w\text{-}ha}$, which participates in eq. (3), can be carried out with the help of the following equations, which are valid for the cases of heating of horizontally situated rectangular surfaces in conditions of force air convection [4,13]:

$$\alpha_{w\text{-}hs} = \frac{Nu_{ha}\lambda_{ha}}{l_w}, \quad (15)$$

where the number of similarity of Nusselt is calculated using the thermo-physical characteristics of the hot air according to following equations

- at laminar regime of the forced convection of the air (i.e. at $Re_{ha} \le 4 \cdot 10^4$):

$$Nu_{ha} = 0.66\, Re_{ha}^{0.5}\, Pr_{ha}^{0.43} \left(\frac{Pr_{ha}}{Pr_{hs}}\right)^{0.25}; \quad (16)$$

- at turbulent regime of the forced convection (i.e. at $Re_{ha} > 4 \cdot 10^4$):

$$Nu_{ha} = 0.037\, Re_{ha}^{0.8}\, Pr_{ha}^{0.43} \left(\frac{Pr_{ha}}{Pr_{hs}}\right)^{0.25}. \quad (17)$$

The Prandtl' numbers of similarity Pr_{ha} and Pr_{hs} in (16) and (17), and also the Reynolds' number of similarity Re_{ha} in (17) are calculated according to the equations [13]

$$Pr_{ha} = \frac{w_{ha}}{a_{ha}}, \quad (18)$$

$$Pr_{hs} = \frac{w_{hs}}{a_{hs}}, \quad (19)$$

$$Re_{ha} = \frac{\rho_{ha} v_{ha} l_w}{\mu_{ha}} = \frac{\rho_{ha} v_{ha} l_w}{\rho_{ha} w_{ha}} = \frac{v_{ha} l_w}{w_{ha}}. \quad (20)$$

The indexes "ha" and "hs" of the thermo-physical characteristics of the air and of the numbers of the similarity in equations (15) to (20) mean that these characteristics and numbers must be calculated depending on the temperature of the **h**ot **a**ir and of the **h**eated **s**urface of the aired elements, respectively.

7. Mathematical Description of the Heat Transfer Coefficient $\alpha_{B\text{-}nhs}$

The calculation of the heat transfer coefficient $\alpha_{B\text{-}nhs}$, which participates in eq. (8), can be carried out with the help of the following equations, which are valid for the cases of heating or cooling of horizontally situated rectangular surfaces in conditions of free air convection [4,13]:

$$\alpha_{B\text{-}nhs} = \frac{1.3 Nu_{nha}\lambda_{nha}}{b_B}, \quad (21)$$

where the Nusselt's number of similarity is calculated with the help of the thermo-physical characteristics of the air from the non-heated side of the rubber band according to following equation:

$$Nu_{nha} = 0.5(Gr_{nha} \cdot Pr_{nha})^{0.25} \left(\frac{Pr_{nha}}{Pr_{nhs}}\right)^{0.25} \quad @ \ 10^3 < Gr_{nha} \cdot Pr_{nha} < 10^9. \quad (22)$$

The Grashoff's number of similarity Gr_{nha} and the Prandtl's numbers of similarity Pr_{nha} and Pr_{nhs} in (22) are calculated according to the equations [13]

$$Gr_{nha} = \frac{g \cdot \beta_{nha} b_B^3}{w_{nha}^2}(T_{B-nhs} - T_{nha}), \quad (23)$$

$$Pr_{nha} = \frac{w_{nha}}{a_{nha}}, \quad (24)$$

$$Pr_{nhs} = \frac{w_{nhs}}{a_{nhs}}. \quad (25)$$

The indexes "nha" and "nhs" of the variables and of the numbers of the similarity in equations (21) to (25) mean that these variables and numbers must be calculated depending on the temperature of the **n**ot **h**eating **a**ir and of the **n**ot **h**eated **s**urface of the furniture elements, respectively.

8. Mathematical Description of the Thermo-physical Characteristics of the Air

For the usage of the equations (15) to (25) it is needed to have a mathematical description of the thermo-physical characteristics of the air, λ, ρ, a and w, in the temperature range form 273.15 K to 393.15 K (i.e. from 0 ˚C to 120 ˚C)

because of the fact that the temperatures T_{ha} and T_{nha} during the unilateral convective heating of the furniture elements before their lacquering in the practice change in this range.

The following equations for the calculation of λ, ρ, a and w were derived using the approach, which is described in [4]:

(26) $\lambda = 0.0036 + 7.8 \cdot 10^{-5} T$,

(27) $\beta = (6.305 - 0.0098T) \cdot 10^{-3}$,

(28) $a = (0.146T - 20.2) \cdot 10^{-6}$,

(29) $w = (0.096T - 12.4) \cdot 10^{-6}$.

9. Modeling of the Energy Consumption for Warming up of the Elements during their Unilateral Convective Heating

It is known that the specific energy consumption for the heating of 1 m^3 of solid materials with an initial mass temperature T_0 to a given average mass temperature T_{avg} is determined using the equation [2]

$$(30) \qquad q = \frac{c \cdot \rho \cdot (T_{avg} - T_0)}{3.6 \cdot 10^3}.$$

After multiplying the right part of eq. (30) with the element's thickness h_w the following equation for the determination of the specific mass energy consumption needed for the heating of 1 m^2 of the subjected to unilateral heating wooden furniture elements, q_w, is obtained:

$$(31) \qquad q_w = \frac{c_w \rho_w (T_{w\text{-}avg} - T_{w0})}{3.6 \cdot 10^3},$$

where

$$(32) \qquad T_{w\text{-}avg} = \frac{1}{h_w} \int_{(h_w)} T(x,\tau)\mathrm{d}x$$

and for the non-frozen wood with moisture content in the hygroscopic range (i.e. when $u < u_{fsp}$) [1,2]

$$(33) \qquad \rho_w = \rho_b \frac{1+u}{1 - \frac{S_v}{100}(u_{fsp} - u)}.$$

It is of practical interest the determination of the time, needed by the surface layers of the furniture elements during their convective heating by hot air to reach specific temperature and to accumulate specific energy consumption, q_L, which is necessary for improving the thermal conditions for further lacquering. In this case, at that stage of the problem solving, it is acceptable to use the time for reaching a predetermined temperature at a point that is 4 mm distant from the heated surface of the furniture elements without, however, exceeding their given allowable (e.g. 60 °C) surface temperature.

The specific energy consumption, which accumulates the most heated surface layer of the furniture elements, q_L, can be calculated according to following equation:

$$(34) \qquad q_L = \frac{c_w \rho_w (T_{L\text{-}avg} - T_{w0})}{3.6 \cdot 10^3},$$

where

$$(35) \qquad T_{L\text{-}avg} = \frac{1}{h_L} \int_{(h_L)} T(x,\tau)\mathrm{d}x.$$

The multiplier $3.6 \cdot 10^3$ in the denominator of eqs. (31) and (34) ensures that the values of q_w and q_L are obtained in Wh·m^{-2}, instead of in J·m^{-2}.

10. Results and Discussion

The mathematical models, which are presented in common form by the eqs. (1)ч(8), have been solved with the help of explicit schemes of the finite difference method. This has been done in a way, analogous to the one used and described in [1] for the solution of a model of the heating process of prismatic wood materials.

The presenting of the eqs. (1) and (5) from the mathematical models through their discrete analogues corresponds to the shown in *figure 2* setting of the coordinate system and the positioning of the nodes in the mesh, in which the 1D non-stationary distribution of the temperature along the thicknesses of the furniture elements and the carrying rubber band during the unilateral convective heating of the elements is calculated.

For the solution of the models a software program has been prepared in FORTRAN in the calculation environment of Visual Fortran Professional. In this program the presented above mathematical descriptions of the wood thermal conductivity λ_w, of the heat transfer coefficients $\alpha_{w\text{-}hs}$ and $\alpha_{B\text{-}nhs}$, of the temperature conductivity of the rubber band α_B, and of the thermo-physical characteristics of the air λ, β, α, and w, are used.

With the help of the program computations have been made for the determination of the 1D change of the temperature in flat oak furniture elelemts with thickness $h_w = 0.016$ m, lengths $l_w = 0.6$ m, $l_w = 1.2$ m, $l_w = 1.8$ m, initial temperature $t_{w0} = 20$ °C, basic density $\rho_b = 670$ kg·m^{-3}, coefficient in (11) cross sectional to the oak fibers $K_{ad} = 1.13$, volume shrinkage $S_v = 11.9\%$, moisture contents $u = 0.08$ kg·kg^{-1} and $u_{fsp} = 0.29$ kg·kg^{-1} [1,2] during their 10 min unilateral convective heating by hot air with temperature $t_{ha} = 100$ °C and velocity $v_{ha} = 5$ m·s^{-1}.

Simultaneously with the above described 1D calculations, computations have been carried out for the determination of the 1D change in the temperature along the thickness of the carrying rubber band reinforced by textile fibres, on which the non-heated surfaces of the subjected to unilateral heating wooden furniture elements lie (see *figure 2*). The band was accepted to be with thickness $h_B = 0.004$ m, width $b_B = 0.8$ m, and initial temperature $t_{B0} = 20$ °C. The temperature of the surrounding air from the non-heated surface of the band during the elements' heating was accepted to be equal to $t_{nha} = 20$ °C. The computations have been carried out with an average value of the band's thermal conductivity perpendicular to the textile fibers $\lambda_{B\text{-}nhs} = 0.281$ W· m^{-1}·K^{-1} (http://www. axelproducts.com).

With the help of the software program, computations

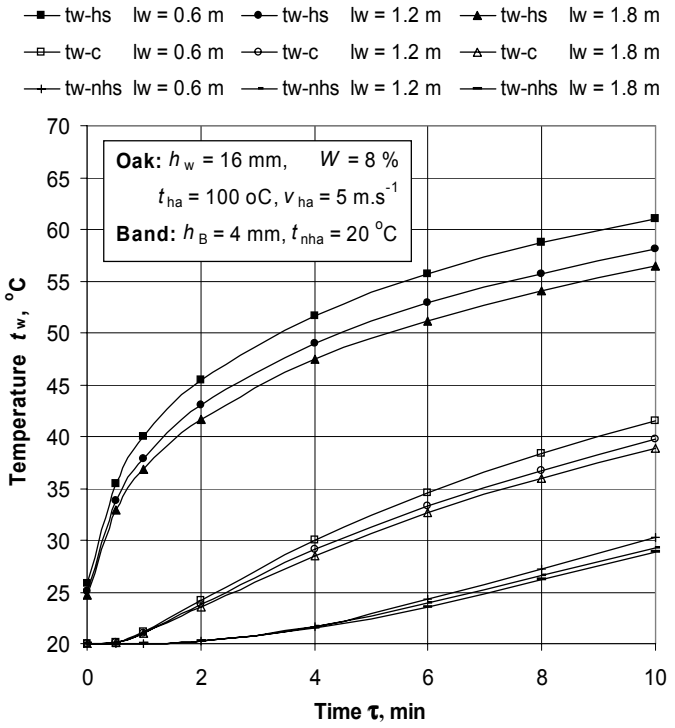

Figure 3. Change in t of the surfaces and of the center of the oak elements during their unilateral convective heating, depending on l_w

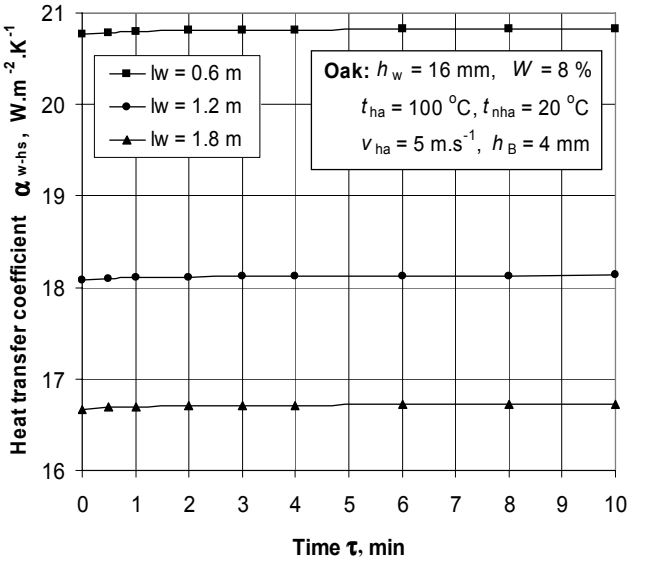

Figure 4. Change in $a_{w\text{-}hs}$ of the oak furniture elements during their unilateral heating, depending on l_w

have been carried out also for the determination of the change in the specific energy, which is consumed by the oak furniture elements subjected to unilateral heating.

For the achieving of the highest precision of the energy computations the Simpson's method [2] instead of trapezoidal method or of Gregory's method is used for the integration of the temperature fields along the element's and layer's thicknesses according to eqs. (32) and (35) respectively.

All computations have been carried out with 21 nodes of the calculation mesh, i.e. with a step along the thicknesses of the furniture elements and the band Δx = 1.0 mm (*figure 2*). With the numbers 1 to 17 and 17 to 21 is marked the following number of the nodes of the 1D calculation mesh along the thickness of the wooden element and along the thickness of the rubber band, respectively.

With the numbers 1 to 5 is marked the following number of the nodes along the thickness of the element's surface layer, which must be most heated before the subsequent lacquering.

Figure 3 presents the calculated change in t_w on both surfaces and in the center, $t_{w\text{-}c}$, of the studied furniture elements during their unilateral heating, depending on the elements' length l_w.

Figure 4 shows the calculated change in the convective heat transfer coefficients of the heated elements' surface, $\alpha_{w\text{-}hs}$, depending on l_w.

On *figure 5*, *figure 6*, and *figure 7* the calculated change in t_w and t_L at l_w = 1.8 mm, in $t_{w\text{-}avg}$ and $t_{L\text{-}avg}$, and in q_w and q_L of the studied oak elements during their 10 min unilateral convective heating is presented, respectively.

The analysis of the obtained results leads to the following conclusions:

1. During the unilateral convective heating of the furniture elements the change of the temperature on their surfaces and also in their center goes on according to complex curves. The curve of the t_w on the heated elements' surface is convex outwardly, but the curve of the temperature on the non-heated surface is concave inwardly (*figure 3*). The curves of $t_{w\text{-}c}$ have both convex and concave sections.

2. The change of the convective heat transfer coefficient of the heated elements' surface, $\alpha_{w\text{-}hs}$, is insignificant during the heating time (*figure 4*). This coefficient decreases when the aired length of the furniture elements, l_w, increases.

The influence of l_w on decreasing of $\alpha_{w\text{-}hs}$ is partly compensated by the increasing of the numbers of similarity Re_{ha} and Nu_{ha} when l_w increases (see equations (20), (16), (17), and (15)). Because of these reasons the influence of l_w on $\alpha_{w\text{-}hs}$ is non-linear.

3. The decreasing of the heat transfer coefficient $\alpha_{w\text{-}hs}$ with an increase of l_w causes a decrease of the intensity of the elements' heating process when l_w increases.

4. The increasing of $t_{w\ -avg}$ and $q_{L\text{-}avg}$, and also of the specific energy consumptions q_w and q_L during the unilateral heating of the furniture elements goes on according to curvilinear dependences.

5. The slope of the dependences $t_{w\text{-}avg} = f(\tau)$ and $t_{L\text{-}avg} = f(\tau)$, and also of $q_w = f(\tau)$ and $q_L = f(\tau)$ slightly decreases with an increase of the length of the furniture elements subjected to unilateral heating.

6. After 10 min heating of the oak furniture elements with studied parameters, the energy consumption q_w and q_L reach the following values:

- at l_w = 0.6 m: q_w = 144.5 Wh.m^{-2} and q_L = 56.1 Wh.m^{-2};
- at l_w = 1.2 m: q_w = 133.0 Wh.m^{-2} and q_L = 51.8 Wh.m^{-2};

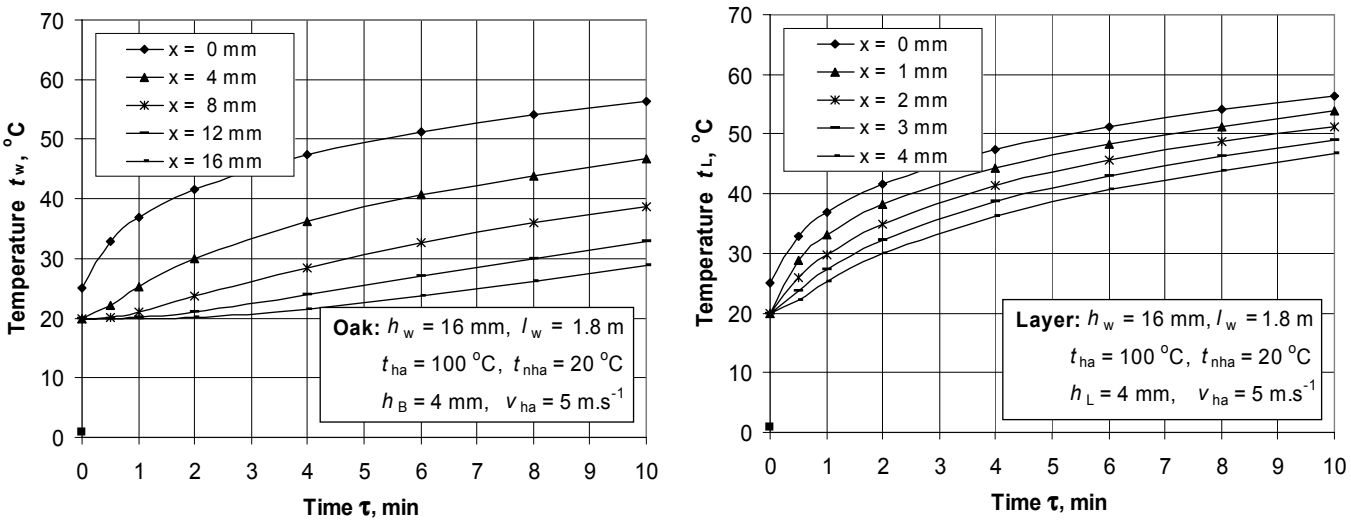

Figure 5. Change in t_w (left) and t_L (right) during 10 min convective heating of element with l_w = 1.8 m

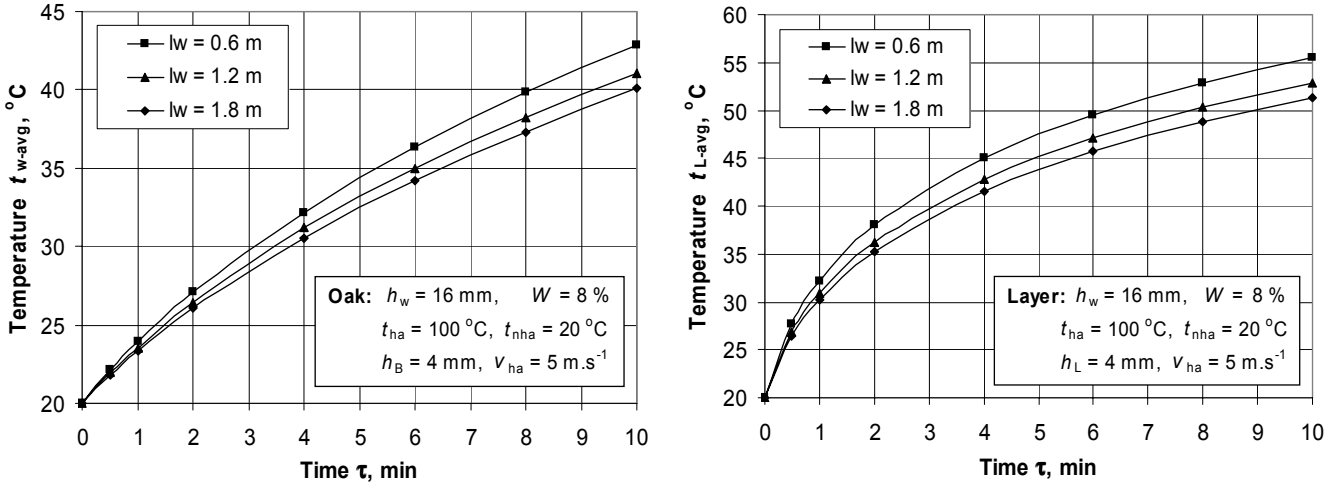

Figure 6. Change in $t_{w\text{-}avg}$ (left) and $t_{L\text{-}avg}$ (right) during 10 min heating of the elements, depending on l_w

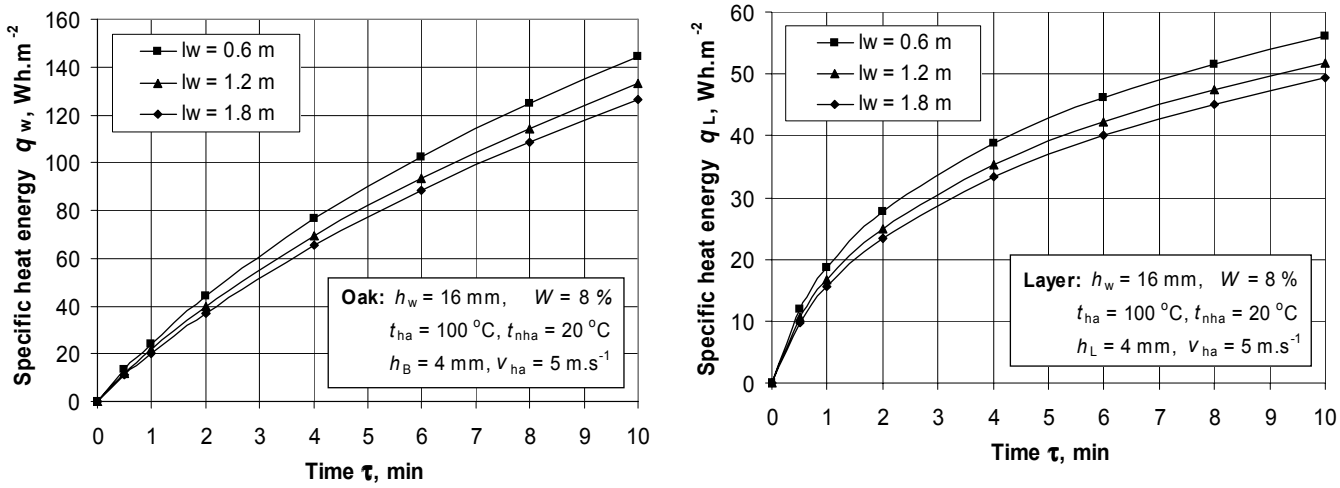

Figure 7. Change in q_w (left) and q_L (right) during 10 min convective heating of the elements, depending on l_w

• at l_w = 1.8 m: q_w = 126.4 Wh.m^{-2} and q_L = 49.4 Wh.m^{-2}.

It can be noted that the obtained and analyzed results are only one example and are valid only for the warming up of oak furniture elements with the above mentioned dimensions. With setting up of different initial and boundary parameters by the input data of the mathematical model, it is possible to compute the energy, which is needed for the warming up of furniture elements from different wood species for each moment of their heating before lacquering.

11. Conclusions

The article describes a mathematical model and a numerical approach for the computation of the specific energy consumption, which is needed for unilateral warming up of flat wooden furniture elements before their subsequent lacquering.

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 subjected to unilateral heating flat furniture elements.

As examples for the use of the model and the suggested approach, computations have been carried out for the determination of the change in the specific energy, which is consumed by oak furniture elements with an initial temperature of 20 °C, moisture content of 8%, thickness of 16 mm, length of 0.6 m, 1.2 m and 1.8 m during their 10 min unilateral convective heating by hot air with temperature of 100 °C and velocity of 5 m·s^{-1}.

The obtained results show that the most heated surface layer of the furniture elements, whose thickness is only 25% of the element's thickness, accumulates approximately 39% of the whole energy of the heated elements.

The computer solutions of the mathematical model could be used for visualization and technological analysis of the temperature change along the thickness of furniture elements made of different wood species, different thickness, length and moisture content, during their unilateral convective heating with different temperature and velocity of the circulated air prior to their lacquering.

The solutions of the model allow determining the duration of the elements' heating, which is necessary for achieving the most suitable thermal conditions for the subsequent lacquering at concrete characteristics of the lacquer, depending on the elements' and hot air's parameters.

The model could be applied also for model-based automatic control [6,7,8] of the process of unilateral convective heating of furniture elements through its input in the software of the programmable controllers used for such kind of process operations.

The approach used in this work could be applied for mathematical modeling of the temperature distribution and specific energy consumption in two or more layer's structures from different materials subjected to convective or/ and conducting heating.

Symbols

a = temperature conductivity (m^2·s^{-1})
b = width (m)
C = Specific Heat Capacity (J'"Kg^{-1}'"K^{-1})
G = Acceleration Of Gravity (G = 9.81 M·S^{-2})
H = Thickness (M)
L = Length (M)
S = Wood Shrinkage (%)
T = Temperature (^{o}c): $T = T - 273.15$
T = Temperature (K): $T = T + 273.15$
U = Moisture Content (Kg·Kg^{-1}): $U = W/100$
W = Moisture Content (%): $W = 100u$
W = Kinematic Viscosity (M^2·S^{-1})
V = Velocity (M·S^{-1})
X = Coordinate Along The Thicknesses Of The Wood Detail And Of The Carrying Rubber Band
A = Heat Transfer Coefficient (W·M^{-2}·K^{-1})
B = Coefficient Of The Volume Expansion (K^{-1})
Λ = Thermal Conductivity (W·M^{-1}·K^{-1})
M = Dynamic Viscosity Coefficient (Pa·S)
P = Density (Kg·M^{-3})
T = Time (S)
Δx = Step On The X-Coordinate, Which Coincides With The Thicknesses Of The Detail And Of The Band (M)

Subscripts And Superscripts

A = Air
Ad = Anatomical Direction Of The Wood Specie
Avg = Average
B = Basic (For Wood Density, Based On Dry Mass Divided By Green Volume)
B = Band
B-Hs = Band's Heated Surface
B-Nhs = Band's Not Heated Surface
B0 = Initial (For The Mass Temperature Of The Rubber Band At The Beginning Of The Heating)
C = Center
Fsp = Fiber Saturation Point Of The Wood
Ha = Heating Air
Hs = Heated Surface
Nha = Not Heating Air
Nhs = Not Heated Surface
V = Volume (For The Wood Shrinkage)
W = Wood
W-Hs = Wood's Heated Surface
W-Nhs = Wood's Not Heated Surface
W0 = Initial (For The Mass Temperature Of The Wooden Furniture Elements In The Beginning Of Their Heating
0 = Initial
@ = At

References

1. Deliiski, N. Transient Heat Conduction in Capillary Porous Bodies. Convection and Conduction Heat Transfer. Rieka, Intech Publishing House, 149-176, 2011.

2. Deliiski, N. Modeling of the Energy Needed for Heating of Capillary Porous Bodies in Frozen and Non-frozen States. Saarbruecken, Scholars' Press, Germany, 116, 2013.

3. Deliiski, N., L. Dzurenda, N. Trichkov, Z. Gochev, D. Angelski.

Modelling of the Unilateral Convective Heating of Furniture Elements before their Lacquer Coating. – *Acta Facultatis Xilologiae,* TU – Zloven, 58, 2016, 2, 51-64.
4. Deliiski, N., R. Stanev, D. Angelski, N. Trichkov, Z. Gochev. Heat Transfer Coefficients during Unilateral Convective Heating of Wood Details before their Lacquering. – *Engineering Sciences,* BAS, LIII, 53, 2016, 3, 26-42.
5. Jaić, M., R. Živanović-Trbojević. Surface Processing of Wood – Theoretical Base and Technological Processes. Beograd, 2000 (in Serbian).
6. Hadjiski, M. Mathematical Models in Advanced Technological Control Systems. – *Automatic & Informatics* 37, 2003, 3, 7-12 (in Bulgarian).
7. Hadjiski, M., N. Deliiski. Cost Oriented Suboptimal Control of the Thermal Treatment of Wood Materials. IFAC-PapersOnLine, 48-24, 2015, 54-59. www.sciencedirect. com.
8. Hadjiski, M., N. Deliiski. Advanced Control of the Wood Thermal Treatment Processing. – *Cybernetics and Information Technologies,* Bulgarian Academy of Sciences, 16, 2016, 2, 179-197.
9. Juma, M., M. Bafrnec, J. Brezani. Thermal Diffusivity of Thick Fibre-elastomer Composites. http://www.tpl.ukf.sk/engl_vers/thermophys/proceedings/juma.pdf: 2001:95-101.
10. Kavalov, A., D. Angelski. Technology of Furniture. University of Forestry, Sofia, 390, 2014 (in Bulgarian).
11. Rüdiger, A. et al. Grundlagen des Mцbel- und Innenausbaus. DRW-Verlag, 1995.
12. Zhukov, E. V., V. I. Onegin. Technology of Protective and Decorative Coatings of Wood and Wood Materials. Moscow, Ecologia, 1993, 304 (in Russian).
13. Telegin, A. S., B. S. Shvidkiy, U. G. Yaroshenko. Heat- and Mass Transfer. Moscow, Akademkniga, 454, 2002 (in Russian).elastomer Composites. http://www.tpl.ukf.sk/engl_vers/thermophys/proceedings/juma.pdf: 2001:95-101.
10. Kavalov, A., D. Angelski. Technology of Furniture. University of Forestry, Sofia, 390, 2014 (in Bulgarian).
11. Rüdiger, A. et al. Grundlagen des Mцbel- und Innenausbaus. DRW-Verlag, 1995.
12. Zhukov, E. V., V. I. Onegin. Technology of Protective and Decorative Coatings of Wood and Wood Materials. Moscow, Ecologia, 1993, 304 (in Russian).
13. Telegin, A. S., B. S. Shvidkiy, U. G. Yaroshenko. Heat- and Mass Transfer. Moscow, Akademkniga, 454, 2002 (in Russian).

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