Physical and technical aspects of the technology of energy-saving drying of wood in chambers with natural circulation of the agent

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Abstract. The problems of energy saving are one of the most urgent problems of modern industry and timber processing is no exception in this. In all wood processing, wood drying stands out for its energy consumption. A possible direction for significantly reducing the energy intensity of wood drying is the use of modes based on the phenomenon of thermal and moisture conductivity in chambers with a natural circulation of the drying agent. The theoretical and experimental studies carried out by the authors made it possible to create a wood drying technology that reduces the energy consumption of the process by 40-45% with a certain (15-17 %) loss in the productivity of drying equipment compared to chambers operating with forced circulation of the drying agent.

1. Introduction

Drying of wood (lumber) is an energy-consuming process. Therefore, of course, researchers strive (as far as possible) to reduce the energy costs of drying [1].

A radical way to reduce energy consumption for drying is the use of chambers with natural circulation of the drying agent, the main feature of which is the absence of fans and, accordingly, the absence of energy costs for their drive. At the same time, it should be taken into account that for modern convective chambers in the total balance of energy consumption, the cost of electricity for driving fans is about 40 % [1].

Having such an undeniable advantage, chambers with natural circulation also have a very noticeable disadvantage: a relatively longer drying process.

Our research has allowed us to offer a technology of energy-saving drying in chambers with natural circulation at an acceptable duration of the process.

2. Materials and methods

The process of low-temperature convective drying of wood in the analysis of processes is usually described by a system of differential equations of heat and mass transfer [2].

$$\frac{\partial t}{\partial \tau} = a \nabla_t^2 t + \frac{\varepsilon \rho}{c} \frac{\partial u}{\partial \tau} \; ; \tag{1}$$

$$\frac{\partial u}{\partial \tau} = a_m \nabla_u^2 u + a_m \delta \nabla^2 t \; , \tag{2}$$

where t – the temperature of the wood; τ – time; a – coefficient of thermal conductivity; ε – the criterion of the phase transition; p –the density of wood; c – specific heat capacity; u – wood moisture content; a_m – coefficient of moisture conductivity; δ – the thermogradient coefficient (or Soret coefficient).

At the same time, a boundary condition of the third kind is most often used as a boundary condition [3, 4 – 10].

In equation (2), the second term of the right part represents the flow of moisture due to the phenomenon of thermal and thermal conductivity [2]. At the same time, it is necessary to take into account that thermal conductivity can both accelerate the process and slow it down.

Our previous studies [11-13] showed the following:

1. When solving the system of heat and mass transfer equations, it is necessary to present the phase transition criterion in the form

$$\varepsilon = k_1(\Delta t) \cdot \varepsilon_1(u) + k_2(\Delta t) \cdot \varepsilon_2(u), \tag{3}$$

where $\mathbf{k_1\,(\Delta t)}$, $\mathbf{k_2\,(\Delta t)}$ are the temperature coefficients depending on the direction of the temperature gradient; $\boldsymbol{\varepsilon_1\,(u)}$, $\boldsymbol{\varepsilon_2\,(u)}$ – criteria for the phase transition.

Calculation formulas for determining temperature coefficients and phase transition criteria:

$$k_1(\Delta t) = -5 \cdot 10^{-3} \Delta t^3 + 1.018 \cdot 10^{-3} \Delta t^2 + 0.55 \Delta t + 0.399 \tag{4}$$

$$k_2(\Delta t) = 5 \cdot 10^{-3} \Delta t^3 + 1.018 \cdot 10^{-3} \Delta t^2 - 0.55 \Delta t + 0.399 \tag{5}$$

$$\varepsilon_1(u) = 42.054 u^5 - 94.787 u^4 + 75.965 u^3 - 27.191 u^2 + 5.229 u + 0.298 \tag{6}$$

$$\varepsilon_2(u) = -78.103 u^5 + 170.324 u^4 - 125.386 u^3 + 34.667 u^2 - 2.778 u + 0.506 \tag{7}$$

2. When solving the system of heat and mass transfer equations (1) – (2), the following must be taken into account.

There is some asymmetry of moisture flows when changing the direction of the temperature gradient vector.

The moisture conductivity equation (2) takes the form

$$\frac{\partial u}{\partial t} = a_m \frac{\partial^2 u}{\partial x^2} + a_m \delta k_\delta \frac{\partial^2 t}{\partial x^2} \; , \tag{8}$$

where k_δ is the coefficient that takes into account the asymmetry of moisture flows,

$$k_\delta = k_1(\Delta t) \cdot k_{\delta 1}(u) + k_2(\Delta t) \cdot k_{\delta 2}(u); \tag{9}$$

$$k_{\delta 1}(u) = -84.154 u^5 + 185.116 u^4 - 139.868 u^3 + 42.552 u^2 - 5.434 u + 1.112; \tag{10}$$

$$k_{\delta 2}(u) = 98.812 u^5 - 217.104 u^4 + 163.626 u^3 - 49.458 u^2 + 6.208 u + 0.862. \tag{11}$$

Thus, the previous studies allowed us to refine the methodology for solving the system of heat and mass transfer equations (1-2). Based on this technique, a large-scale computational experiment was conducted.

3. Results

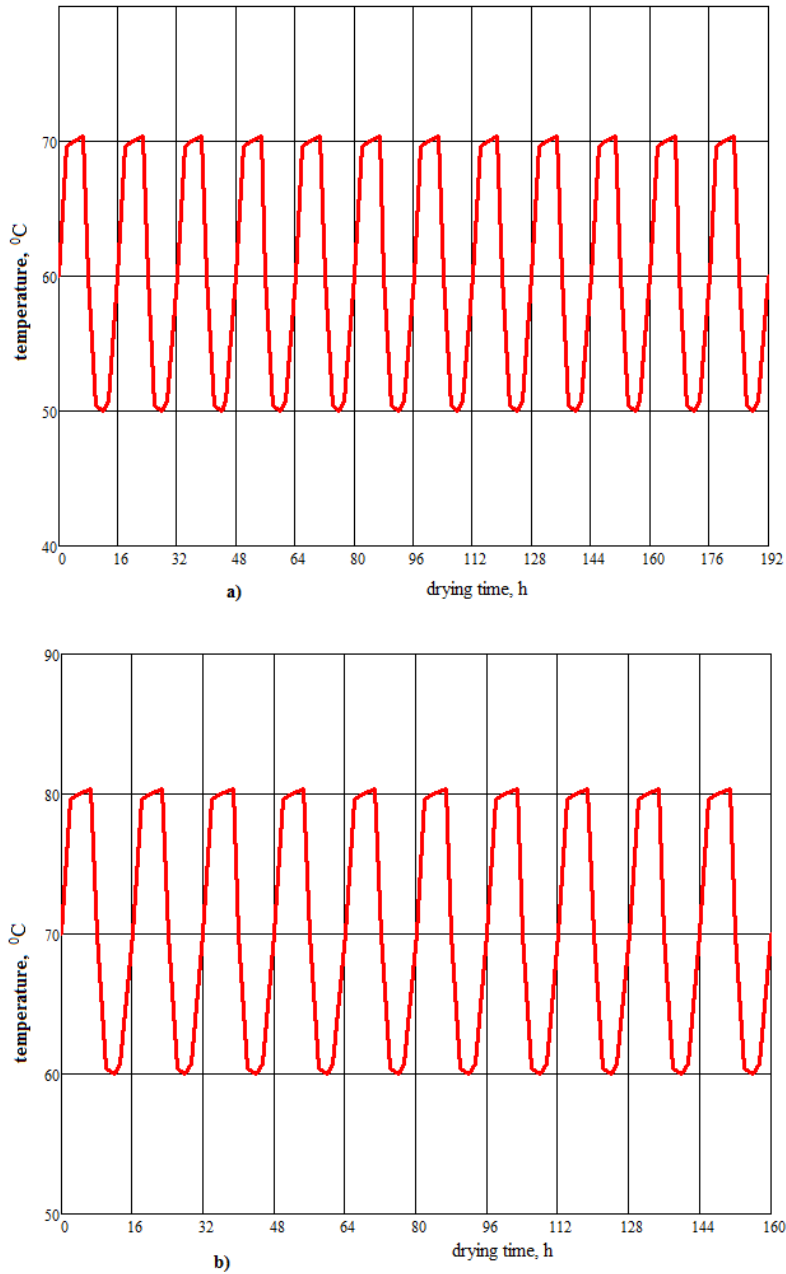The results of the computational experiment are presented in figures 1-7.

Figure 1. Temperature oscillation in the chamber. a) the average value of the medium temperature is 60 ^{0}C; b) the average value of the medium temperature is 70 ^{0}C.
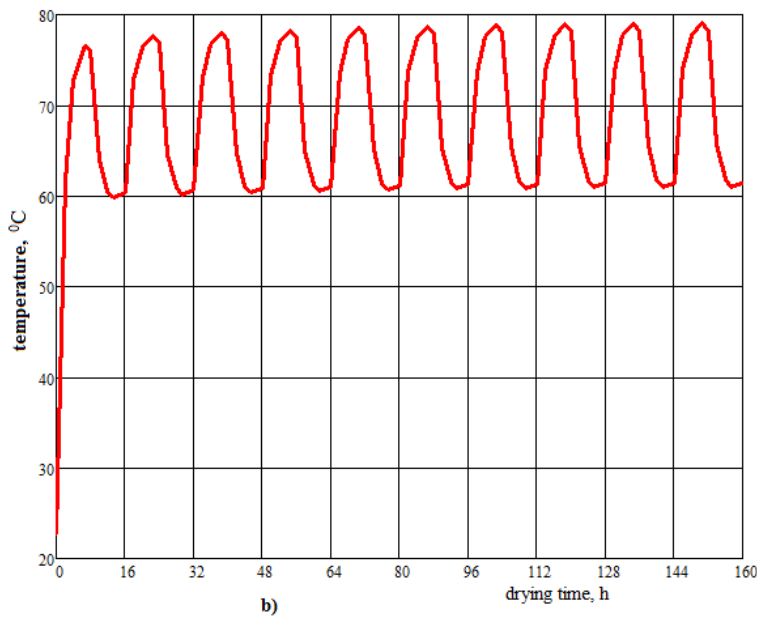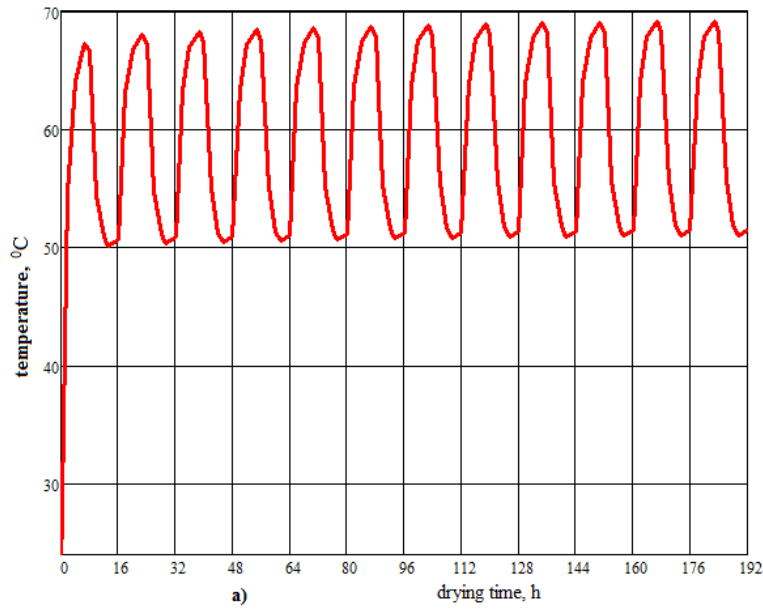
Figure 2. Change in the temperature of wood during drying by oscillating mode (middle of the assortment). a) the average value of the medium temperature is 60 ^{0}C; b) the average value of the medium temperature is 70 ^{0}C.
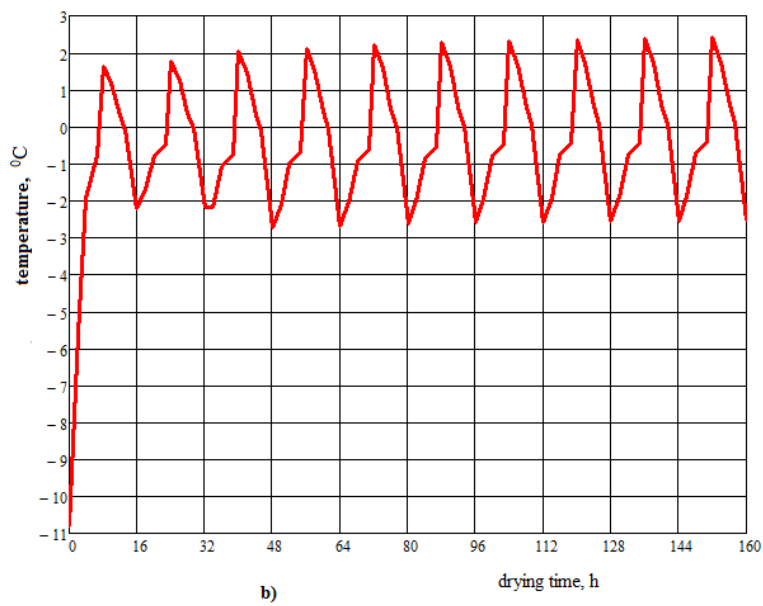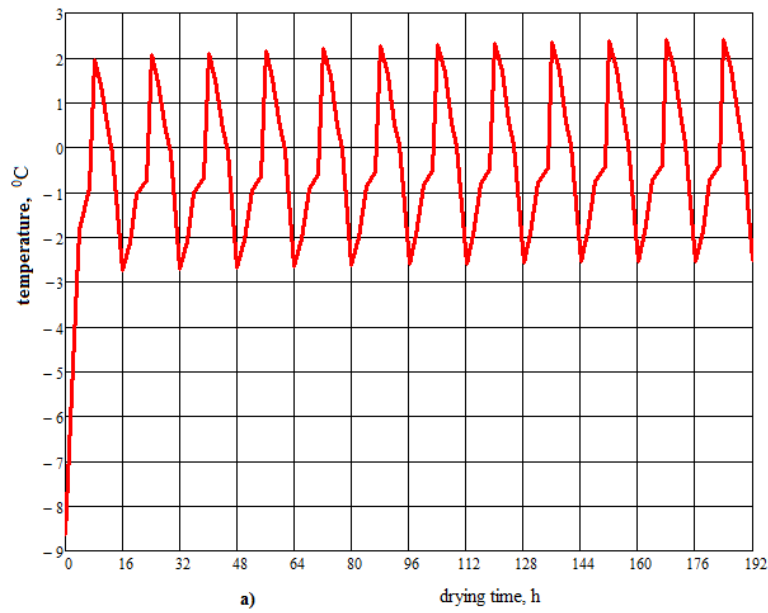
Figure 3. Changing the temperature gradient in the drying assortment. a) the average value of the medium temperature is 60 ^{0}C; b) the average value of the medium temperature is 70 ^{0}C.
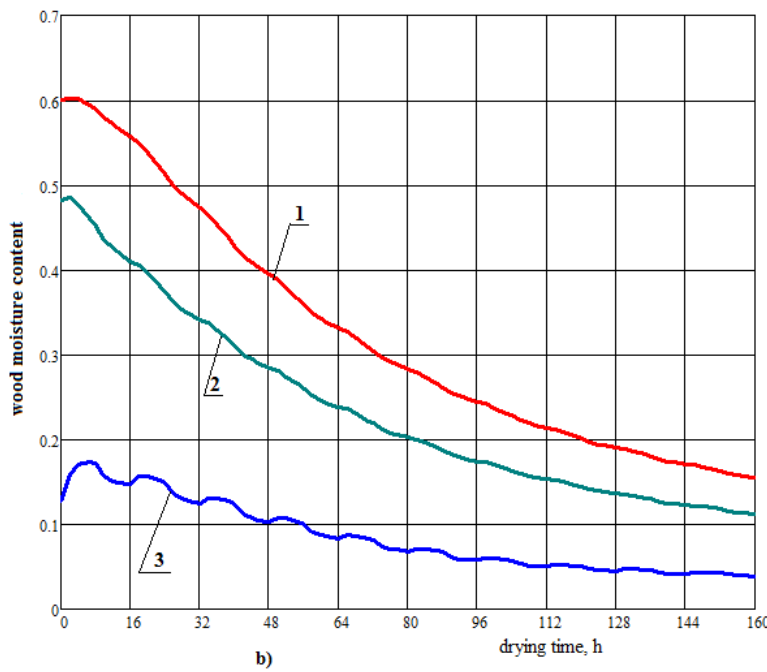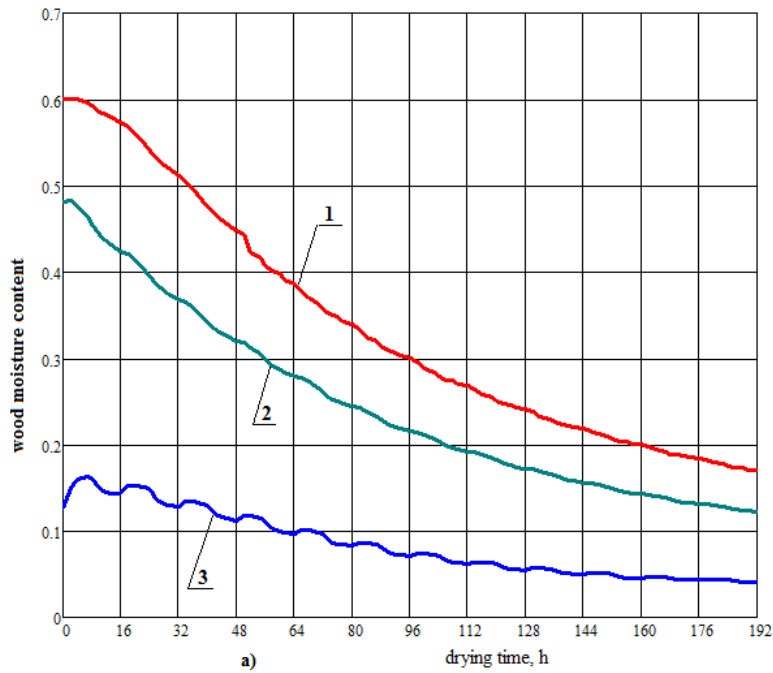
Figure 4. The drying process by oscillating mode. a) the average value of the medium temperature is 60 ^{0}C; b) the average value of the medium temperature is 70 ^{0}C. 1 – in the middle of the board; 2 – the average humidity of the assortment; 3 – on the surface of the board.
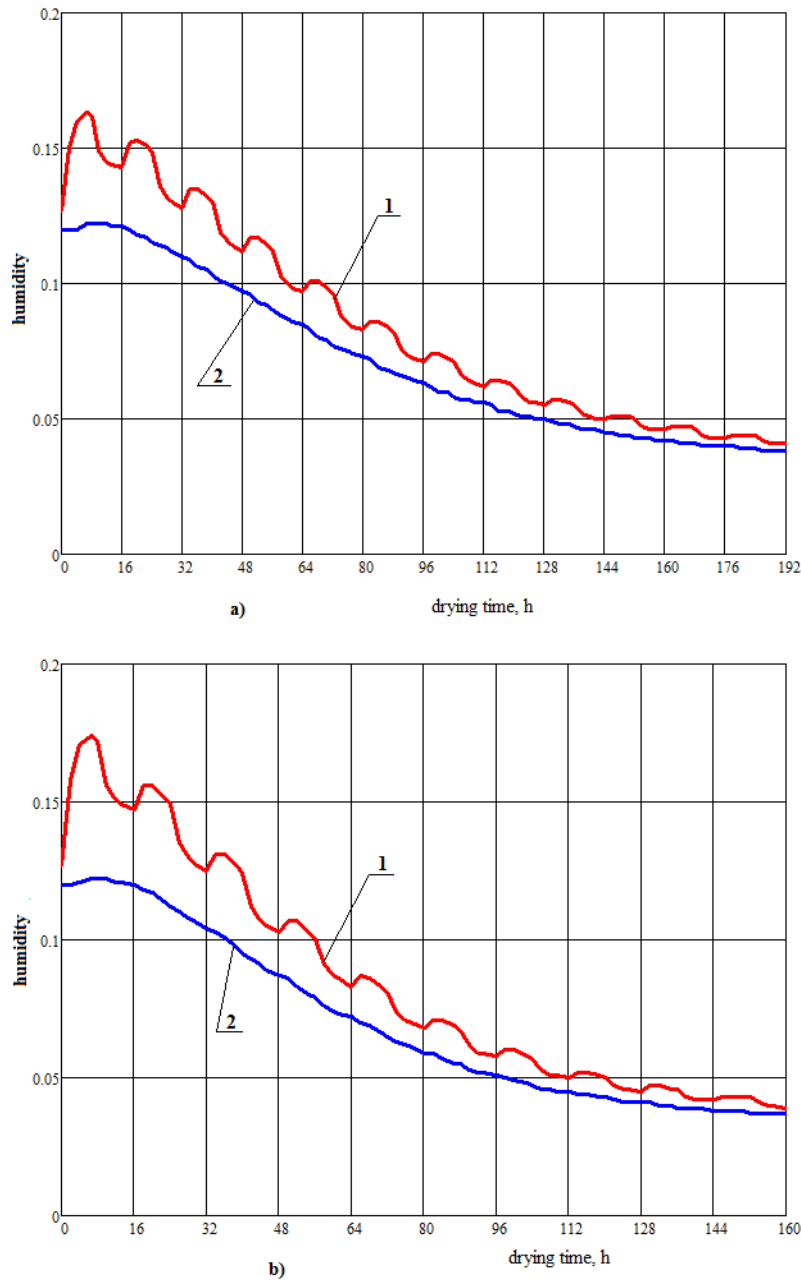
Figure 5. The drying process by oscillating mode. a) the average value of the medium temperature is 60 ^{0}C; b) the average value of the medium temperature is 70 ^{0}C. 1 – humidity on the surface of the assortment; 2 – the equilibrium moisture content of the wood.
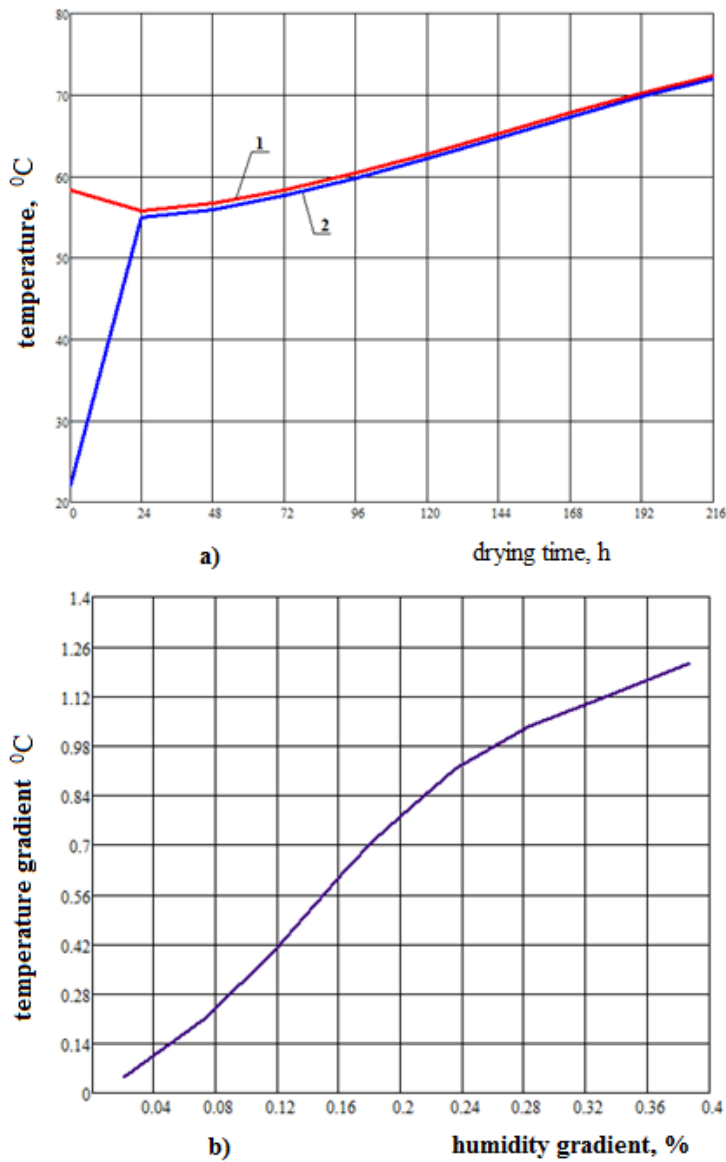
Figure 6. a) Change in the temperature of the medium and wood in the chamber during drying by the soft mode. 1 – the temperature of the drying agent, ^0C; 2 – the average temperature of the drying assortment, ^0C; b) The temperature gradient in the function of the humidity gradient over the cross-section of the drying assortment (soft drying mode).
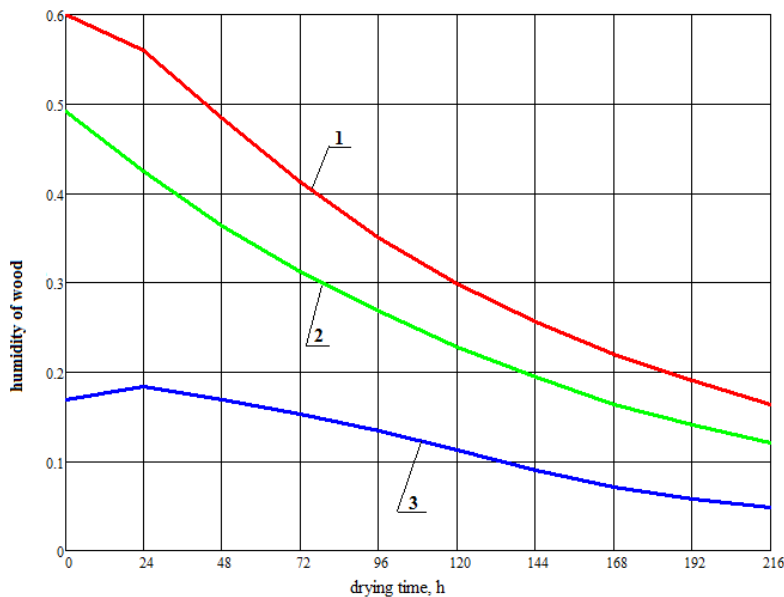
Figure 7. The process of drying with a soft mode. 1 – in the middle of the board; 2 – the average humidity of the assortment; 3 – on the surface of the board.

4. Discussion

The analysis of the experimental results shows that:

- the change in the temperature of wood over time during drying by an oscillating mode practically repeats the oscillation of the medium temperature (figures 1 and 2). The oscillation amplitude of the wood temperature is noticeably (by 10-20 %) less than that of the medium, which, in our opinion, is explained by the significantly higher heat capacity of the wood, and, consequently, by the inertia of thermal processes.
- the maximum value of negative values of the temperature gradient is 2-2.5 ^{0}C, and their total duration is from 30 to 40 % of the total duration of drying by oscillating mode. This shows that the parameters of this mode are determined very accurately (figures 3 and 4).
- the value of the positive temperature gradient during soft drying reaches a value of 1 ^{0}C or more, which, of course, slows down the drying process (figure 6 b).
- the oscillatory nature of the moisture content of the wood surface (figure 5) during drying by an oscillating mode indicates, in our opinion, periodic intensive moisture removal from the depth of the assortment due to the work of thermal and moisture conductivity.
- the drying process by the standard soft mode is almost 20 % longer than the drying of the same material by the oscillating mode.
- full-scale laboratory and industrial experiments [1] have confirmed the effectiveness of applying the modes of the oscillating structure.

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