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ANALYSIS OF THE HEAT ENERGY USED FOR STEAMING EDGED BEECH LUMBER (*Fagus Sylvatica* L.) WITH THICKNESS OF 50 MM

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ABSTRACT

Milled lumber steaming is a technological procedure, during which lumber is exposed to the influence of saturated water vapor, temperature and pressure, in a closed system. The purpose of the steaming process is to change the color, improve the properties of the lumber, sterilization, as well as to remove some lumber defects that had occurred during the drying process. This paper presents the results obtained from analysis of the heat energy required for steaming edged beech lumber with thickness of 50 mm. Beech (*Fagus Sylvatica* L.) is the dominant wood species in primary wood processing industry on the territory of North Macedonia. That being the case, the data related to steaming beech lumber is of particular interest. The heat energy of a metal automated steaming chamber with a capacity of 28 m^3/cycle was analyzed. Based on the parameters given, an analysis and technical calculation of the heat energy required for steaming the beech lumber were conducted.

Key words: beech, milled lumber, temperature, heat energy, effective heat, heat loss, heat consumption, water vapor consumption.

1. INTRODUCTION

The consumption of heat energy during the lumber steaming process has always attracted attention, how to rationalize it, and most importantly, how to reduce heat loss.
Lumber steaming is an important and complex operation, and an essential part of primary wood processing. Steaming, in addition to being technological, is also a heat procedure. For that reason, this paper is focused on heat analysis of a steaming chamber with capacity of 25 to 30 m^3.

2. RESEARCH METHOD

The research method is based on the following calculations:

– applied models of mathematical formulas for calculation of the total amount of heat, and
– applied mathematical formulas for calculation of water vapor consumption.

The general formula for calculating the total amount of heat required for the steaming process is as follows:

$Q = Q_1 + Q_2$ [kJ]
where Q – total amount of heat [kJ] ,Q_1 – effective heat [kJ], Q_2 – heat loss [kJ].

The effective heat consists of calculations for:

– heat used for lumber heating [kJ],
– heat used for heating 1 m^3 lumber [kJ/m^3],
– heat used for heating the walls, ceiling and the door of the chamber [kJ] and

– heat used for heating the floor [kJ].

The calculations for the heat loss consist of:

– heat loss through the chamber floor [kJ/h],
– heat loss through the installation of the heating medium [kJ/h] and
– heat loss due to poor airtightness [kJ].

The calculations for water vapor consumption consist of:

– heat consumption for 1 h [kJ/h],
– total consumed heat for 1 h [kJ/h],
– heat consumption for 1 h and 1 m^3 lumber [kJ/hm^3],
– heat transfer during the steaming process [kJ/kg],
– water vapor consumption for 1 h and 1 m^3 lumber q_{kg} [kg/hm^3], and
– water vapor consumption for 1 m^3 lumber $q_{kgm}{}^3$ [kg/m^3].

In this paper the research objective is analysis of the heat energy used for steaming edged beech lumber. According to the given input parameters of the steaming process, the results obtained will be analyzed and observed. The purpose of the research is to justify the technological process of steaming the lumber with thickness of 50 mm.

Heat analysis will be expressed through Chamber Analysis. Heat loss will be treated with equal attention as the effective heat. The effective heat and heat loss will be calculated, as well as the total water vapor consumption calculated in kg/hm^3 and kg/m^3.

3. RESULTS AND DISCUSSION

The research results will be mainly aimed at:

– analysis of the heat energy used for steaming lumber,
– the total heat consumption for steaming lumber, and
– water vapor consumption.

3.1. Analysis of the heat energy used for steaming the milled lumber

For the calculation of the required amount of heat for steaming beech edged lumber with thickness of 50 mm, a Chamber Analysis containing the necessary parameters has been put together.

Chamber Analysis

1) Wood species: beech (*Fagus sylvatica* L.)
2) Lumber thickness: b = 50.0 mm
3) Type of lumber: edged beech planks
4) Lumber grade: 1st
5) Initial moisture content of the lumber: $W_{initial} > 40$ %
6) Steaming chamber type: metal chamber

– Structural parts: aluminum - steel grid structure, walls, door and ceiling made of panel (sandwich) plates in combination with 99.7 % pure aluminum with integrated mineral wool for heat insulation;

– Method of direct vaporization: perforated stainless-steel pipes, lumber probes, air temperature sensors with silicon conductors, automatic process guiding, heat consumption meter, condensate siphon, vaulting of the chamber with aluminum canvas, floor made of reinforced concrete.

7) Steaming chamber capacity: $Q_{chamber} =$ 28 (m^3/cycle)
8) Chamber wall thickness: b = 12 cm
9) Chamber ceiling thickness: $b_1 = 12$ cm
10) Chamber floor thickness: $b_2 = 20$ cm
11) Lumber pile length: $l_{pile}= 4$ m
12) Lumber pile width: $s_{pile} = 1.4$ m
13) Lumber pile height: $h_{pile} = 1.5$ m
14) Coefficient of volume reduction of the lumber pile in the chamber: $f_k = 0.85$
15) Distance from the lumber pile to the walls and door of the chamber: $a_1 = 50$ cm
16) Distance between the lumber piles: $a_2 = 10$ cm

17) Distance from the floor to the lumber piles: a_3 = 10 cm
18) Height distance between lumber piles: a_4 = 10 cm
19) Distance between the uppermost lumber pile and the ceiling of the chamber: a_5 = 50 cm
20) Wood density (*Fagus Sylvatica* L.): ρ_{wood} = 680 kg/m^3 (Table 2)
21) Specific heat capacity of wood: C_{wood} = 1.35 kJ/kg°C (Table 1)
22) Lumber temperature before the steaming process: t_{lumber} = 16 °C
23) Temperature of the saturated water vapor supplied to the chamber: t_{vapor} = 110 °C
24) Relative air humidity in the chamber: φ = 100 %
25) Pressure of saturated water vapor: p = 1.5 bar (Table 3)
26) Temperature in the chamber: $t_{chamber}$ = 100 °C
27) Maximum heating temperature of the walls, floor and ceiling: t_{max} = 100 °C
28) Minimum heating temperature of the walls, floor and ceiling: t_{min} = 30 °C
29) Atmosphere temperature: t_{atm} = -15 °C
30) Chamber exterior temperature correction factor: t_{kr} = 10
31) Chamber floor exterior temperature: t_{fe} = 24 °C
32) Water vapor installation length: L_i = 40 m
33) Heat conductivity of reinforced concrete: λ = 7.33 kJ/m^{2}h°C (Table 1)
34) Heat of vaporization of dry saturated water vapor: $Q_{vaporization}$ = 2228 kJ/kg (Table 3)
35) Coefficient of heat transfer from the vapor to the walls, ceiling and floor of the chamber: α_1 = 44000 kJ/m2h°C [3]
36) Heat transfer coefficient from the walls and ceiling to the atmosphere: α_2 = 3.08 kJ/m^{2}h°C
37) Soil temperature: t_{soil} = 5 °C
38) Specific mass of the material from which the walls, ceiling and the floor of the chamber are made: γ_{wcf} = 2900 kg/m^3 (Table 1: Al + mineral wool)
39) Specific heat of the material from which the walls, ceiling and the floor of the chamber are made: C_{wcf} = 0.850 kJ/kg°C (Table 1: Al + mineral wool)
40) Specific mass of the material from which the chamber floor is made: γ_{floor} = 2400 kg/m^3 (Table 1: reinforced concrete)
41) Specific heat of the material from which the chamber floor is made: C_{floor} = 0.922 kJ/kg°C (Table 1: reinforced concrete)
42) Coefficient of heat release from the vapor to the floor: α_1 = 44000 kJ/m^{2}h°C
43) Heat conductivity of reinforced concrete: λ = 7.33 kJ/m^{2}h°C (Table 1)
44) Coefficient of heat conductivity in the installation: K_{inst} = 8.0 kJ/m^{2}h°C
45) Vaporization heat (P = 1.5 bar, t = 110 °C): $q_{vaporization}$ = 2228 kJ/kg
46) Total steaming time: Z = 48 h
47) Lumber treatment time in the chamber: Z_0 = 15 ÷ 50 h

Table 1: *Heat values of some materials*

Material	Specific mass	Specific heat		Heat conductivity	
	γ [kg/m^3]	C [kJ/kg°C]	t_{scope} [°C]	α [kJ/m°Ch]	t_{scope} [°C]
Aluminum (99,7 %)	2700	0.939	100	729 ÷ 1026	200 ÷ 600
Copper	8930	0.387	38	1341 ÷ 1400 1370	20 ÷ 200
Steel, iron	7850	0.551	15 ÷ 300	188	20
Reinforced concrete	2400	0.922	/	7.33	/
Glass wool	/	0.656	/	/	/
Mineral wool	200	0.754	0.100	0.142	30
Styrofoam	15 ÷ 25	1.466	/	0.107	±50
Coal	/	0.669	/	/	/
Water	/	4.186	/	/	/
Air	/	1.005	/	/	/
Celluloses	/	1.550	/	/	/
Oak - beech	650 ÷ 680	1.341÷1.885 1.61	/	0.754	15

Pine	500	2.723	/	0,.587	15
Particle board	300 ÷ 650	/	/	0.21 ÷ 0.38	/
Burned brick	/	/	/	2.993	/
Fireclay brick	/	/	/	3.77 ÷ 5.03	/
Asbestos	/	/	/	0.54 ÷ 0.75	/
Ice	/	2,10	/	/	/
Wood - aluminum	/	1,28	/	/	/

Table 2: *Wood density*

Wood species	Absolute dry density ρ_{aps} [g/cm^3]	Wood species	Absolute dry density ρ_{aps} [g/cm^3]
Beech (*Fagus sylvatica*)	0.68	Black locust (*Robinia pseudoacacia*)	0.73
Oak (*Quercus sessiliflora*)	0.64	Field elm (*Ulmus campestris*)	0.64
Walnut (*Juglans regia* L.)	0.56	Scotch elm (*Ulmus montana)*	0.64
Black walnut (*Juglans nigra* L.)	0.65	White willow (*Salix alba*)	0.52
Ash (*Fraxinus excelsior*)	0.59	Elm (*Caprinus betulus*)	0.79
Chestnut (*Castanea vesca* L.)	0.58	Maple (*Acer pseudoplatanus*)	0.59
Platanus (*Platanus orientalis*)	0.49	Spruce (*Picea excelsa*)	0.43
Alder (*Alnus glutinosa*)	0.49	Scotch pine (*Pinus sylvestris*)	0.49
Linden (*Tilia parvifolia*)	0.49	Silver fir (*Abies alba*)	0.41
Common pear (*Pirus communis*)	0.70	European larch (*Larix europaea)*	0.55
Birch (*Betula verrucosa*)	0.61	Mediterranean cypress (*Cupressus sempervirens*)	0.55

Table 3: *Parametars of dry saturated water vapor*

Pressure P [bar]	Temperature [°C]	Specific mass γ [kg/m^3]	Steam heat content i_n [kJ/kg]	Heat of vaporization $Q_{vaporization}$ [kJ/kg]
0.01	7	0.008	2511	2483
0.02	17	0.015	2531	2458
0.03	24	0.022	2543	2443
0.04	29	0.028	2552	2431
0.05	33	0.035	2559	2422
0.06	36	0.042	2565	2415
0.08	41	0.054	2575	2402
0.10	45	0.067	2583	2932
0.12	50	0.079	2589	2383
0.15	54	0.098	2597	2372
0.20	60	0.128	2608	2358
0.25	65	0.158	2616	2346
0.30	69	0.188	2624	2336

0.35	72	0.217	2631	2327
0.40	75	0.246	2636	2320
0.45	78	0.274	2641	2313
0.50	81	0.303	2654	2307
0.60	86	0.359	2652	2294
0.70	90	0.415	2659	2285
0.80	93	0.470	2665	2275
0.90	96	0.525	2671	2269
1.0	99 (100)	0.579	2675	2260
1.5	111	0.846	2694	2228
2.0	120	1.107	2707	2205
3.0	133	1.619	2726	2167
4.0	143	2.121	2739	2137
5.0	151	2.616	2749	2112
6.0	158	3.106	2757	2090
7.0	164	3.600	2763	2069
8.0	170	4.058	2768	2051
9.0	175	4.568	2773	2034
10.0	180	5.051	2777	2018

3.2. Effective heat

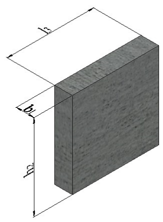
1) Heat used for heating the lumber

$Q_{lumber} = V_{lumber} \cdot C_{lumber} \cdot \rho_{lumber} \cdot (t_{chamber} - t_{lumber})$ [kJ]
$Q_{lumber} = 28.0 \cdot 1.35 \cdot 680 \cdot (100 - 16)$
Qlumber = 2159136 [kJ]

2) Heat used for heating 1 m^3 lumber

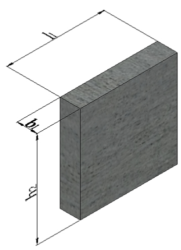
$Qm^3 = \frac{Qlumber}{Vlumber}$ [kJ/m^3]
$Qm^3 = \frac{2159136}{28}$
Qm3 = 77112 [kJ/m^3]

3) Volume of the walls, ceiling, floor and door of the chamber
a) Volume of the two lateral walls



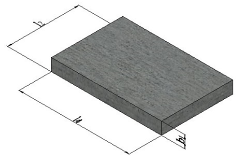
$l_3 = 3.9$ m
$h_2 = 3.7$ m
$b_1 = 0.12$ m
$V_{lw} = (l_3 \cdot h_2 \cdot b_1) \cdot 2$ [m^3]
$V_{lw} = (3.9 \cdot 3.7 \cdot 0.12) \cdot 2$
$V_{lw} = 3.46$ [m^3]

b) Volume of the frontal wall



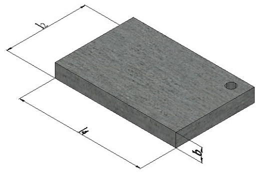
$l_1 = 5.0$ m
$h_2 = 3.7$ m
$b_1 = 0.12$ m
$V_{fw} = l_1 \cdot h_2 \cdot b_1$ [m^3]
$V_{fw} = 5.0 \cdot 3.7 \cdot 0.12$
$V_{fw} = 2.22$ [m^3]

c) Volume of the ceiling



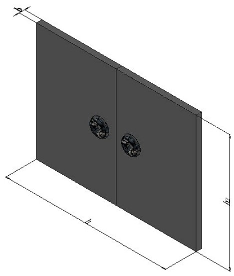
$l_2 = 5.24$ m
$l_4 = 4.0$ m
$b = 0.12$ m
$V_{ceiling} = l_2 \cdot l_4 \cdot b\ [m^3]$
$V_{ceiling} = 5.24 \cdot 4.0 \cdot 0.12$
$V_{ceiling} = 2.52\ [m^3]$

d) Volume of the floor



$b_2 = 0.2$ m
$l_2 = 5.2$ m
$l_4 = 4.0$ m
$V_{floor} = l_2 \cdot l_4 \cdot b_2\ [m^3]$
$V_{floor} = 5.2 \cdot 4.0 \cdot 0.2$
$V_{floor} = 4.16\ [m^3]$

e) Volume of the door



$l_1 = 5.0$ m
$h_2 = 3.7$ m
$b = 0.12$ m
$V_{door} = l_1 \cdot h_2 \cdot b\ [m^3]$
$V_{door} = 5.0 \cdot 3.7 \cdot 0.12$
$V_{door} = 2.22\ [m^3]$

3) Heat used for heating the walls, ceiling and the door of the chamber

$Q_{wcd} = V_{wcd} \cdot \gamma_{wcd} \cdot C_{wcd} \cdot \frac{t_{max} - t_{min}}{2}$ [kJ]
$V_{wcd} = V_{lw} + V_{fw} + V_{ceiling} + V_{door}\ [m^3]$
$V_{wcd} = 3.46 + 2.22 + 2.52 + 2.22$
$V_{wcd} = 10.42\ [m^3]$
γ_{wcd} – aluminum + mineral wool = 2900 [kg/m^3] (Table 1)
C_{wcd} – aluminum + mineral wool = 0,850 [kJ/kg°C] (Table 1)
$t_{max} = 100$ °C
$t_{min} = 30$ °C
$Q_{wcd} = 10.42 \cdot 2900 \cdot 0.850 \cdot \frac{100-30}{2}$
$Q_{wcd} = 898985$ [kJ]

4) Heat used for heating the floor

$Q_{floor} = V_{floor} \cdot \gamma_{flor} \cdot C_{floor} \cdot \frac{t_{max} - t_{min}}{2}$ [kJ]
$V_{floor} = 4.6\ [m^3]$
γ_{floor} – reinforced concrete = 2400 kg/m^3 (Table 1)
C_{floor} – reinforced concrete = 0.922 kJ/kg°C (Table 1)
$t_{max} = 100$ °C
$t_{min} = 30$ °C
$Q_{floor} = 4.6 \cdot 2400 \cdot 0.922 \cdot \frac{100-30}{2}$
$Q_{floor} = 322184$ [kJ]

5) Total amount of effective heat

$Q_1 = Q_{lumber} + Q_{wcd} + Q_{floor}$
$Q_1 = 2159136 + 898985 + 322184$
$Q_1 = 3380000$ [kJ]

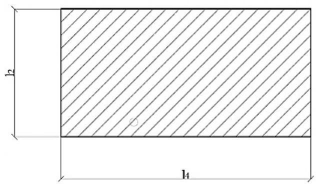
Based on the given mathematical analysis, we can conclude that the heat used for lumber heating is $Q_{lumber} = 2159136$ kJ, the heat used for heating 1 m^3 lumber is $Qm^3 = 77112$ kJ/m^3, the heat used for heating the walls, ceiling and the door is $Q_{wcd} = 898985$ kJ and the heat used for heating the floor is $Q_{floor} = 322184$ kJ. The total amount of effective heat is $Q_1 = 3380000$ kJ.

3.3. Heat loss

The chosen materials from which the steaming chamber is constructed offer elimination of the heat loss through the walls, the ceiling and the door. The following subject of analysis will be the heat loss through the floor of the chamber, the installation of the heating medium and the hermeticity of the chamber.
1) Heat loss through the chamber floor

$Q_{fhl} = P_{floor} \cdot \Delta t \cdot k$ [kJ/h]

a) Floor area



$P_{floor} = l_2 + l_4$ [m^2]
$P_{floor} = 5.24 \cdot 4.0$
$P_{floor} = 20.96 \approx 21.0$ [m^2]

b) Temperature differences

$\Delta t = t_{chamber} - t_{soil}$ [°C]
$\Delta t = 100 - 5$
$\Delta t = 95$ [°C]

c) Heat transfer coefficient

$K = \frac{1}{\frac{1}{\alpha_1}+\frac{b_2}{\lambda}+\frac{1}{\alpha_2}}$ [kJ/m^2h°C] for a single-layer floor constructed of one kind of material
where: α_2 – coefficient of heat release from the floor to the soil.
$\alpha_2 = [8.4 + 0.06 \cdot (t_{fe} - t_{soil})] \cdot 4.19$ [kJ/m^2h°C]
$\alpha_2 = [8.4 + 0.06 \cdot (24.0 - 5.0)] \cdot 4.19$
$\alpha_2 = (8.4 + 1.14) \cdot 4.19$
$\alpha_2 = 39.9726 \approx 40.0$ [kJ/m^2h°C]
$K = \frac{1}{\frac{1}{44\,000}+\frac{0.20}{7.33}+\frac{1}{40}}$
$K = \frac{1}{0.000023+0.0273+0.025}$
$K = 19.11$ [kJ/m^2h°C]

d) Heat loss for 1 h

$Q_{hlf/h} = P_{floor} \cdot \Delta t \cdot k$ [kJ/h]
$Q_{hlf/h} = 21.0 \cdot 95.0 \cdot 19.11$
$Q_{hlf/h} = 38124$ [kJ/h]

e) Heat loss in correlation with the total steaming time
Z – total steaming time [h] (z = 48 h)

$Q_{zhlf} = Q_{floor} \cdot Z$ [kJ]
$Q_{zhlf} = 38124 \cdot 48$
$Q_{zhlf} = 1830000$ [kJ]

2) Heat loss through the installation of the heating medium
a) Heat loss through the installation of the heating medium for 1 h

$Q_{zli} = L_i \cdot \pi \cdot (t_{vapor} - t_{atm}) \cdot \frac{K_{inst}}{f_{kr}}$ [kJ]
$Q_{zli} = 40.0 \cdot 3.14 \cdot (110.0 - (-15.0)) \cdot \frac{8.0}{10.0}$
$Q_{zli} = 12560$ [kJ/h]

b) Amount of condensate in the pipeline

$Q_{condensate} = \frac{Q_{inst}}{q_{condensate}}$ [kg/steam for 1h]
$Q_{condensate} = \frac{12500}{2228}$
$Q_{condensate} = 5.6$ [kg/steam fop 1h]

c) Heat loss through the installation of the heating medium in correlation with the total steaming time (Z = 48 h)

$Q_{linst} = Q_{inst} \cdot Z$ [kJ]
$Q_{linst} = 12500 \cdot 48$
$Q_{linst} = 600000$ [kJ]

d) Amount of condensate in the pipeline for the total steaming time (Z = 48 h)

$Q_{vcondensate} = Q_{condensate} \cdot Z$ [kg/steam for 48h]
$Q_{vcondensate} = 5.6 \cdot 48$
$Q_{vcondensate} = 269 \approx 270$ [kg/steam for 1h]

3) Heat loss due to poor airtightness
Heat loss due to poor airtightness is calculated as 10 % of the total amount of heat for steaming.

a) Total amount of heat loss for 1 h

$Q_{lh} = Q_{floor} + Q_{inst}$ [kJ/h]
$Q_{lh} = 38124 + 12500$
$Q_{lh} = 50684$ [kJ/h]

b) Heat loss in correlation with the total steaming time (Z = 48 h)

$Q_z = Q_{lh} \cdot Z$ [kJ]
$Q_z = 50684 \cdot 48$
$Q_z = 2432832$ [kJ]

c) Total amount of heat for steaming (I)

$Q = Q_1 + Q_z$ [kJ]
$Q = 3380000 + 2432832$
$Q = 5813000$ [kJ]

d) Heat loss due to poor airtightness (10% of Q)

$Q_{at} = \frac{1}{10} \cdot Q$ [kJ]
$Q_{at} = \frac{1}{10} \cdot 5813000$
$Q_{at} = 581300$ [kJ]

e) Heat loss due to poor airtightness for 1 h

$q_{1h} = \frac{Q_{at}}{z}$ [kJ/h]
$q_{1h} = \frac{581300}{48}$
$q_{1h} = 12111$ [kJ/h]

4) Total amount of heat loss

$Q_2 = Q_{zhlf} + Q_{linst} + Q_{at}$ [kJ]
$Q_2 = 1836000 + 600000 + 581300$
$Q_2 = 3011300$ [kJ]

It can be concluded that the heat loss through the chamber floor is $Q_{zhlf} = 1830000$ kJ, the heat loss through the installation of the heating medium is $Q_{linst} = 600000$ kJ and the heat loss due to poor airtightness is $Q_{at} = 581300$ kJ. The total amount of heat loss is $Q_2 = 3011300$ kJ.

3.4. Total amount of steaming heat

The total amount of heat for steaming edged beech lumber with thickness of 50 mm is a sum of the effective heat and the heat loss.

$Q = Q_1 + Q_2$ [kJ]
$Q = 3380000 + 3011300$
$Q = 6391300$ [kJ]

3.5. Water vapor consumption

1) Heat consumption for 1 h

$q_h = \frac{Q_{lumber}}{z_1}$ [kJ/h]
where z_1 – heating time of the milled lumber ($z_1 = 12$ h)
$q_h = \frac{2160000}{12}$
$q_h = 180000$ [kJ/h]

2) Total consumed heat for 1 h

$Q_{1h} = Q_{floor} + Q_{inst} + Q_{at}$ [kJ/h]
$Q_{1h} = 38124 + 12560 + 12111$
$Q_{1h} = 62795 \approx 63000$ [kJ/h]

3) Heat consumption for 1 h and 1 m^3 lumber

$q_m^3 = \frac{q_1}{V_{gr}}$ (kJ/hm^3)
$q_m^3 = \frac{304000}{28}$
$q_m^3 = 11000$ [kJ/hm^3]

4) Heat transfer during the steaming process
The water vapor pressure is in the range $p_{vapor} = 1.0 \div 1.5$ bar and temperature of $t_{vapor} = 100$ °C.
a) Under the given conditions, the parameters are as follows:

– the amount of heat in the vapor is $i_{nvapor} = 2694$ kJ/kg (Table 3) and
– the temperature at which the vapor condensates is $t_{vapor} = 100$ °C and the amount of heat in the condensate is $i_{vcondensate} = 100$ kJ/kg.

Accordingly, the following parameters can be presented:

– water vapor temperature: $t_{vapor} = 100$ °C,
– water vapor pressure: $p_{vapor} = 1.0 \div 1.5$ bar,
– the amount of heat in the vapor: $i_{nvapor} = 2694$ (kJ/kg), and
– the amount of heat in the condensate: $i_{vcondensate} = 100$ kJ/kg.

b) With the parameters given, the heat transfer during the steaming process is:

$i_{nvapor} - i_{vcondensate} = 2694 - 100$
$i_{nvapor} - i_{vcondensate} = 2594$ [kJ/kg]

5) Water vapor consumption for 1 h and 1 m^3 lumber

$q_{kg} = \frac{q_{m^3}}{i_n\text{vapor} - i_v condensate}$ [kg/hm^3]
$q_{kg} = \frac{11000}{2594} = 4.27 \approx 4.3$ (kg/hm^3)
$q_{kg} = 4.27 \approx 4.3$ [kg/hm^3]

6) Water vapor consumption for 1 m^3 lumber

$q_{kgm}{}^3 = q_{kg} \cdot Z$ [kg/m^3]
where Z – total steaming time (Z = 48 h)
$q_{kgm}{}^3 = 43 \cdot 48$
$q_{kgm}{}^3 = 210$ [kg/m^3]

4. CONSLUSION

This paper presents the results obtained by the researches related to the analysis of heat energy in a metal steaming chamber for steaming edged lumber with thickness of 50 mm. This problem has always attracted the attention of the primary wood processing industry. Accordingly, we will list the most crucial conclusions.

1) Lumber properties:

– wood species: beech (*Fagus Sylvatica* L.),
– lumber type: plank with thickness b = 50 mm,
– level of processing: sawn, edged lumber,
– lumber grade: 1st, and
– initial moisture content of the lumber: $W_{initial} > 40$ %.

2) Steaming mode:

– temperature: t ≈ 95 ˚C,
– relative air humidity: φ = 100 (%),
– initial humidity of rust, → $W_{poc} > 40$ %, and
– total steaming time: Z = 48 (h).

3) Chamber constructional properties:

– metal chamber above the ground,
– automatized steaming process,
– steaming chamber capacity: Qchamber = 28 (m3/cycle)
– steaming method: direct vaporization and

– structural parts of the chamber: aluminum - steel grid structure, walls, door and ceiling made of panel (sandwich) plates in combination with 99.7 % pure aluminum with integrated mineral wool for heat insulation.
4) Heat used for heating the lumber: Q_{lumber} = 2159136 [kJ]
5) Heat used for heating 1 m^3 lumber: Qm3 = 77112 [kJ/m^3]
6) Total amount of effective heat: Q_1 = 3380000 [kJ]
7) Total amount of heat losses: Q_2= 3011300 [kJ]
8) Total amount of steaming heat: Q = 6391300 [kJ]
9) Heat consumption for 1 h: q_h = 180000 [kJ/h]
10) Heat consumption for 1 h and 1 m^3 lumber: $q_m{}^3$ = 11000 [kJ/hm^3]
11) Water vapor consumption for 1 h and 1 m^3 lumber: q_{kg} = 4.3 [kg/hm^3]
12) Water vapor consumption for 1 m^3 lumber: $q_{kgm}{}^3$ = 210 [kg/m^3]

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