Vol. 4, No. 1, 2022

https://doi.org....

UDK 004.94; 536.2

Ya. I. Sokolovskyy [1], O.V. Sinkevych [2]
[1] Lviv Polytechnic National University, Lviv, Ukraine
[2] National Forestry University of Ukraine, Lviv, Ukraine

THE USE OF CELLULAR AUTOMATA IN THE SIMULATION OF WOOD DRYING PROCESSES IN A WOOD DRYING CHAMBER OF PERIODIC ACTION

In this work, research the essence of the wood drying process in a periodic wood drying chamber. This paper provides a mathematical model of a wood drying chamber, which describes the general essence of physical drying processes using the equipment available in the wood drying chamber. This approach allows to take into account the physical parameters of the necessary equipment, such as heaters, fans, humidifying nozzles or other. This approach also allows to ignore some design characteristics that may differ depending on the type of wood drying chamber. Considering this, the main task in this work is to determine the temperature and humidity of the drying agent and lumber in the stack, as well as the temperature of the main components of the wood drying chamber. Taking into account such a large number of input parameters and describing a complex non-stationary process of heat transfer, there is a need to create complicated mathematical models. The presence of such mathematical models greatly complicates their application and requires significant computer resources for their calculation. In this way, the mathematical description is reduced to the description of non-linear partial differential equations. To simplify and speed up the calculations of this mathematical model, the use of cellular automata is suggested. To do this, the 3D model of the wood drying chamber is represented as a cell-automatic field, which consists of cells of the same size but different types. As a result, neighboring cells contain local relationships that describe their general behavior. This behavior depends on the type of tangent cells and is described by transition rules based on a mathematical model. Through the use of the developed cell-automatic model and transition rules, it is possible to obtain the values of the temperature and moisture content of the wood in the stack, the drying agent in the chamber, as well as the temperature of the main components of the chamber. The work also shows the corresponding graphs of changes in temperature and moisture content. To check the adequacy and reliability, the obtained results were compared with the results of other authors' experiments. As a result of the verification, the values of the average absolute error aren't high, which confirms the adequacy of the mathematical model and the prospects of using the developed cell-automatic model.

Key words: **mathematical model; Non-stationary process of heat and moisture transfer; 3D model; Cellular-automata model; Transition rules.**

Introduction

Modeling of wood drying processes is a very relevant task, which consists in determining the values of temperature and moisture content of wood. These values for the drying agent are often assumed to be constant, which is a rough assumption that should be avoided. Some authors in their work [1] quite rightly claim that these values of the drying agent are constant, since they are constantly maintained at the same level along the entire wood drying chamber, but this is far from the case. Another authors, in their work [2], have clearly demonstrated that the values of the drying agent have completely different values in other areas of the drying chamber. This is due to the intensive process of evaporation of moisture from wood in stacks. Therefore, when modelling wood drying processes, it is necessary to take into account changes in temperature and humidity of the wood drying agent. It is also necessary to take into account the design features of the studied 3D model of the wood drying chamber, namely the number of heaters, fans or nozzles. They must be taken into account, because they directly affect the temperature and moisture content of the drying agent. In this way, everything comes down to solving the problem of numerical modeling of a dynamic system, which consists of a large number of boundary and initial conditions. To do this, we can use a system of differential equations, but their implementation requires significant computer system resources and time [3].

It is for this reason that scientists are constantly looking for new and more effective approaches to solving this class of problems. One such approach can be the use of the cellular automata method [4]. This method is quite convenient for describing and determining changes in the physical characteristics of lumber. This definition occurs by using some rules of behavior for each element of the system. Each such element is a cell located on a cell-automatic field and has its own characteristics that represent part of the simulated physical space. All this transition rules makes it possible to change the characteristics of cells using their previous values and the values of its neighboring cells. In general, the use of such local dependencies significantly reduces the amount of computer system resources required for their execution and significantly increases the speed of calculations [5].

The analysis of recent publications shows that many researchers already use the method of cellular automata in solving various problems, including problems of heat and mass transfer. Some authors managed to use the method of cellular automata in modeling heat conduction processes taking into account the phenomenon of segregation [6]. In another work [7], the authors simulation of static recrystallization during non-isothermal annealing. In turn, the authors of the work [8] were able to use the method of cellular automata when building a series of infinite Petri nets. Some authors managed to significantly speed up the calculation process [9]. Other authors [10] succeeded in determining the mechanical characteristics of composite materials based on micro-level cellular structures. All these works clearly demonstrate the possibility of using cellular automata in the simulation of wood drying processes in a wood drying chamber. At the same time, the number of scientists who use cellular automata to solve various problems is steadily increasing every year, which confirms the perspective of the chosen direction of research.

The object of research is the heat and moisture transfer processes between the wood drying agent and stacks of dried wood.

The subject of the study is a model of an asynchronous cellular automata for simulating heat and moisture transfer processes in a periodic wood drying chamber.

The main goal of this work is for the development and research of a cellular automata model using developed algorithms and software tools. To achieve the set goal, the following **main tasks of the research are defined:**

1. Determine the main parameters of the studied 3D model of the wood drying chamber and conduct an analysis of its main components.
2. Describe a mathematical model of wood drying processes in a wood drying chamber, which would allow determining changes in temperature and moisture content for wood and its drying agent.
3. Present the studied 3D model in the form of a set of cells located on the cellular-automata field.
4. Develop a model of an asynchronous cellular automata and provide an algorithm for its working based on the use of transition rules.
5. Modeling the process of wood drying in a wood drying chamber using the developed cellular automata model and determine the accuracy of the obtained results.

Scientific novelty – A new model of an asynchronous cellular automaton was developed to determine the value of temperature and moisture content in wood, on its surface and in its drying agent.

Practical significance – An algorithm for the use of a cellular automata model has been developed. This model used transition rules based on a mathematical model of heat and moisture transfer processes in a wood drying chamber and its boundary conditions. The use of such an algorithm significantly speeds up the modeling process compared to other methods, in particular the finite difference method.

Research methods. In this work used the methods of heat balance, computer modeling, and asynchronous cellular automata.

The results of the study and their discussion

Description of the studied 3D model. For the development of the studied 3D model of the periodic wood drying chamber, the following components were taken into account:

- External and internal fencing (walls, doors, ceiling, roof);
- Water heaters (left side passage of the ceiling);
- Axial fans (central part of the ceiling);
- Humidifying nozzles (right side passage of the ceiling);
- Stacks of drying wood.

In general, five types of wood drying chambers, which have the same structure but different geometric dimensions, were parameterized. Parameterization of all components of the 3D model was carried out using the SolidWorks API [11], and their appearance is shown in Fig. 1. Depending on the number and size of the stacks, chosen what type of wood drying chamber will be used. Each type of wood drying chamber contains a specific type of equipment for heating, ventilation and air humidification systems, and their number may be changed.

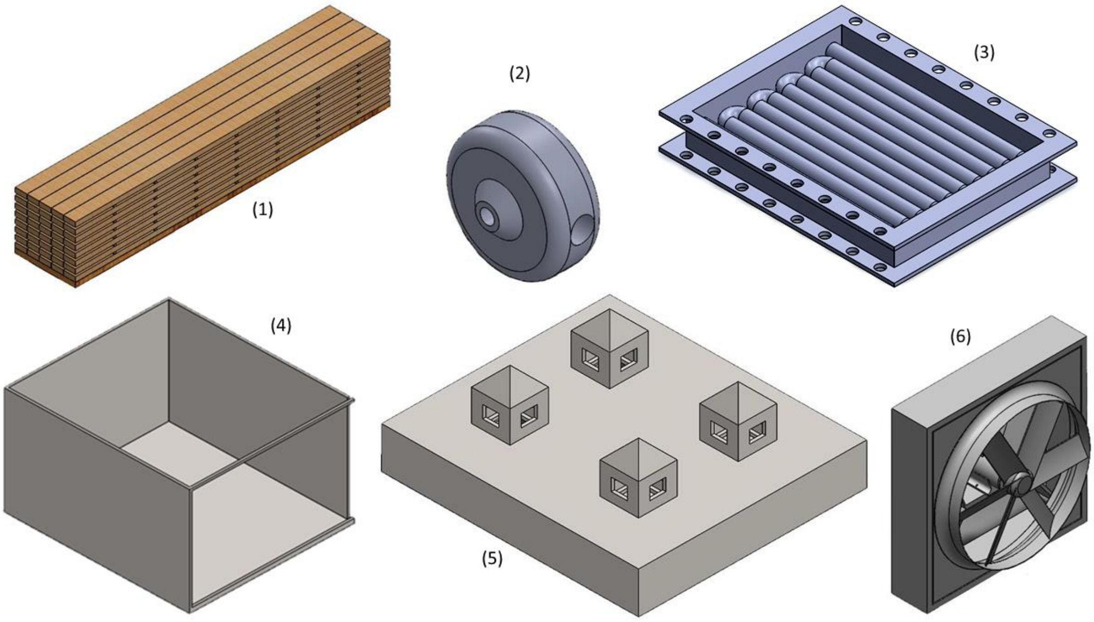

Fig. 1. View of the wood drying chamber components assembled in the SolidWorks, 1 – stack of wood, 2 – humidifying nozzle, 3 – water heater, 4 – walls, 5 – ceiling and roof, 6 – axial fan

Table 1 shows the main characteristics of the wood drying chamber, which include the dimensions of the drying space, the type of equipment for different systems and their maximum permissible number.

Table 1. The main characteristics of the wood drying chamber

Type of the wood drying chamber	The dimensions of the drying space				Heating system		Ventilation system		Humidification system	
	L_s, m.	W_s, m.	H_s, m.	Vol., m^3	Type	Max.	Type	Max.	Type	Max.
C1S	3.85	3.90	2.00	≈ 30	H450	5	V743	4	N10	5
C2L	5.70	4.80	2.20	≈ 60	H477	6	V843	6	N15	6
C3A	6.60	5.70	2.40	≈ 90	H504	6	V943	6	N20	6
C4H	7.00	6.60	2.60	≈ 120	H531	6	V1043	6	N25	5
C5B	7.60	7.50	2.80	≈ 160	H558	5	V1143	6	N30	5

The main geometric characteristics of the studied 3D model of wood drying chamber should include:

- Height to the ceiling (l_1), m;
- Ceiling height (l_8), m;
- The dimensions of the side passages in the ceiling (l_5, l_6), m;
- Length (l_2) and width (l_3) of the wood drying chamber, m;
- Thickness of walls (l_w) and ceiling (l_9), m;
- Number (N_s), type and dimensions of supply and exhaust ducts (l_4), m;
- Number (N_h) and dimensions of water heaters (H_G, H_E, H_D, H_A, H_C, H_F), m;
- Number (N_v) and dimensions of axial fans (V_F, V_G, V_D, V_E, V_B, V_T), m;
- Number (N_g) and dimensions of humidifying nozzles (G_A, G_B, G_D, G_E), m;
- The number of stacks (N_{st}) and the number of lumbers in one stack (N_l);
- Wood species and dimensions of lumber (***W, H, L***), m.

- Moisture content of drying agent ($\boldsymbol{\varphi_a}$), fresh air ($\boldsymbol{\varphi_n}$) and wood ($\boldsymbol{U_m}$), kg/kg;
- Coefficients of heat transfer ($\boldsymbol{\alpha}$) W/(m^2·K), and thermal conductivity ($\boldsymbol{\lambda}$) W/(m·K);
- Specific heat capacity ($\boldsymbol{C}$) J/(kg·°C), and material density ($\boldsymbol{\rho}$) kg/m^3;
- Temperature of walls ($\boldsymbol{T_w}$), heaters ($\boldsymbol{T_h}$), coolant ($\boldsymbol{T_t}$), drying agent ($\boldsymbol{T_a}$), fresh air ($\boldsymbol{T_n}$) and wood or lumber ($\boldsymbol{T_m}$), °C.

Description of the mathematical model. It is necessary to describe such a mathematical model of wood drying processes in a wood drying chamber, which would take into account all the above parameters. To do this, first of all, it is worth highlighting the main parameters that need to be determined. These include the temperatures of the drying agent, heater, walls, and lumber, as well as the moisture content of the drying agent and lumber. By modeling and knowing how these parameters will change over time, we can choose optimal drying parameters, which allows us to significantly save time and material resources during real drying.

During drying, there is always a heating process in which heat is transferred from one object to another. In this case, the source of heat is the heaters, which are constantly heated by the coolant (hot water). At the same time, this heat is used by the drying agent, walls and lumber. Therefore, the entire process of heat transfer can be divided into internal and external. The temperature change in the lumber can be attributed to the internal heat transfer. The temperature change of the drying agent in the entire drying zone of the wood drying chamber, as well as the temperature change of the heater and walls can be attributed to the external heat transfer. So, the mathematical model of external heat transfer [12] takes into account the heat balance equations of the capacity of the drying agent, heaters and walls:

$$\begin{aligned} &C_h N_h m_h \frac{\partial T_h(x,y,\tau)}{\partial \tau} + N_g G_p I_p + L_{in}(C_n + C_p\varphi_n)T_n - G_0 \frac{\partial U_m(x,y,\tau)}{\partial \tau} - \\ &- C_m \rho_m V_m \frac{\partial T_m(x,y,\tau)}{\partial \tau} - C_w m_w \frac{\partial T_w(x,y,\tau)}{\partial \tau} - L_{out}(C_n + C_p\varphi_a(x,y,\tau))T_a(x,y,\tau) = \\ &= \left(\frac{V_a \cdot 0.622 P_{bar}(1+\varphi_a(x,y,\tau))C_a}{R(273+T_a(x,y,\tau))(0.622+\varphi_a(x,y,\tau))} + m_w C_w \right) \frac{\partial T_a(x,y,\tau)}{\partial \tau}; \end{aligned} \tag{1}$$

$$C_1 \alpha_t S_t (T_t - T_h(x,y,\tau)) - C_2 \alpha_h S_h (T_h(x,y,\tau) - T_a(x,y,\tau)) = C_h m_h \frac{\partial T_h(x,y,\tau)}{\partial \tau}; \tag{2}$$

$$\alpha_w (T_a(x,y,\tau) - T_w(x,y,\tau)) - \alpha_s (T_w(x,y,\tau) - T_n) = C_w \rho_w l_w \frac{\partial T_w(x,y,\tau)}{\partial \tau}, \tag{3}$$

where: C_h is specific heat capacity of the heater metal, J/(kg·K); m_h is the mass of the heater, kg; τ is simulation time, s; G_p is the amount of water vapor entering through the humidifying nozzle, kg/s; I_p is enthalpy of 1 kg of water vapor, J/kg; L_{in} is the amount of fresh air that enters through the roof ducts, kg/s; C_n is the specific isobaric heat capacity of incoming dry air, J/(kg·K); C_p is the specific isobaric heat capacity of water vapor, J/(kg·K); G_0 is a mass of absolutely dry wood, kg; C_m is specific heat capacity of wood, J/(kg·K); ρ_m is the density of wood in the stacks, kg/m^3; V_m is the volume of dried wood, m^3; C_w is the average specific heat capacity of the wall materials, taking into account the thermal insulation layers, J/(kg·K); m_w is the mass of the walls of the chamber, kg; L_{out} is the amount of humidified air that leaves the drying chamber through the roof ducts, kg/s; V_a is a volume of drying agent, m^3; P_{bar} is barometric pressure, Pas; C_a is the specific isobaric heat capacity of the drying agent, J/(kg·K); R is universal gas constant, J/(mol·K); C_1 is the coefficient of heat losses of the heater; α_t is the coefficient of heat transfer from water vapor condensing to the inner surface of the heater, W/(m^2·K); S_t is wood heat transfer surface area, m^2; C_2 is the coefficient of the condition of the heat-emitting surface of the heater; α_h is the combined coefficient of heat transfer of the cylindrical surface of the heater, W/(m^2·K); S_h is the area of the complete outer surface of the heater, m^2; α_w is the coefficient of heat transfer of the drying agent with the walls of the wood drying chamber, W/(m^2·K); α_s is the coefficient of heat transfer from the outer surface of the walls to the external environment, W/(m^2·K); ρ_w is the average density of wall materials, taking into account thermal insulation layers, kg/m^3.

To determine the heat capacity of the heater, a high coefficient of thermal conductivity of iron (80.4 W/(m·K)), which is the main material of the heater, is taken. In turn, the following assumption was made to determine the heat capacity of all the walls of the wood drying chamber. The temperature of the fans always rises during their working, which is connected with the intensity of work their engines. However, this temperature is not high compared to the temperature of the drying agent, which quickly heats up from the heaters. For this reason, the temperature of the fans very quickly begins to increase, but not because of the heat of their own engines, but because of the heat transferred by the drying agent. Essentially, the fan material begins to assimilate heat by analogy with other components of the wood drying chamber, such as walls, doors and ceilings. Therefor, the temperature of the fans and humidifying nozzles is equal to the temperature of this components of the wood drying chamber.

Since the temperature of the drying agent changes together with its moisture content, it is necessary to formulate a differential equation of the moisture balance [13]. This equation can have the following form:

$$N_g G_p + L_{in}\varphi_n - G_0 \frac{\partial U_m(x,y,\tau)}{\partial \tau} - L_{out}\beta_a \varphi_a(x,y,\tau) = \\ = \frac{V_a \cdot 0.622 P_{bar}}{R(273+T_a(x,y,\tau))(\varphi_a(x,y,\tau)^2 + 1.622\varphi_a(x,y,\tau)+0.622)} \cdot \frac{\partial \varphi_a(x,y,\tau)}{\partial \tau}, \quad (4)$$

where: β_a is moisture exchange coefficient, m^2/s.

In general, during the drying of wood, according to the law of conservation of energy, the amount of heat that enters it is equal to the amount spent on heating it and evaporating moisture from it [14]. Therefore, the internal process of heat transfer takes into account the heat balance equation for the capacity of wood, which has the following form:

$$\lambda_{m(x)} \frac{\partial^2 T_m(x,y,\tau)}{\partial x^2} + \lambda_{m(y)} \frac{\partial^2 T_m(x,y,\tau)}{\partial y^2} + \varepsilon \rho_0 r \frac{\partial U_m(x,y,\tau)}{\partial \tau} = C_m \rho_m \frac{\partial T_m(x,y,\tau)}{\partial \tau}. \quad (5)$$

At the same time, the moisture content of wood can be determined as follows:

$$a_{m(x)} \frac{\partial^2 U_m(x,y,\tau)}{\partial x^2} + a_{m(y)} \frac{\partial^2 U_m(x,y,\tau)}{\partial y^2} + \delta a_{m(x)} \frac{\partial^2 T_m(x,y,\tau)}{\partial x^2} + \delta a_{m(y)} \frac{\partial^2 T_m(x,y,\tau)}{\partial y^2} = \frac{\partial U_m(x,y,\tau)}{\partial \tau}, \quad (6)$$

where: $\lambda_{m(x,y)}$ are coefficients of thermal conductivity of lumber, W/(m·K); ε is coefficient of phase transition; ρ_0 is basic density of lumber, kg/m^3; r is specific heat of vapor formation, J/kg; $a_{m(x,y)}$ are coefficients of moisture conductivity, m^2/s; δ is thermogradient coefficient.

Therefore, the system of differential equations (1) – (6) can be considered the initial mathematical model of the wood drying chamber. This model makes it possible to determine the temperature and moisture content of the drying agent in the wood drying chamber and of the lumbers in stacks. When writing boundary conditions for this initial mathematical model, it is first necessary to determine the coordinates of all boundaries (Fig. 2).

According to this figure, you can see that the wood drying chamber has general boundaries, which, according to the X coordinate are in the interval [$0; X_m$] and according to the Y coordinate are in the interval [$0; Y_m$]. At the same time, the Y_s point reflects the ceiling location line. In the same coordinate, there are side passages in which there are water heaters and humidifying nozzles. These passages always have the value Y_s according to the Y coordinate, and can be located in the intervals [$P_1; P_2$] or [$P_7; P_8$] according to the X coordinate. At the same time, if we take the point Y_m along the Y coordinate and the interval [$P_3; P_4$] or [$P_5; P_6$], then there are supply and exhaust channels through which the transfer of air masses takes place.

Here it is also worth noting the coordinates of the location of the stacks. Due to the fact that their number in the wood drying chamber can change, the final values of the coordinates of the points X_n and Y_p can be determined only by knowing the total number of stacks. Despite this, the initial values of the stack location coordinates always start from the point X_1. At the same time, the value of the point at the end of the stack according to the X coordinate will always be equal to +1 above the starting point, for example X_2. The length of the interval [$X_1; X_2$] will always be equal to the width of one stack. A similar situation occurs with the Y coordinate. For example, the height of one stack will always be equal to the distance from point Y_1 to Y_2. In turn, the distance between the stacks will always be equal to the distance, for example, from point X_2 to X_3.

In a similar way, the coordinate points of the location of lumber in one stack are given. At the same time, the location points of lumber always start with the letter "S" and end with the letter "E". The second letter always corresponds to the selected coordinate, for example X or Y. Thus, one piece of lumber can be in the interval [$S_{x1}; E_{x1}$] according to coordinates X and [$S_{y1}; E_{y1}$] according to the Y coordinate. In turn, the distance from point E_{y1} to S_{y2}, for example, will always be equal to the height of one gasket, which is located under one row of lumber.

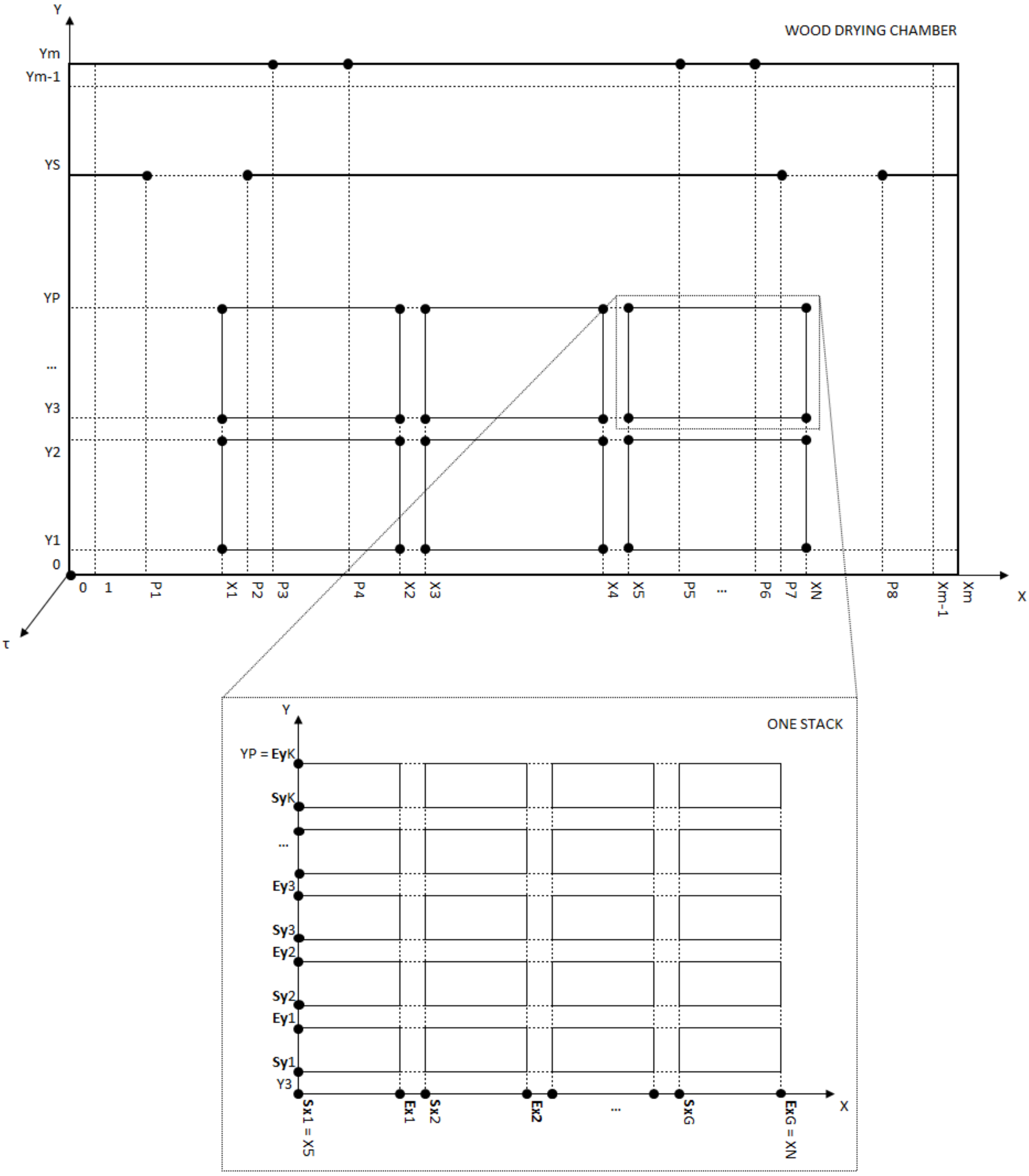

Fig. 2. The coordinates of the boundaries of the initial mathematical model

For this mathematical model, it is proposed to apply the following initial conditions that characterize the beginning of the drying process ($\tau = 0$):

$$T_m(x,y,0) = 20°C; \quad T_a(x,y,0) = 20°C; \quad T_w(x,y,0) = 18°C; \quad T_h(x,y,0) = 50°C;$$

$$U_m(x,y,0) = 0.4kg/kg; \quad \varphi_a(x,y,0) = 0.6kg/kg; \quad \varphi_n(const) = 0.6kg/kg;$$

$$T_t(const) = 90°C; \quad T_n(const) = 10°C; \quad \rho_s(x,y,0) = 0.0173kg/m^3.$$

In turn, due to the complexity of the initial mathematical model, its boundary conditions are divided into three zones:

- Area of drying wood;
- Stacks location area;
- Wood drying chamber area.

In the first zone, boundary conditions of the 3rd kind are used, which make it possible to determine the temperature and moisture content of one lumber on its surface [15]. These boundary conditions have the following form:

$$\begin{cases} \lambda_{m(x)} \dfrac{\partial T_m(x_{b1}, y_{b1}, \tau)}{\partial x} + \rho_0(1-\varepsilon)\beta I_p(U_m(x_{b1}, y_{b1}, \tau) - U_p) = \alpha_{m(x)}(T_m(x_{b1}, y_{b1}, \tau) - T_a(x_{b1}, y_{c1}, \tau)), \\ \lambda_{m(y)} \dfrac{\partial T_m(x_{b2}, y_{b2}, \tau)}{\partial y} + \rho_0(1-\varepsilon)\beta I_p(U_m(x_{b2}, y_{b2}, \tau) - U_p) = \alpha_{m(y)}(T_m(x_{b2}, y_{b2}, \tau) - T_a(x_{c2}, y_{b2}, \tau)), \\ a_{m(x)}\delta \dfrac{\partial T_m(x_{b3}, y_{b3}, \tau)}{\partial x} + a_{m(x)} \dfrac{\partial U_m(x_{b3}, y_{b3}, \tau)}{\partial x} = \beta(U_p - U_m(x_{b3}, y_{b3}, \tau)), \\ a_{m(y)}\delta \dfrac{\partial T_m(x_{b4}, y_{b4}, \tau)}{\partial y} + a_{m(y)} \dfrac{\partial U_m(x_{b4}, y_{b4}, \tau)}{\partial y} = \beta(U_p - U_m(x_{b4}, y_{b4}, \tau)), \end{cases} \tag{7}$$

where: U_p is equilibrium humidity, kg/kg; $\alpha_{m(x,y)}$ is the coefficient of heat transfer from the drying agent to the wood surface, W/(m^2·K) and the coordinates of points on the borders must be in the following ranges:

$$\begin{gathered} ((x_{b1} \in [S_x, E_x], y_{b1} = E_y, y_{c1} = E_{y+1}) \cup (x_{b1} \in [S_x, E_x], y_{b1} = S_y, y_{c1} = S_{y-1})) \cap \\ \cap ((x_{b2} = S_x, y_{b2} \in [S_y, E_y], x_{c2} = S_{x-1}) \cup (x_{b2} = E_x, y_{b2} \in [S_y, E_y], x_{c2} = E_{x+1})) \cap \\ \cap (x_{b3} \in [S_x, E_x], y_{b3} = S_y \cup E_y) \cap (x_{b4} = S_x \cup E_x, y_{b4} \in [S_y, E_y]). \end{gathered}$$

In the second zone, boundary conditions of the 3rd kind are also used, which make it possible to determine the temperature and moisture content of the drying agent, which is in direct contact with the surface of the lumber in the stacks [16]. These boundary conditions have the following form:

$$\begin{cases} \dfrac{\partial T_a(x_{b5}, y_{b5}, \tau)}{\partial x} = \dfrac{\alpha_{m(x)}(T_m(x_{b5}, y_{c5}, \tau) - T_a(x_{b5}, y_{b5}, \tau))}{Rv\rho_a C_a}, \\ \dfrac{\partial T_a(x_{b6}, y_{b6}, \tau)}{\partial y} = \dfrac{\alpha_{m(y)}(T_m(x_{c6}, y_{b6}, \tau) - T_a(x_{b6}, y_{b6}, \tau))}{Rv\rho_a C_a}, \\ \dfrac{\partial \varphi_a(x_{b7}, y_{b7}, \tau)}{\partial x} = \dfrac{a_{m(x)}\rho_0(U_m(x_{b7}, y_{c7}, \tau) - U_p)}{Rv\rho_s(x_{b7}, y_{b7}, \tau)} - \varphi_a(x_{b7}, y_{b7}, \tau) \dfrac{\partial \rho_s(x_{b7}, y_{b7}, \tau)}{\partial x} \dfrac{1}{\rho_s(x_{b7}, y_{b7}, \tau)}, \\ \dfrac{\partial \varphi_a(x_{b8}, y_{b8}, \tau)}{\partial y} = \dfrac{a_{m(y)}\rho_0(U_m(x_{c8}, y_{b8}, \tau) - U_p)}{Rv\rho_s(x_{b8}, y_{b8}, \tau)} - \varphi_a(x_{b8}, y_{b8}, \tau) \dfrac{\partial \rho_s(x_{b8}, y_{b8}, \tau)}{\partial y} \dfrac{1}{\rho_s(x_{b8}, y_{b8}, \tau)}, \end{cases} \tag{8}$$

where: v is the drying agent movement speed, m/s; ρ_a is the density of the drying agent, kg/m^3; ρ_s is saturated vapor density, kg/m^3 and the coordinates of points on the borders must be in the following ranges:

$$\begin{gathered} ((x_{b5} \in [S_x, E_x], y_{b5} = E_{y+1}, y_{c5} = E_y) \cup (x_{b5} \in [S_x, E_x], y_{b5} = S_{y-1}, y_{c5} = S_y)) \cap \\ \cap ((x_{b6} = S_{x-1}, y_{b6} \in [S_y, E_y], x_{c6} = S_x) \cup (x_{b6} = E_{x+1}, y_{b6} \in [S_y, E_y], x_{c6} = E_x)) \cap \\ \cap ((x_{b7} \in [S_x, E_x], y_{b7} = E_{y+1}, y_{c7} = E_y) \cup (x_{b7} \in [S_x, E_x], y_{b7} = S_{y-1}, y_{c7} = S_y)) \cap \\ \cap ((x_{b8} = E_{x+1}, y_{b8} \in [S_y, E_y], x_{c8} = E_x) \cup (x_{b8} = S_{x-1}, y_{b8} \in [S_y, E_y], x_{c8} = S_x)) \end{gathered}$$

In the third zone, boundary conditions of the 3rd kind are also used, which make it possible to determine the temperature and moisture content of the drying agent at its other boundaries, for example, in contact with walls, a heater or fresh air [17]. These boundary conditions have the following form:

$$\begin{cases} T_a(x_{b9}, y_{b9}, \tau) = T_n, \\ T_a(x_{b10}, y_{b10}, \tau) = T_h, \\ \varphi_a(x_{b11}, y_{b11}, \tau) = \varphi_n, \\ \dfrac{\partial T_a(x_{b12}, y_{b12}, \tau)}{\partial x} = -\dfrac{\alpha_{w(x)}}{\lambda_{w(x)}}(T_w(x_{b12}, y_{c12}, \tau) - T_a(x_{b12}, y_{b12}, \tau)), \\ \dfrac{\partial T_a(x_{b13}, y_{b13}, \tau)}{\partial y} = -\dfrac{\alpha_{w(y)}}{\lambda_{w(y)}}(T_w(x_{c13}, y_{b13}, \tau) - T_a(x_{b13}, y_{b13}, \tau)), \end{cases} \tag{9}$$

where: $\lambda_{w(x,y)}$ are thermal conductivity coefficients of the walls, W/(m·K) and the coordinates of points on the borders must be in the following ranges:

$$(x_{b9} \in [P_3, P_4] \cup [P_5, P_6], y_{b9} = Y_{m-1}) \cap (x_{b10} \in [P_1, P_2], y_{b10} = Y_{s+1} \cup Y_{s-1}) \cap$$
$$\cap (x_{b11} \in [P_3, P_4] \cup [P_5, P_6], y_{b11} = Y_{m-1}) \cap ((x_{b12} \in (0, X_1) \cup (X_2, X_3) \cup ... \cup (X_n, X_m),$$
$$y_{b12} = Y_1, y_{c12} = 0) \cup (x_{b12} \in (0, P_3) \cup (P_4, P_5) \cup (P_6, X_m), y_{b12} = Y_{m-1}, y_{c12} = Y_m)) \cap$$
$$\cap ((x_{b13} = 1, y_{b13} \in (0, Y_m), x_{c13} = 0) \cup (x_{b13} = X_{m-1}, y_{b13} \in (0, Y_m), x_{c13} = X_m))$$

Creating a cellular automata field. In order to develop an algorithm for representing a studied 3D model of wood drying chamber in the form of cellular automata field, it is first necessary to understand the principle of such representation. For this task, a special graphic scheme was developed. This scheme shows how the process of presenting takes place [18]. For example, Fig. 3 shows part of this scheme, which represent stacks. At the output of this scheme, we get a set of cells of the same size, which are a component of the cellular automata field, and which is necessary for using cellular automata.

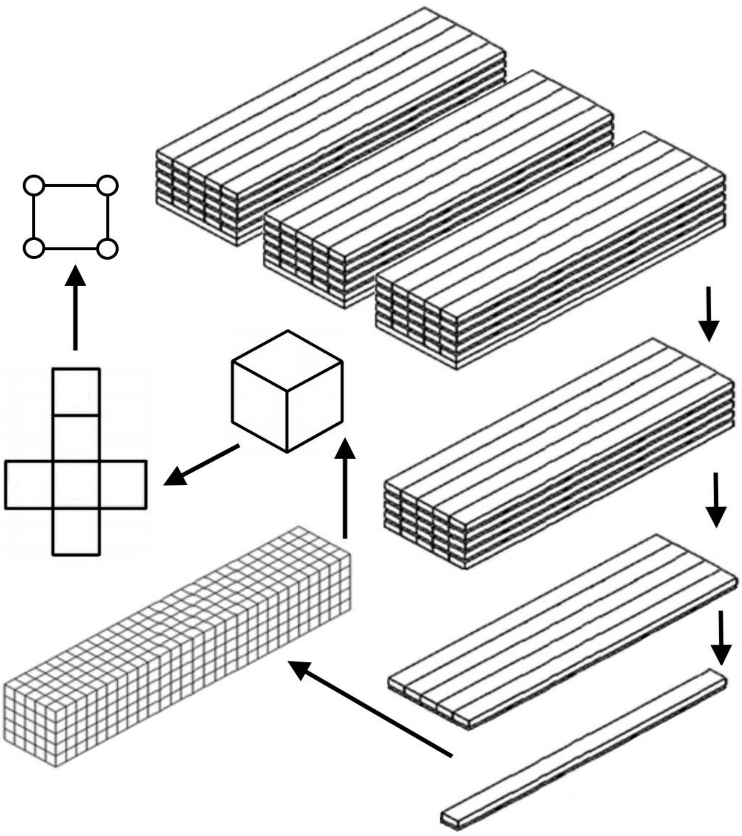

Fig. 3. The diagram of representation the 3D model in the form of cellular automata field

To create a cellular automata field, we need to perform the following steps:

- Specify the main geometric dimensions of the studied 3D model;
- Choose the maximum allowable density of division of the studied 3D model (**d_m**). This value is necessary because all created cells must have the same size;
- Specify the desired level of division (**d_i**). By default, it is equal to 1. To increase the accuracy of calculations, this level must be increased several times. In general, there are no restrictions on the values of this level, but it is worth paying attention to the power of the computer system on which the modelling will be carried out. Because of the higher level of division, we need more time and computer resources for calculations;
- Determine the final density of division of the studied 3D model (**d**):

$$d = d_m / 2^{di-1}. \tag{10}$$

- Specify the amount of lumber in one stack (**S_{lmb}**). At the same time, this amount is inside the range of 4 pcs. up to 40 pcs. with a step of 4 pcs.;
- Determine the number of lumbers in one row (**l_x**) and the number of these rows (**l_y**) in one stack;
- Specify the number of stacks (**S_{stk}**);
- Determine the number of cells of the cellular automata field for stacks according to each of the coordinates (**S_x, S_y, S_z**):

$$S_x = \sum_{1}^{S_{stk}} \left(2 + l_x \frac{W}{d}\right); \quad S_y = \sum_{1}^{l_y} \left(2 + \frac{H}{d}\right); \quad S_z = 2 + \frac{L}{d}. \tag{11}$$

- Create a multidimensional array **a**, the elements of which are points of the cells on the cellular automata field. Each point stores the values of its coordinates, type, time, temperature and moisture content. At the same time, each point has one of the following types: "**A**" is a drying agent located within the wood drying chamber; **"M"** is lumber in stacks; **"W"** are the walls and ceiling of the wood drying chamber; **"H"** are water heaters; **"G"** are moisturizing nozzles; **"V"** are axial fans; **"*"** are not active points, which are not used in modeling.

Since the cellular automata field is created for the entire wood drying chamber, a practical algorithm must be created to determine the type of each cell. In general, this algorithm is divided into several sub-algorithms, which are executed sequentially one after another. Each of these sub-algorithms once checks the values of all cells and their neighbors on the cellular automata field, making a so-called pass. The number of these passes depends on the complexity of the geometric form and physical dimensions of the studied 3D model. In general, this number is from 3 to 5 passes. All these passes are closely related to each other. Each subsequent pass takes into account the changes in the value of the cells in the cellular automata field, which were made during the execution of the previous pass. As a result of the implementation of these algorithms, a cellular automata field was obtained (Fig. 4).

*	W	W	W	W	W	W	A	A	A	W	W	W	W	W	W	*	W	W	W	W	W	W	A	A	A	W	W	W	W	W	W	*
W	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	V	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	V	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	V	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	W
*	W	W	H	H	H	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	G	G	G	W	W	*
W	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	*	M	M	M	M	M	M	*	A	*	M	M	M	M	M	M	*	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	*	M	M	M	M	M	M	*	A	*	M	M	M	M	M	M	*	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	*	M	M	M	M	M	M	*	A	*	M	M	M	M	M	M	*	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	M	M	M	M	M	M	M	M	A	M	M	M	M	M	M	M	M	A	A	A	A	A	A	A	W
W	A	A	A	A	A	A	A	*	M	M	M	M	M	M	*	A	*	M	M	M	M	M	M	*	A	A	A	A	A	A	A	W
*	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	W	*

Fig. 4. Graphic view of the created cellular automata field

Development of a cellular automata model. The development of this model is important from the point of view that it can be used to describe and determine changes in physical characteristics of the material, including temperature and moisture content. To determine them, it is necessary to describe certain rules of behavior for each element of the system, which is one specific cell on the cellular automatic field. Each cell has a set of characteristics and is part of the simulated physical space. The change of these characteristics occurs according to the transition rules and using its previous values and the values of its neighboring cells. The use of such local dependencies allows us to significantly increase the speed of calculations compared to the finite difference method.

To develop a cellular automata model, it is necessary to determine how each cell will be represented. Taking into account the main input data and the appearance of the cellular automata field (Fig. 4), the structure of each cell will have the following appearance (Fig. 5).

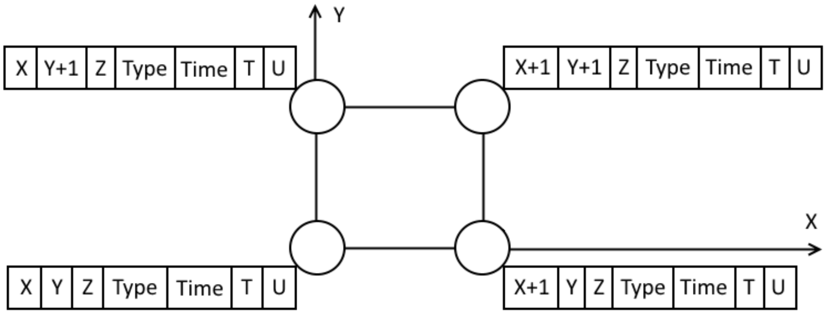

Fig. 5. The structure of one cell of the cellular automata field

According to this structure, we see that each cell consists of four points. Each of this point has seven parameters, including: "X, Y, Z" are coordinates of the location on the cellular automata field, "Type" is type of point, "Time" is modelling time, "T" is the temperature and "U" is the moisture content at this point.

In general, the modeling process using cellular automata is an iterative cycle of interactions between cells. To perform this task, we can use an asynchronous scheme of interaction between cells, which involves the cyclic execution of several steps (Fig. 6).

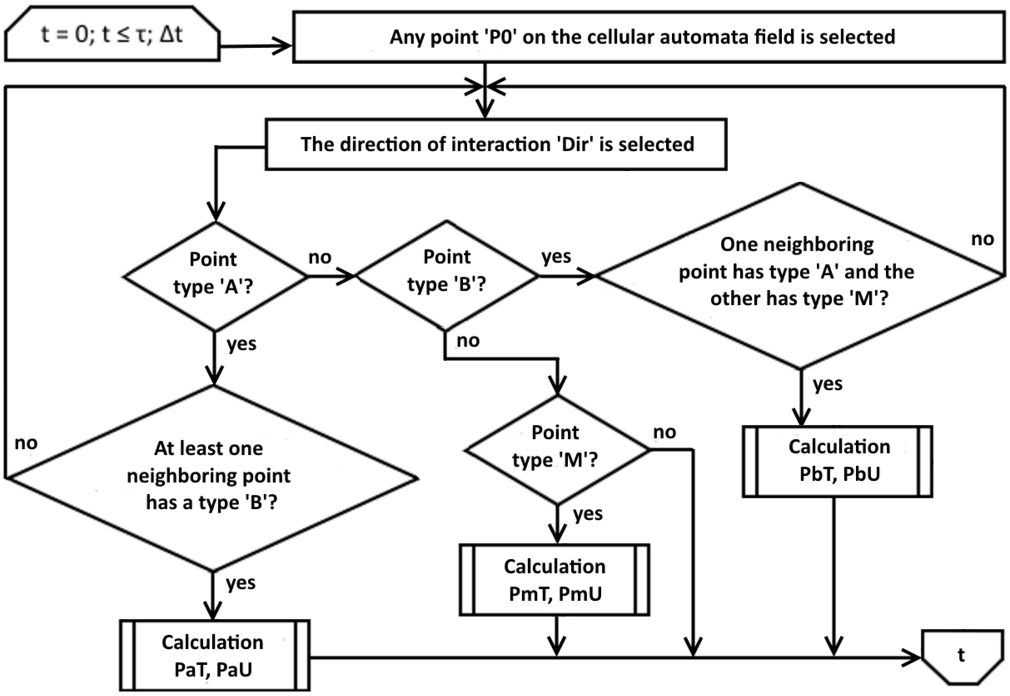

Fig. 6. Algorithm of work of asynchronous cellular automaton

The selection of the point "P0" of some cell and the direction of interaction "Dir" is carried out using the uniform distributive law. The direction of interaction allows us to determine the target point along which the selected point of the cell. This point will interact with the neighboring point of the same or neighboring cell. Depending on the type of two points interacting with each other, different transition rules will be used.

The basic rules of transitions make it possible to determine changes in the temperature and moisture content of lumber and the drying agent that is in direct contact with lumbers in stacks. In order to better understand the principle of applying transition rules, we can use the following scheme (Fig. 7). This scheme also displays the conventions used in transition rules.

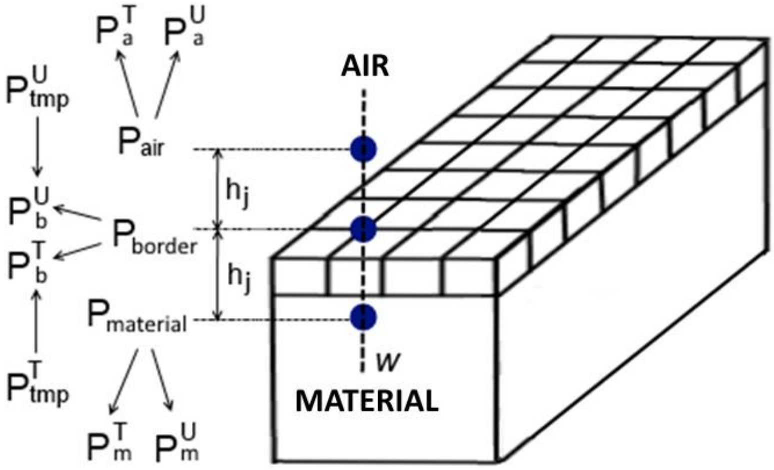

Fig. 7. The scheme of marking points for the rules of transitions

In general, all transition rules are based on the finite-difference approximation of equations (1) – (9). On the basis of this work are the rules of transitions that allow determining the heat and mass transfer in the stack for both the material and the drying agent. For example, to determine the change in the temperature and moisture content of lumber in one stack, transition rules use the following system of equations:

$$\begin{cases} P_{m(new)}{}^{U} = P_m{}^{U} - C_1\left(P_{m+1}{}^{U} - 2P_m{}^{U} + P_{m-1}{}^{U} + \delta\left(P_{m+1}{}^{T} - 2P_m{}^{T} + P_{m-1}{}^{T}\right)\right), \\ P_{m(new)}{}^{T} = P_m{}^{T} + C_2\left(P_{m+1}{}^{T} - 2P_m{}^{T} + P_{m-1}{}^{T}\right) + C_3\left(P_{m(new)}{}^{U} - P_m{}^{U}\right). \end{cases} \tag{12}$$

The values of the coefficients $C_1 - C_3$ are determined as follows:

$$C_1 = \frac{a_j \Delta t}{h_j{}^2}; \quad C_2 = \frac{\lambda_j \Delta t}{c_m \rho_m h_j{}^2}; \quad C_3 = \frac{\varepsilon \rho_0 r}{c_m \rho_m}, \tag{13}$$

Where: h_j can take the value *x (j=1)* or *y (j=2).*

In the process of modeling, the wood drying agent transfers part of its heat to the lumber, thereby heating it. At the same time, the lumber loses part of its moisture. Therefore, the rules of transitions at the border of lumber use the following system of equations:

$$\begin{cases} P_{b(new)}{}^{T} = \dfrac{P_a{}^{T}(C_3 - C_2 - C_1\delta) + P_m{}^{T}(C_5 - C_4) - C_1(P_m{}^{U} - P_a{}^{U})}{C_3 + C_5 - C_2 - C_4 - C_1\delta}, \\ P_{b(new)}{}^{U} = \dfrac{C_6(P_m{}^{T} - P_b{}^{T}) + a_j P_m{}^{U} + C_7 P_a{}^{U}}{a_j + C_7}. \end{cases} \tag{14}$$

The value of the coefficients $C_1 - C_7$ are determined as follows:

$$\begin{matrix} C_1 = a_j \rho_0 (1-\varepsilon)\beta; & C_3 = \beta\lambda_j; & C_5 = \alpha_m \beta h_j; \\ C_2 = (a_j \lambda_j)/h_j; & C_4 = \alpha_m a_j; & C_6 = a_j \delta; \end{matrix} \quad C_7 = \beta h_j. \tag{15}$$

In turn, the change in temperature and moisture content in the wood drying agent occurs most in the places of its contact with the lumber in the stacks. To determine these changes, transition rules use the following system of equations:

$$\begin{cases} P_{a(new)}{}^{T} = P_a{}^{T} + \dfrac{C_1(P_b{}^{T} - P_a{}^{T})}{C_2}, \\ P_{a(new)}{}^{U} = P_a{}^{U} + \dfrac{C_3(P_b{}^{U} - U_p)}{C_4} - \dfrac{P_a{}^{U}(P_n - P_s)}{C_5 P_a{}^{T}} + \dfrac{P_a{}^{U} P_s P_{a(new)}{}^{T}}{C_5 (P_a{}^{T})^2} - \dfrac{P_a{}^{U} P_s}{C_5 P_a{}^{T}}. \end{cases} \tag{16}$$

The value of the coefficients $C_1 - C_5$ are determined as follows:

$$C_1 = \alpha h_j; \quad C_3 = a_j \rho_0 h_j; \quad C_2 = vc_c \rho_c h_s; \quad C_4 = v\rho_s h_s; \quad C_5 = h_s \rho_s, \tag{17}$$

Where: h_s is the distance between the lumber in one stack and the distance between the two stacks, m.

For this reason, when we using the method of cellular automata, there are relationships between neighboring cells that can be described as follows:

If the points P_b, P_a^+, P_m^- interact **THEN** $P_{b(new)}^T$ and $P_{b(new)}^U$ calculate according to Eq. 14

If the points P_m, P_m^+, P_m^- interact **THEN** $P_{m(new)}^T$ and $P_{m(new)}^U$ calculate according to Eq. 12

If the points P_a, P_a^+, P_b^- interact **THEN** $P_{a(new)}^T$ and $P_{a(new)}^U$ calculate according to Eq. 16

Calculations and analysis of results. The developed software application [19] was used for modeling. This application is written by using C# programming language in the Microsoft Visual Studio 2012 programming environment. The input parameters for modeling are taken from works [20-22]. As a result of this modeling, the following change graphs were obtained: the temperature of the heater and the walls in relation to time (Fig. 8), the temperature of wood and its moisture content in relation to time (Fig. 9) and the temperature of the drying agent and its moisture content in relation to time (Fig. 10).

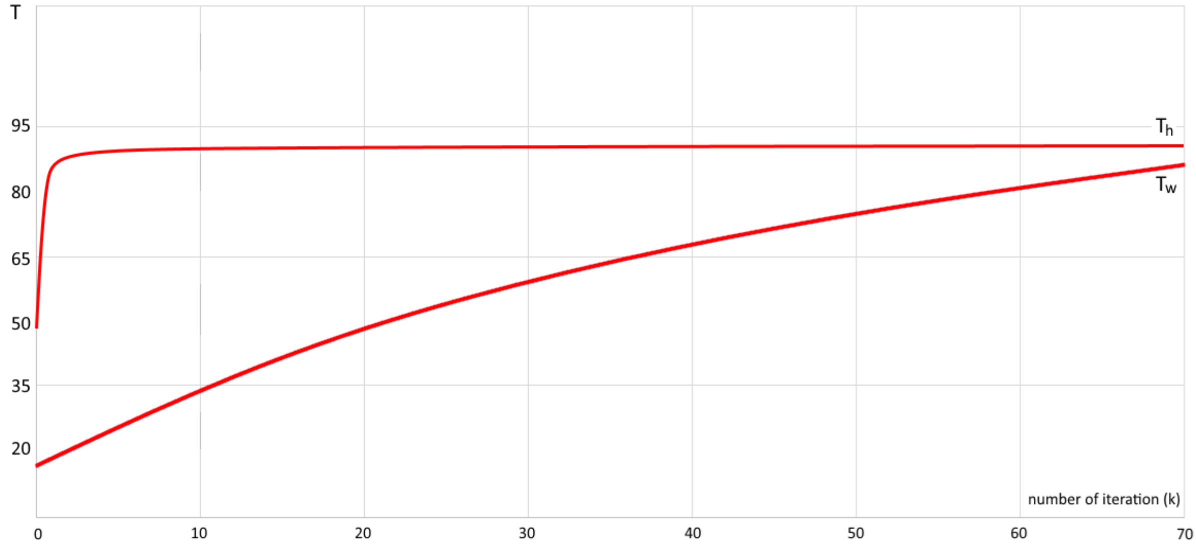

Fig. 8. Graphs of changes in the temperature of the heater and walls over time

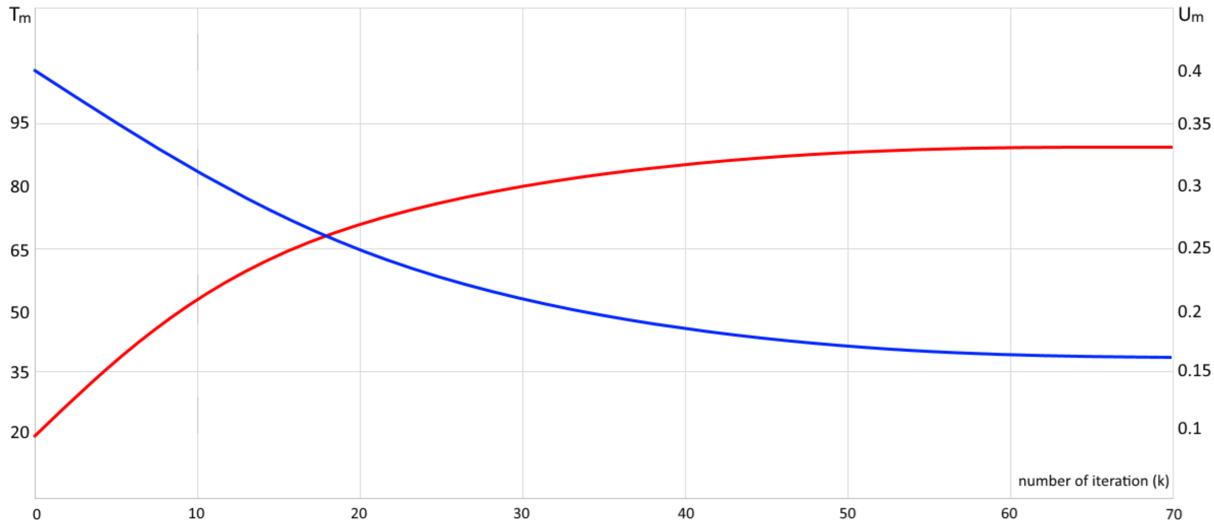

Fig. 9. Graphs of changes in the temperature and moisture content of wood over time

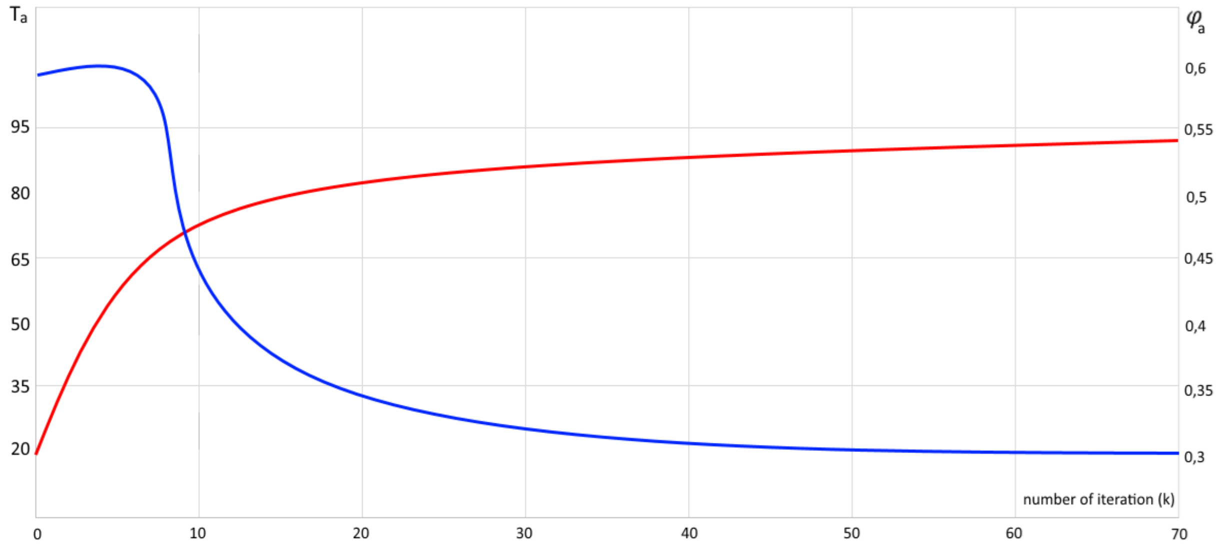

Fig. 10. Graphs of changes in the temperature and humidity of the wood drying agent over time

To check the adequacy of the obtained results, the relative error is determined. This error is determined by comparing the obtained results with the results given in the works [20-22]. The value of this error is calculated for the moisture content of the wood, because these values have the greatest value in modeling, and their accuracy is decisive. As a result of the calculations, the average value of the relative error is 5.37%. The largest values of this error, which are 20%, are recorded at the beginning of the modeling. This indicates the use of a relatively small number of cells on the cellular automata field, as well as the rules of transitions between them. Over time, this number increases and the accuracy of the results improves significantly (Fig. 11).

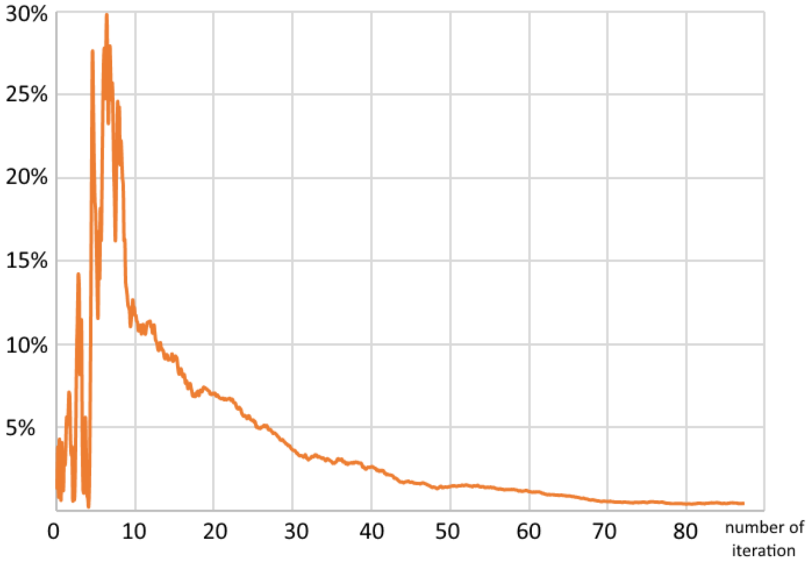

Fig. 11. Graph of the relative error of wood moisture content

Conclusions

As a result of the work, a model of an asynchronous cellular automata was studied. This model uses transition rules based on a finite-difference approximation of the initial mathematical model of the wood drying process in a periodic wood drying chamber. Despite the fact that this model is described in the studied 3D model, it can be changed for any other 3D model of a wood drying chamber. Because this model contains a description of the main wood drying chamber components. For this aim, the paper presents an algorithm for representing the studied 3D model in the form of cells on a cellular automata field.

As a result of the modeling, graphs of changes in the temperature of the main components of the studied 3D model, as well as the moisture content and temperature of the wood drying agent were obtained. These graphs confirm the performance of the asynchronous cellular automata model. This proves the adequacy of the initial mathematical model, on the basis of which the transition rules are described.

As a result of the work, the obtained values of wood moisture content are compared with the results of other authors. The value of the relative error didn´t exceed 6%, which confirms the perspective of using cellular automata in modeling problems of heat and moisture transfer in wood drying chambers of periodic action.

References

1. Volkhonov M., Jabbarov I., Soldatov V., & Smirnov I. (2018). Development of the method of exposure control of grain drying in high-temperature dryers. *Eastern-European journal of enterprise technologies.*, *3*, 22–29. https://doi.org/10.15587/1729-4061.2018.133607

2. Ivanova D., Valov N., Valova I., & Stefanova D. (2017). Optimization of Convective Drying. *Tem journal., 6.3,* 572-577. https://doi.org/10.18421/TEM63-19

3. Solomon A., Claudiu V., & Bogoi A. (2022). Some practical remarks in solving partial differential equations using reduced order schemes obtained through the POD method. *Incas Bulletin., 14.1,* 187-196. https://doi.org/10.13111/2066-8201.2022.14.1.15

4. Gibson, M. J., Keedwell, E. C., & Savi'c, D. A. (2015). An investigation of the efficient implementation of cellular automata on multi-core CPU and GPU hardware. *Parallel Distrib. Comput., 77,* 11–25. https://doi.org/10.1016/j.jpdc.2014.10.011

5. Sitko, M., Chao, Q., Wang, J., Perzynski, K., Muszka, K., & Madej, L. (2020). A parallel version of the cellular automata static recrystallization model dedicated for high performance computing platforms – Development and verification. *Comput. Mater. Sci., 172,* 109–283. https://doi.org/10.1016/j.commatsci.2019.109283

6. Shumylyak, L., Zhikharevich, V., & Ostapov, S. (2016). Modeling of impurities segregation phenomenon in the melt crystallization process by the continuous cellular automata technique. *Applied Mathematics and Computation*, *290*, 336–354. https://doi.org/10.1016/j.amc.2016.06.012

7. Salehi, M. S., & Serajzadeh, S. (2012). Simulation of static recrystallization in non-isothermal annealing using a coupled cellular automata and finite element model. *Comput. Mater. Sci.*, *53*, 145–152. https://doi.org/10.1016/j.commatsci.2011.09.026

8. Zaitsev, D. A. (2018). Simulating Cellular Automata by Infinite Petri Nets. *Journal of Cellular Automata*, *13*(1–2), 121–144.

9. Bandini, S., & Magagnini, M. (2001). Parallel Processing Simulation of Dynamic Properties of Filled Rubber Compounds Based On Cellular Automata. *Parallel Comput., 27,* 643–661. https://doi.org/10.1016/S0167-8191(00)00082-X

10. Svyetlichnyy, D. S. (2010). Modeling of the microstructure: From classical cellular automata approach to the frontal one. *Comput. Mater. Sci.*, *50*, 92–97. https://doi.org/10.1016/j.commatsci.2010.07.011

11. Sokolovskyy, Ya., Sinkevych, O., & Voliansky R. (2019). Software for Studying Wood Drying Chambers Based on SolidWorks Flow Simulation Experiment. *Experience of Designing and Application of CAD Systems*, *2019*, 24-27. https://doi.org/10.1109/ACITT.2019.8780040

12. Lee J.-Y., Seid E.R., & Majozi M. (2015). Heat Integration of Material Transfer Streams in Batch Processing Plants. *Chemical engineering transactions, 45,* 127-132. https://doi.org/10.3303/CET1545022

13. Benthien J.T., Riegler M., Engehausen N., & Nopens M. (2020). Specific Dimensional Change Behavior of Laminated Beech Veneer Lumber in Terms of Moisture Absorption and Desorption. *Fibers*, *8.47*, 47. https://doi.org/10.3390/fib8070047

14. Sokolovskyy, Ya., Sinkevych, O., & Volianskyi, R. (2020). The study of cellular automata method when used in the problem of capillary-porous material thermal conductivity. *Advances in Intelligent Systems and Computing V: Springer Computer Science, 1293,* 714–729. https://doi.org/10.1007/978-3-030-63270-0_49

15. Faiza M., Kamilia A., Mohammed E., Rachid B., & Slimane G. (2017). Numerical analysis of heat, air, and moisture transfers in a wooden building material. *Thermal science, 21.2,* 785-795. https://doi.org/10.2298/TSCI160421248M

16. Sokolovskyy, Ya., & Sinkevych, O. (2021). The use of cellular automata in modeling the processes of wood drying in a stack. *Ukrainian Journal of Information Technology, 3.2,* 39-44. https://doi.org/10.23939/ujit2021.02.039

17. Sychevsky V.A., Chorny A.D., & Baranova T.A. (2016). Optimization of aerodynamic conditions of the chamber drier operation. *Izvestiâ vysših učebnyh zavedenij i ènergetičeskih ob edinennij sng. Ènergetika, 59.3,* 260-271. https://doi.org/10.21122/1029-7448-2016-59-3-260-271

18. Sokolovskyy, Ya., & Sinkevych, O. (2018). Software and algorithmic support for represettation of 3D models in 2D von Neumann neighborhood. *CEUR Workshop Proceedings, 2300,* 215–218. https://ceur-ws.org/Vol-2300/Paper52.pdf

19. Sokolovskyy, Ya., Sinkevych, O., & Voliansky, R. (2019). Development the software for simulation of physical fields in wood drying chambers by using cellular automata. *Materials of the XV International Conference CADSM'2019,* 24–27. https://doi.org/10.1109/CADSM.2019.8779262

20. Sokolovskyy, Ya., Shymanskyi, V., Levkovych, M., & Yarkun V. (2017). Mathematical and software providing of research of deformation and relaxation processes in environments with fractal structure. *Computer Sciences and Information Technologies CSIT 2017,* 24-27. https://doi.org/10.1109/STC-CSIT.2017.8098728

21. Sokolovskyy, Ya., & Shymanskyi, V. (2014). Mathematical Modelling of Non-Isothermal Moisture Transfer and Rheological Behavior in Cappilary-Porous Materials with Fractal Structure During Drying. *Canadian Center of Science and Education, 7.4,* 111-122. https://doi.org/10.5539/cis.v7n4p111

22. Sokolovskyy, Ya., Shymanskyi, V., & Levkovych, M. (2016). Mathematical modeling of non-isothermal moisture transfer and visco-elastic deformation in the materials with fractal structure. *Computer science and information technologies CSIT 2016,* 91-95. https://doi.org/10.1109/STC-CSIT.2016.7589877

Я.І. Соколовський [1], О.В. Сінкевич [2]
[1] НУ «Львівська політехніка», Львів, Україна
[2] Національний лісотехнічний університет України, Львів, Україна

ВИКОРИСТАННЯ КЛІТИННИХ АВТОМАТІВ ПРИ МОДЕЛЮВАННІ ПРОЦЕСІВ СУШІННЯ ДЕРЕВИНИ У ЛІСОСУШИЛЬНІЙ КАМЕРІ ПЕРІОДИЧНОЇ ДІЇ

В даній роботі розглядається сутність процесу сушіння деревини в лісосушильній камері періодичної дії. В роботі також наведено математичну модель лісосушильної камери, яка описує загальну суть фізичних процесів сушіння з використанням наявного в лісосушильній камері обладнання. Такий підхід дозволяє враховувати фізичні параметри необхідного обладнання, такого як калорифери, вентилятори, зволожуючі форсунки, та знехтувати деякими конструкторськими характеристиками, які можуть відрізнятися залежно від типу лісосушильної камери. Зважаючи на це, головним завданням в даній роботі являється визначення температури та вологовмісту агенту сушіння та пиломатеріалів у штабелі, а також температури основних компонентів лісосушильної камери. Звичайно, при врахуванні такої кількості різних параметрів та при описі складного нестаціонарного процесу теплообміну, виникає необхідність створення складних математичних моделей, що значно ускладнює їхнє застосування та вимагає значних комп'ютерних ресурсів для їх обчислення. Таким чином, математичний опис зводиться до опису нелінійних диференціальних рівнянь у частинних похідних. Для пришвидшення обчислень цієї математичної моделі, пропонується використання клітинних автоматів. Для цього, 3D модель лісосушильної камери представляється у вигляді клітино-автоматного поля, яке складається з клітин, що мають однакові розміри але різні типи. Таким чином, сусідні між собою клітини містять локальні взаємозв'язки, які описують їх загальну поведінку. Ця поведінка залежить від типу дотичних клітин та описується правилами переходів, які базуються на математичній моделі. Завдяки використанню розробленої клітино-автоматної моделі та правил переходів, можна отримати значення температури та вологовмісту деревини у штабелі, агенту сушіння в камері, а також температури основних компонентів камери. В роботі також наведені відповідні графіки зміни температури та вологовмісту. Для перевірки адекватності та достовірності, проведено порівняння отриманих результатів із результатами експериментів інших авторів. В результаті перевірки, значення середньої абсолютної похибки є не значні, що підтверджує адекватність математичної моделі та перспективи використання розробленої клітино-автоматної моделі.

***Ключові слова*: Математична модель; нестаціонарний процес тепло та волого обміну; 3D модель; клітино-автоматна модель; правила переходів.**