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STUDY OF HEAT AND MASS TRANSFER IN WOOD-COMPOSITE MATERIALS BY MEANS OF COMPUTATIONAL FLUID DYNAMICS

Wood-composite materials (WCM), undergoes complex heat and mass transfer processes during its conditioning. Understanding these interactions is crucial for optimizing the conditioning process and ensuring high quality of the final product. This study focuses on the problem of modeling the interactions that occur during WCM conditioning, taking into account their characteristics that depend on temperature, moisture content, and density of the material. In addition, various input parameters are taken into account in the modeling process to set the optimal conditioning conditions. Despite the availability of these parameters in the literature based on the results of real experiments, consolidating this data in computer modeling is still a major problem. To resolve this issue, this study focuses on modeling the heat and mass transfer processes during WCM cooling using computational fluid dynamics (CFD) software such as SolidWorks Flow Simulation. By using the capabilities of CFD, it is relatively possible to utilize technical parameters involved in the WCM conditioning process with relative simplicity. The paper provides a detailed description of the created 3D model of the WCM-conditioning chamber and its main components. In addition, the paper describes the various input parameters used in the modeling process, including temperature, moisture content, and density of WCM. In addition, the operation of the fans was set up and the initial values of temperature, moisture content, and air velocity were set. Based on the simulation, the results obtained include the distribution of the temperature field and moisture content on the surface of the WCM at different material densities and air conditioning parameters. Additionally, the trajectory of air masses and their velocity within the 3D model was obtained. In general, the obtained results provide a better understanding of the influence of various input parameters on the process of heat and mass transfer in WCM during their cooling. Given the comprehensive analysis, this research this work can be useful for improvement of WCM production processes and quality control of final products. In particular, it emphasizes the importance of further research in this area and the need for computer modeling of such processes to further develop effective engineering solutions.

Keywords: SolidWorks Flow Simulation, computer modeling, CFD software, 3D model, temperature, moisture content.

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ДОСЛІДЖЕННЯ ТЕПЛОМАСОПЕРЕНЕСЕННЯ В ДЕРЕВИНО-КОМПОЗИТНИХ МАТЕРІАЛАХ ЗАСОБАМИ ОБЧИСЛЮВАЛЬНОЇ ГІДРОДИНАМІКИ

Деревино-композитні матеріали (ДКМ), під час свого кондиціонування проходить складні процеси тепломасообміну. Розуміння цих взаємодій має вирішальне значення для оптимізації процесу кондиціонування та забезпечення високої якості кінцевого продукту. У цьому дослідженні розглядається проблема моделювання взаємозв'язків, що виникають під час кондиціонування ДКМ, враховуючи їх характеристики, що залежать від температури, вмісту вологи та щільності матеріалу. Крім того, у процесі моделювання враховуються різні вхідні параметри для задання оптимальних режимів кондиціонування. Незважаючи на наявність цих параметрів у довідковій літературі, заснованій на результатах реальних експериментів, консолідація цих даних при комп'ютерному моделюванні все ще залишається серйозною задачею. Щоб усунути цю прогалину, це дослідження спрямоване на моделювання процесів тепломасообміну під час охолодження ДКМ за допомогою програмного забезпечення для обчислювальної гідродинаміки (CFD), таке як SolidWorks Flow Simulation. Використовуючи можливості CFD, можна відносно легко використати технологічні та технічні параметри, що задіяні в процесі кондиціонування ДКМ. При цьому, в роботі наведено детальний опис створеної 3D моделі камери кондиціонування ДКМ та її основних компонентів. Окрім цього, в роботі наведено опис різних вхідних параметрів, що використовуються в процесі моделювання, серед яких температура, вологовміст та густина ДКМ. Також здійснено налаштування роботи вентиляторів та задано початкові значення температури, вологовмісту та швидкості руху повітряних мас. В результаті проведеного моделювання отримані результати, серед яких розподіл температурного поля та вологовмісту на поверхні ДКМ при різній густині матеріалу та параметрах кондиціонування. Додатково, отримано вигляд траєкторії руху та швидкості повітряних мас в межах 3D моделі. Загалом отримані результати дозволяють краще зрозуміти вплив різних вхідних параметрів на процес тепломасоперенесення в ДКМ під час їх охолодження. Враховуючи всебічний аналіз, дана робота може бути корисною для вдосконалення процесів виробництва ДКМ та контролю якості кінцевої продукції. Зокрема, вона підкреслює важливість подальших досліджень у цій області та потребу у комп'ютерному моделюванні таких процесів для подальшого розвитку ефективних інженерних рішень.

Ключові слова: SolidWorks Flow Simulation, комп'ютерне моделювання, програмне забезпечення CFD, 3D модель, температура, вологовміст.

Formulation of the problem

The difficulty of modeling the interrelationships that arise during WCM conditioning lies in their thermo physical and mechanical characteristics, which depend on temperature, humidity, and material density. In addition, the modeling process requires a large number of determining parameters and their combination to determine the optimal conditioning conditions for these WCM. Scientists and engineers are challenged to combine a variety of data from reference literature based on experimental data to create a consistent model. It is also worth noting that the structure of the WCM determines the importance of analyzing the physical and mathematical model for simulating the cooling process in specialized computer programs. Despite this, the WCM belong to the class of highly filled composite materials with a porous structure, the change in temperature and humidity in which can be described based on general equations of heat and mass transfer of porous materials. However, such modeling should take into account the regularities of heat generation and the adsorption of moisture from wood. Due to this complexity, the development of specialized computer programs is resource-intensive and impractical in terms of time and money. Therefore, computational fluid dynamics programs are suitable for performing such tasks, one of the most developed of which is SolidWorks Flow Simulation. As a result, it is necessary to improve the methods of modeling and determining the optimal conditioning regimes for WCM, which requires a deeper understanding of the physical and mathematical aspects of heat and mass transfer processes in such materials.

Analysis of recent publications

In the modern scientific and technical literature, analytical calculations for modeling the cooling process of a WCM rarely encountered. Most existing approaches to their study based on theoretical models developed in fundamental scientific works [1-3]. However, the use of even such models in practical engineering calculations is difficult due to the need of obtaining numerical values for capillary-porous materials and the problem of system closure with respect to the phase transition criterion. Despite this, some authors pay attention to these problems and propose their own solutions. In particular, in [4], the authors developed a mathematical model that allows theoretically calculating the cooling time of WCM made with low-toxic resins and displaying the temperature on its surface as well as throughout the entire cross-section during any time interval. In turn, in [5], the authors developed a model to predict the formation of a vertical profile of WCM density, which depends on the processing parameters. The analysis of the results allows us to determine the optimal processing parameters for obtaining WCM with high mechanical and physical properties. In particular, in [6], the authors investigate the effect of the cooling process during WCM pressing on continuous presses. They analyze how this process affects the heat distribution in the pressed material and the properties of the WCM. In general, the results of all these researches indicate that the cooling process directly affects the physical characteristics of WCM, which makes it necessary to model and optimize the technological and technical parameters of this process.

The aim of the work is to simulate heat and mass transfer processes during WCM cooling using the computational fluid dynamics program SolidWorks Flow Simulation.

Design and main components of the WCM air conditioning chamber and creation of its 3D model

The main components of a WCM-conditioning chamber are a conveyor, support posts, a cool air supply system, and a chamber body consisting of walls, roof, and door [7, 8]. Some of the most complex parts in this case are the cold air supply system and the conveyor, which is responsible for moving the WCM through the chamber. Since we are planning to perform calculations in SolidWorks Flow Simulation, the geometric part of the cold air supply system can be neglected. However, in this case, it will be necessary to use the LIDS tool in the cross-section of the ventilation duct to set the airflow parameters. In turn, due to the complexity and three-dimensional design of the conveyor (see Fig. 1), certain simplifications must also be applied to it. If this is not done, the calculation process will be long, which we don't want. In this regard, the best way to simplify its design is to reduce the number of its support posts for holding WCM to the minimum number, which in this case is 18 pieces. This number will be enough to place 4 standard-sized WCM [9]. When designing the conveyor structure, special attention paid to its strength and stability for efficient and safe transportation of WCM [10, 11]. In particular, it is envisaged that the thickness of the support posts will always be greater than the maximum height of one WCM.

Fig. 1. View of the real conveyor of WCM air conditioning chambers

In general, the WCM-conditioning chamber design developed to allow us for set the correct trajectory and speed of the airflow in the chamber. In Figure 2, a 3D model of this chamber consisting of all the above components is shown. The cold air supply system is also shown here but only for illustrative purposes, because as mentioned earlier, it won't be used in the modeling process. Overall, each of these components plays an important role in providing optimal air conditioning conditions for WCM.

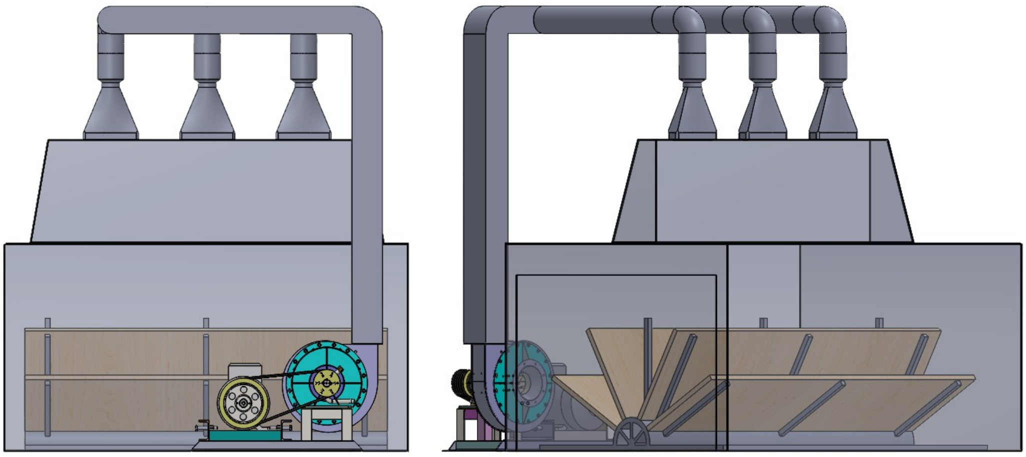


Fig. 2. View of two projections of the 3D model of the WCM air conditioning chamber

Input parameters for modeling heat and mass transfer in WCM

For the research, we used WCM made of spruce in the amount of 50%, as well as hardwoods of birch in the amount of 30% and poplar in the amount of 20%. Therefore, the WCM structure is three-layer, and its density, taking into account the total amount of materials, is approximately 560 ± 20 kg/m3. The WCM thickness is 16 mm. The adhesive concentration is at least 50%. The moisture content of dry WCM is 2-3%, and the average moisture content of the WCM after pressing is approximately 8~13%. The technological modes of manufacturing the studied WCM are the pressing temperature of 200°C and the pressing pressure of 2.8 MPa.

Since this study is going to investigate the process of WCM cooling [12-14] after it has been pressed, the above pressure can be neglected. It is also important to note that there is no WCM material with the above-mentioned characteristics in the SolidWorks material library, so it was created and saved in the user's material library. In addition, to simplify the calculations, it was decided to design 3D models of solid plates of a given geometric size and density.

In general, to fully study the process of convective WCM conditioning in SolidWorks Flow Simulation, the following ranges of variables should be investigated, in particular: the temperature of cold air for blowing WCM is 8-50°C, the relative humidity of this air is 20-90%, the temperature of the WCM when they are stacked is 40-160°C, and the duration of the WCM in the stack is 1-167 hours. In this case, it was decided to set the temperature of the blowing air to 10.05°C, the relative humidity to 50%, and the air velocity to 3 m/s. It is clear that all these parameters are not difficult to set in the SolidWorks Flow Simulation experiment settings (see Fig. 3).

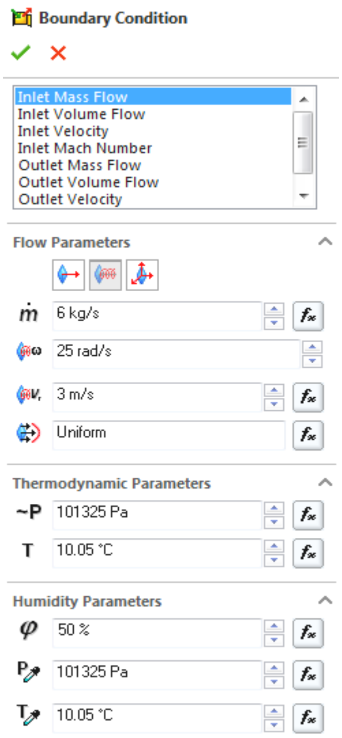


Fig. 3. Input air parameters

Results of modeling heat and mass transfer in WCM and their analysis

Since we don't consider the process of WCM pressing, it is necessary to have the initial parameters of the WCM before it is cooled. In general, these data can be taken from real experimental data [15-17]. After setting them, the corresponding graphical dependencies can be taken in SolidWorks Flow Simulation (see Fig. 4). It is worth noting that these data are taken from the height of each WCM placed on the conveyor. Therefore, we can start the simulation, which will last for 24 hours (321 iterations) with a step of 270 s.

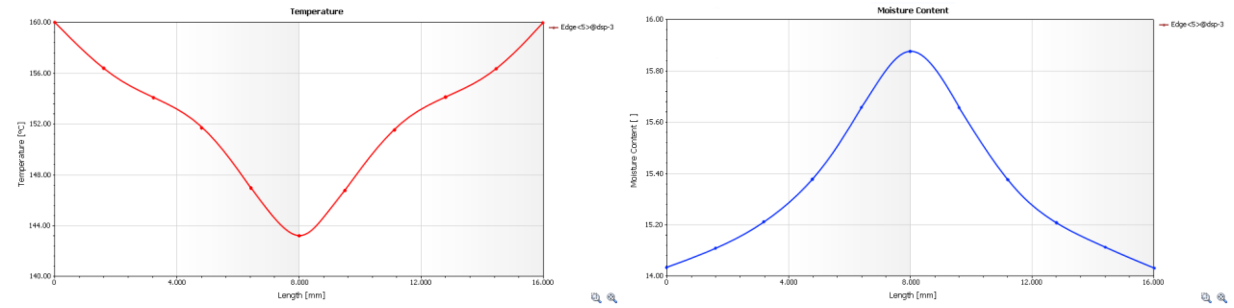


Fig. 4. Initial values of WCM temperature and moisture content

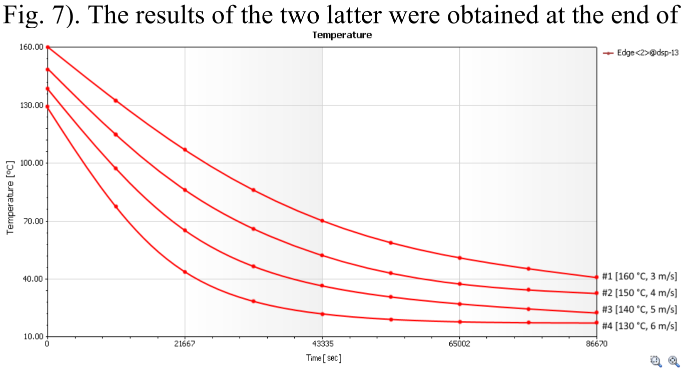
To investigate the dynamics of temperature and moisture content distribution on the surface of WCM, several experiments were conducted with different input parameters (see Table 1).

Table 1

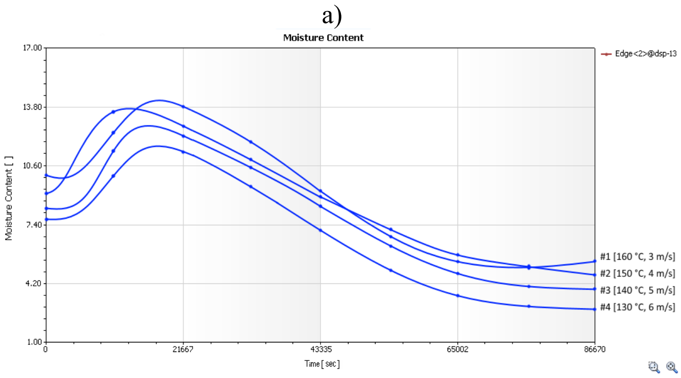
Input parameters for the studies

Study No.	Air temperature	Air relative humidity	WCM temperature	WCM moisture content	Density	Velocity
1	10.05 °C	50 %	160 °C	10 %	560 kg/m^3	3 m/s
2	15.05 °C	40 %	150 °C	9 %	620 kg/m^3	4 m/s
3	20.05 °C	30 %	140 °C	8 %	680 kg/m^3	5 m/s
4	25.05 °C	20 %	130 °C	7 %	730 kg/m^3	6 m/s

The results of the experiments are presented in the form of graphical dependences of the temperature and moisture content of WCM (see Fig. 5), trajectories of air masses with indication of speeds (see Fig. 6) and surface areas (see Fig. 7). The results of the two latter were obtained at the end of the simulation for 321 iterations.



a)



b)

Fig. 5. Distribution of WCM temperature (a) and moisture content (b) over time

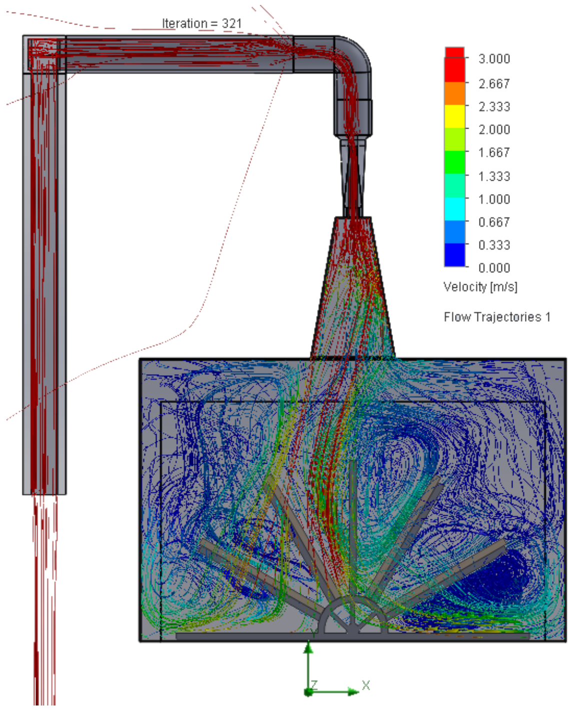
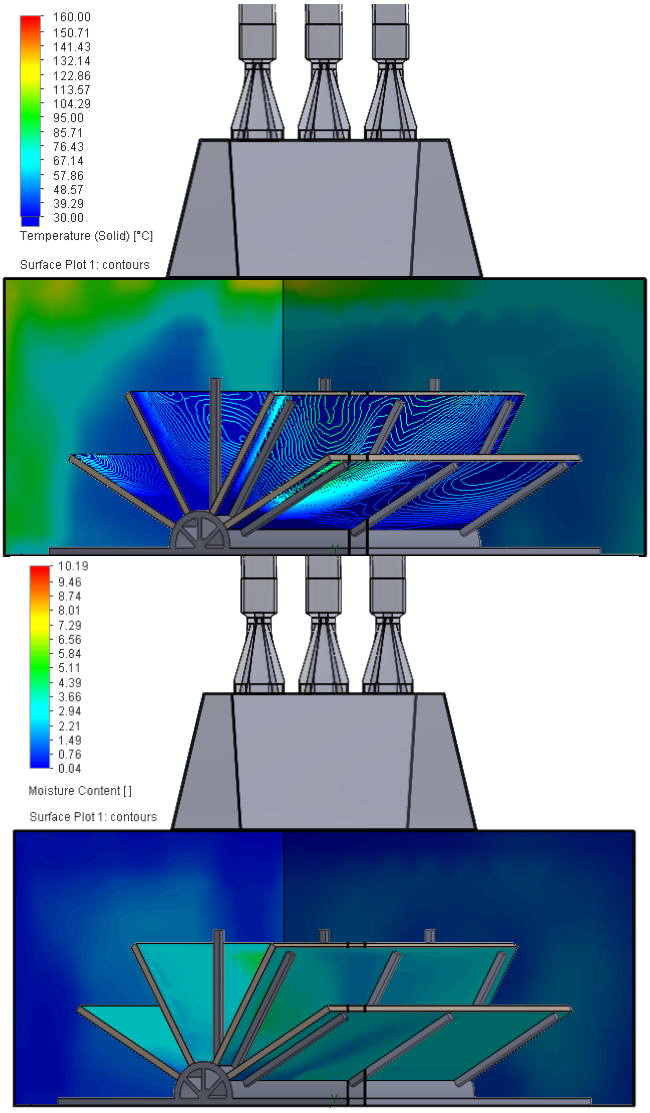


Fig. 6. trajectories of air masses in a 3D model of a WCM air conditioning chamber with its speeds specified

The analysis of the obtained graphical dependencies shows sufficient adequacy according to the experimental data [15-17], and the error doesn't exceed 10%. It is also worth noting that with an increase in the duration of conditioning, the error decreases. In particular, starting from 120-140 iterations, the error ranges from 4-6%. The results also indicate that the moisture content values differ not only in quantity but also in quality. In addition, the analysis of the results indicates that with an increase in the duration of conditioning, the moisture content on the surface increases, which may be due to the release of moisture from the inside [18, 19]. Nevertheless, starting from the 180-200 iterations, the moisture content leveling over the entire surface and thickness of the WCM is observed. Therefore, the equalization of moisture content on the surface of WCM during its conditioning is complex and depends mainly on the initial air parameters.



a) b)

Fig. 7. View of WCM surface areas and adjacent walls with display of isosurfaces for temperature (a) and moisture content (b) of these areas

The results also indicate that the moisture content distribution in WCM is uniform during the cooling process. For example, with an initial moisture content of 7-10% on the WCM surface, this moisture content changes during cooling. At the same time, the first 50-70 iterations are characterized by a significant increase in moisture content at the boundary, which is associated with the release of moisture from the inside of the WCM. After this period, the moisture content on the surface begins to return to the initial level and gradually decreases to 3-4%. As for the temperature, this dynamic is not observed, since the temperature on the surface of the WCM begins to decline immediately.

Conclusions

As a result of this work, it was possible to study the processes of heat and mass transfer in WCM during air conditioning using computational fluid dynamics. The modeling was performed in SolidWorks Flow Simulation, and it provided important information about the distribution of temperature and moisture content on the surface of the WCM, as well as the trajectories of air masses and their velocity inside the air conditioning chamber. The results of the study confirmed high adequacy compared to the experimental data, with an average accuracy of up to 10%. In general, this study found that the conditioning process significantly affects the physical characteristics of WCM, so it is very important to optimize the technological parameters of this process. In addition, it was found that the moisture distribution in WCM is uniform during the cooling process. At the same time, it was possible to establish the dynamics of moisture changes on the surface of the WCM, which provides a better understanding of moisture transfer processes and their impact on the final quality of the material.

In general, the results of this work can be important for WCM manufacturers, as it provides them with a tool for optimizing the technological processes that occur during the conditioning of WCM. Although this work doesn't cover the WCM pressing process itself, it opens up new opportunities and prospects for further research in this area to develop more efficient engineering solutions.

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