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DESIGN AND OPERATION MODE OPTIMIZATION OF THE DRYING CHAMBER BASED ON ITS 3D MODEL

This paper focuses on the analysis and optimization of the drying chamber design using SolidWorks Simulation software. One of the main problems that arises in the design of drying chambers is the need to ensure optimal conditions for efficient drying of materials. In this regard, this study determines the optimal design parameters of the drying chamber and its operating mode to ensure uniform temperature distribution in the stack. The methodology includes creating a 3D model of the drying chamber and its main components in SolidWorks, generating a difference mesh, conducting a thermal study in SolidWorks Simulation, and applying Design Study to optimize the design parameters of the drying chamber and its operating modes. The simulation results include the output of the heat flow in the stack and temperature measurements at various points, which allows us to assess the temperature differences and the impact of optimization parameters on them. Temperature measurements at different points were performed using the Prob tool, which takes into account the exact geometry and location of nodes on the tetrahedral elements of the difference grid of the 3D model of the drying chamber used for the calculations. In general, the study consists of applying an integrated approach to the design of drying chambers using SolidWorks and automating the optimization process through the SolidWorks API, for which software has been created. The software also allows users to enter input data for the 3D model design and thermal study parameters for their transfer to SolidWorks. In addition, the software provides the ability to perform calculations directly in SolidWorks Simulation but in the background, so that the results obtained will be displayed in a special program window in a fully automated mode. It is also worth noting that performing calculations without visualizing this process significantly reduces the time to obtain results that can be used to improve the technological processes of drying various materials in drying chambers.

Keywords: SolidWorks Simulation, Design Study, Software, Thermal analysis, Automation, Heat flow, Lumbers.

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ОПТИМІЗАЦІЯ КОНСТРУКЦІЇ ТА РЕЖИМУ РОБОТИ СУШИЛЬНОЇ КАМЕРИ НА ОСНОВІ ЇЇ 3D МОДЕЛІ

Дана робота присвячена аналізу та оптимізації конструкції сушильної камери за допомогою ПЗ SolidWorks Simulation. Однією з основних проблем, яка виникає при проектуванні сушильних камер, є необхідність забезпечення оптимальних умов для ефективного сушіння матеріалів. У зв'язку з цим, в даному дослідженні визначаються оптимальні параметри конструкції сушильної камери та режиму її роботи для забезпечення рівномірного розподілу температури в штабелі. Методологія включає створення 3D-моделі сушильної камери та її основних компонентів у SolidWorks, генерацію різницевої сітки, проведення термічного дослідження в SolidWorks Simulation та застосування Design Study для оптимізації конструктивних параметрів сушильної камери та режимів її роботи. Результати моделювання включають вивід теплового потоку у штабелі та вимірювання температури в різних точках, що дає змогу оцінити різницю температур і вплив на них параметрів оптимізації. Вимірювання температури в різних точках виконано за допомогою інструменту Prob, який враховує точну геометрію та розташування вузлів на тетраедричних елементах різницевої сітки 3D моделі сушильної камери, використаної для розрахунків. Загалом дослідження полягає в застосуванні комплексного підходу до проектування сушильних камер з використанням SolidWorks та автоматизації процесу оптимізації через SolidWorks API, для використання якого створено відповідне ПЗ. Дане ПЗ також дозволяє користувачам вводити вхідні дані для проектування 3D-моделі та параметри термічного дослідження, з метою їх передавання у SolidWorks. Окрім цього, ПЗ надає можливість виконувати обчислення безпосередньо в SolidWorks Simulation але у фоновому режимі, завдяки чому, отримані результати будуть відображатися у спеціальному програмному вікні повністю в автоматизованому режимі. Варто також зазначити, що проведення розрахунків без візуалізації цього процесу значно скорочує час отримання результатів, які в подальшому можна застосовувати для вдосконалення технологічних процесів сушіння різних матеріалів у сушильних камерах.

Ключові слова: SolidWorks Simulation, Design Study, Програмне забезпечення, Термічне дослідження, Автоматизація, Тепловий потік, Пиломатеріали.

Formulation of the problem

Drying chambers provide a crucial role in a variety of industrial processes, ensuring that moisture effectively removed from materials while maintaining optimal conditions for their preservation and quality [1]. The design and operation of these chambers have a significant impact on the efficiency and cost-effectiveness of drying processes. Therefore, there is a constant demand for innovative approaches to optimize the design of drying chambers and their operating modes. One of the main challenges in the design of drying chambers is to achieve an even temperature distribution across the stack, which is important for ensuring consistent drying speeds and product quality. Traditional design methods often rely on empirical approaches or simplified analytical models that may not fully capture the complex thermal dynamics in the drying chamber. In the last few years, computer-aided design (CAD) and simulation tools have become valuable assets in the design and optimization of drying chambers. In particular, SolidWorks Simulation offers a powerful platform for thermal analysis and optimization of chamber design parameters using finite element analysis (FEA). This study presents a comprehensive analysis and optimization of both the drying chamber design and its operating modes to achieve a uniform temperature distribution in the stack using SolidWorks Simulation.

Analysis of recent publications

The use of software for designing and modeling various processes, including the drying of various materials, has been gaining immense popularity in recent years. For example, in work [2], software tools are used to optimize the parameters of the drying process and modeling on the COMSOL Multiphysics platform. The optimal parameters found allow for maximum productivity and uniform product quality in each drying batch. At the same time, work [3] proposes a new model of a hybrid dryer and software for designing and simulating a dryer, which allows improving the efficiency of hybrid dryer design. The methodology includes functional analysis, mathematical modeling, and virtual prototyping, using SolidWorks for CAD modeling and Matlab for numerical simulations and implementation of mathematical models in the user interface. In turn, work [4] develops hybrid solar dryers that make it possible to dry a variety of agricultural materials and other porous products. To select the optimal design of the dryer, numerical simulation of heat and mass transfer in a solar dryer was investigated using appropriate software tools. All these works demonstrate the relevance of the chosen research direction. Unfortunately, none of these studies consider the possibility of improving the design of traditional drying chambers. Nevertheless, such improvements are extremely necessary because they make it possible to improve the drying process, which in turn will positively affect the quality of the final product.

The aim of the work: To conduct a comprehensive study of the heat transfer process in a drying chamber using SolidWorks Simulation software. The research objectives include studying the temperature distribution in a stack of materials, establishing optimal parameters to ensure uniform heating of materials, and developing and implementing software to automate the modeling and research process.

Overview of the 3D model of the drying chamber assembly

The drying process requires precise and efficient control over all aspects of drying, including temperature, ventilation, and moisture distribution [5]. In this context, a 3D model of a drying chamber becomes a key tool for analyzing, designing, and optimizing its operation. This 3D model not only allows visualization of the drying chamber structure, but also provides an opportunity to analyze its elements in three-dimensional space, which is critical for identifying potential problems in the design and determining rational solutions to solve them.

In this case, the 3D model of the drying chamber consists of the following elements:

- An air supply system, which is necessary to ensure uniform air distribution throughout the drying chamber, which is necessary to achieve uniform drying of materials.
- Heaters, which are used for heating the air circulating in the drying chamber and are a key element for controlling the temperature and drying speed.
- Fans that are used to actively mix the air in the drying chamber, which contributes to the uniform distribution of heat and moisture.

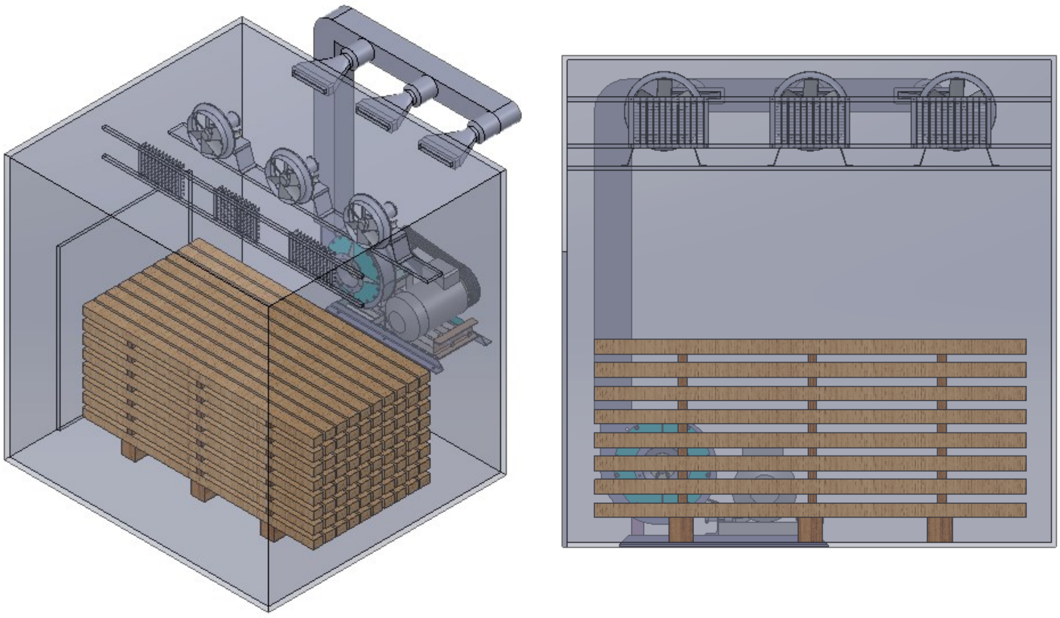

Fig. 1. View of the designed 3D model of the drying chamber in isometric (on left) and side views (on right)

- Stacks on which materials are placed for drying. Their number and size affect the efficiency of air circulation and heat distribution in the drying chamber.
- Walls, doors, ceiling, which are the main structural elements of the drying chamber and determine its shape and size. They are important for heat retention and controlling energy losses.

To better understand the design of the drying chamber and its components, we consider the appearance of their 3D models in the assembly (see Fig. 1).

Performing a thermal analysis in SolidWorks Simulation

Conducting a thermal analysis in SolidWorks Simulation is an important step in determining the heat flow in the drying chamber. Based on the results of this heat flow, it is possible to determine whether the design of the drying chamber and the set mode of its operation are optimal [6]. Below is described the process of conducting and analyzing the thermal analysis, which allows for a better understanding of the thermal processes occurring in the drying chamber.

After selecting the designed 3D model of the drying chamber and creating a new "Thermal study", it is necessary to establish important input parameters that affect the thermal processes in the drying chamber. These parameters include: the contact area between the heaters and the drying chamber structure (Connections / Contact Set), the distributed thermal resistance between the selected surfaces (Thermal Resistance), the heat power of the heaters (Thermal loads / Heat Power), convection for heat transfer to the external environment (Thermal loads / Convection), and the ambient temperature (Bulk ambient temperature). It is worth noting that the research is conducted at a constant drying rate and for materials with parameters that differ from those presented in the SolidWorks material database. In particular, three materials were selected that are most commonly used for drying in Ukraine, i.e. oak, beech, and pine. The parameters of these materials are taken from [7], which was formed according to the results of measurements of real experiments.

To estimate the heat losses, a general calculation of heat transfer through the walls of the chamber can be used [8]. In this case, the height of the drying chamber is 3.2 m, the width is 2.6 m, and the length is 3.6 m. The walls have a thickness of d_{walls} = 0.15 m and are made of heat-insulating material with a thermal conductivity coefficient λ_{walls} = 0.05 W/(m°C). It was determined that the temperature difference (ΔT) between the drying chamber and the ambient environment at the initial time is approximately 10°C, and the area of the walls (S_{walls}) is 54.4 m^2. Therefore, the heat losses through the walls (Q_{lose}) can be calculated as follows:

$$Q_{\text{lose}} = \lambda_{walls} S_{walls} \Delta T / d_{walls} \tag{1}$$

In this case, $Q_{lose} \approx 180$ W. In turn, the heat loads during drying can be determined depending on various factors, such as the moisture content of the material and the heat consumption for evaporation of a unit of water. On average, these values for a drying chamber of a given size are in the range of 200 to 400 W per heater. It is worth noting that in this study, the optimal values of heat loads will be selected taking into account the temperature difference of materials in different places of the stack [9]. Thus, the total heat demand should be in the range of 380 - 580 W, or 400 - 600 W can be taken for convenience.

To determine the distributed thermal resistance between the selected surfaces [10], it is necessary to divide the wall thickness by the thermal conductivity of the material multiplied by the surface area where heat transfer occurs. In this case, heat transfer will occur through the ceiling, which is 0.15 m in thickness, with an area of 6.76 m^2 (with a central aisle width of 1 m) and a thermal conductivity coefficient of 0.05 W/(m°C). Therefore, if we substitute these values, we can obtain the following thermal resistance: 0.45 (m^2°C)/W.

It is also worth noting that the convection value for heat transfer to the external environment [11] can be calculated using the general heat transfer equation, which involves dividing the total heat output by the product of the heat transfer surface area and the temperature difference. If we assume that the initial temperature difference is not significant and is about 1 °C, then convection will be approximately 80 W/(m^2°C).

After setting the input parameters, it is necessary to create a tetrahedral mesh for calculations. This is an important step because a good mesh ensures accurate results. SolidWorks Simulation automatically creates a tetrahedral mesh, but if necessary, it is possible to manually configure the mesh parameters. To save resources, some components of the 3D model of the drying chamber were extinguished. In this case, only the heaters, the stack, and the ceiling between them were retained. In this case, it was necessary to apply Control Mesh technology. This technology will allow us to build a mesh in hard-to-reach places of the 3D model of the heaters, especially at the pipe connections. In addition, it will increase the accuracy of the results by creating additional tetrahedral elements. This is especially important for areas with rounded elements, where it is necessary to further increase the mesh density to obtain accurate results [12].

After setting up the study parameters and creating a tetrahedral mesh, the study is run. SolidWorks Simulation calculates the thermal processes in the drying chamber and provides results that include the temperature distribution in the stack. One of the key results of the experiment is also the heat flow along the stack (see Fig. 2). This information allows us to assess the efficiency of heat transfer and the uniformity of heating of materials in the drying chamber. The results show that the top row of the stack has the highest heat flux, with a value of 94.41 W/m^2. It is worth noting that five studies were conducted with different widths of the central passage of the raised ceiling.

Another very important step in the analysis is to measure the temperature at different points in the stack using the tool Prob. This allows us to determine the temperature difference in different parts of the stack and assess its impact on the quality of drying materials. It is worth noting that it is best to take these values in the middle of the stack but in different rows (see Fig. 3). It is also possible to consider the temperature distribution across the stack (see Fig. 4) at its top.

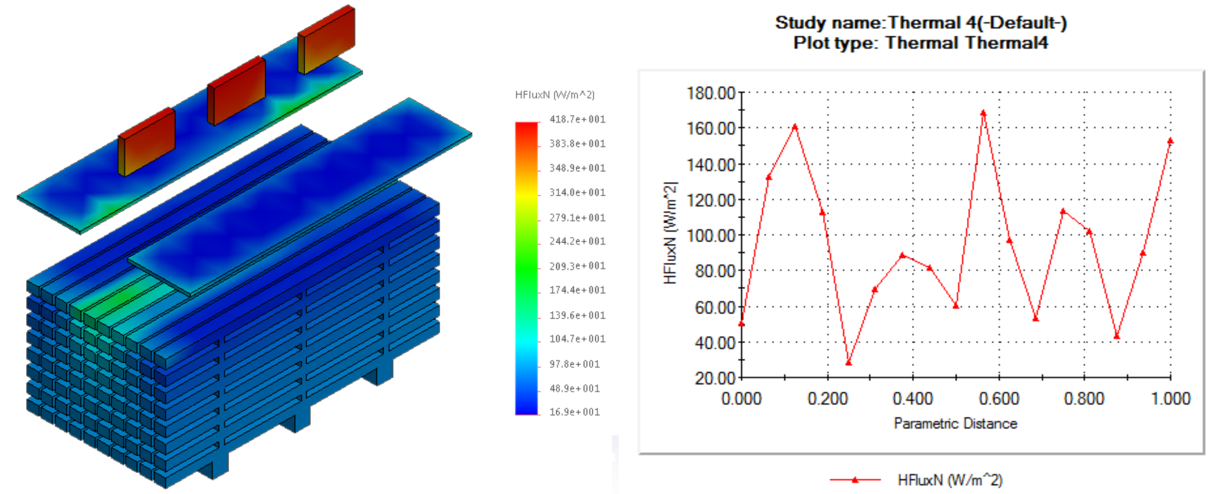

Fig. 2. Heat flux in the isometric view of the stack (left) and heat flux distribution plot along the top row of the stack at 17 nodes (right) at the first iteration (60 seconds)

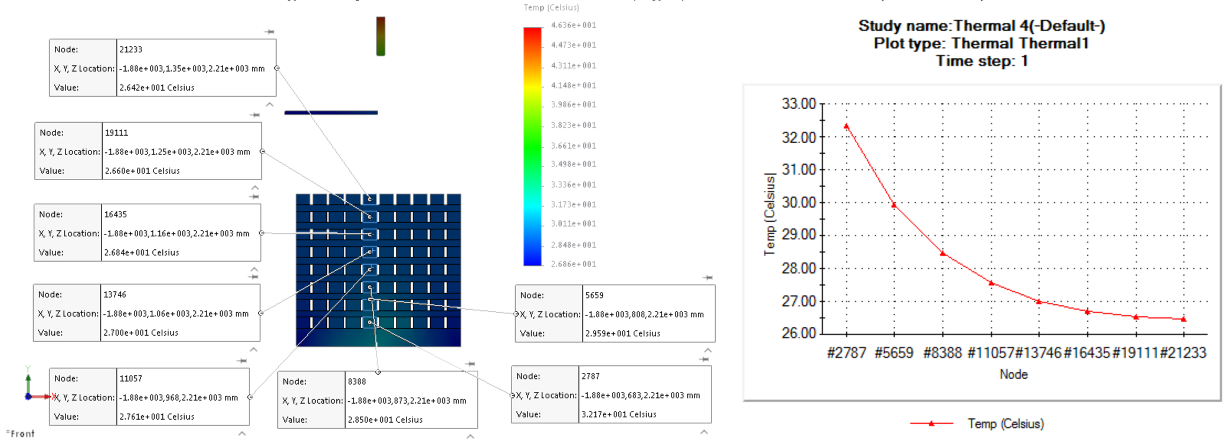

Fig. 3. The position of the 8 selected nodes located inside the stack along its height (left) and the temperature distribution graph for these nodes (right) at the first iteration (60 seconds)

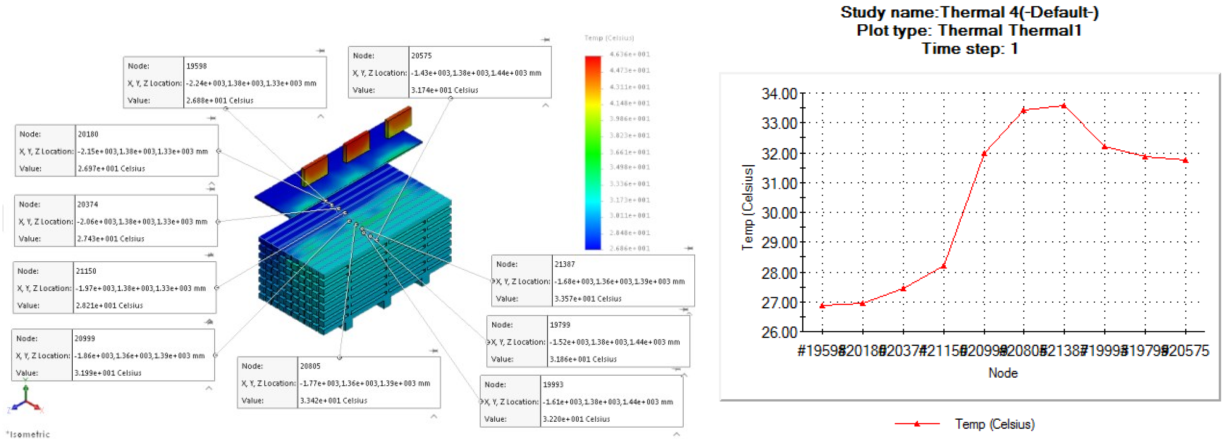

Fig. 4. The position of the 10 selected nodes located across the stack on its surface (left) and the temperature distribution graph for these nodes (right) at the first iteration (60 seconds)

It is worth noting that all the results presented in Figures 2-4 reflect the state of the system after the first iteration, which corresponds to a time interval of 60 seconds. However, in order to obtain a more complete understanding of the dynamics of thermal processes, it is also important to evaluate temperature changes over time. For this purpose, a sensor for node #20374 was created, which, according to Fig. 4, shows a temperature value of 27.43 °C. As we can see in Figure 5, after ten iterations, corresponding to 10 minutes of simulation, the temperature value increased to 32.27 °C, which is 4.84 °C higher than in the first iteration of the simulation. Such results confirm the correctness of the selected input parameters of the study and indicate the adequacy of the model in reproducing thermal processes in the drying chamber over time.

Studying through research in SolidWorks Design Study

From the results of the temperature distribution and heat flux, we can conclude that the heat distribution in the stack is irregular. Nevertheless, the temperature difference between the upper and lower rows of materials in the stack is sometimes 4 °C, which requires adjustments to the input parameters of the study to optimize the drying process. In this case, it is proposed to use the "Design Study", which is a powerful tool for optimizing various parameters in the SolidWorks environment [13]. In general, the optimization of the power of heaters, convection, and the width of the central passage is carried out (see Fig. 6). As mentioned above, the power of the heaters should be approximately 400 W, so as optimization parameters, these values will vary from 200 to 600 in 100 W increments. The calculated convection values are set at 80 W/(m²·°C), but to use it in the "Design Study", it is necessary to convert these values to Cal/(sm²·s°C). If we use the conversion factor for measuring heat power from watts to calories per second, which is approximately 0.239 Cal/s, then the convection value will be approximately 0.001912 Cal/(sm²·s°C). In this regard, as optimization parameters, these values will vary from 0.0015 to 0.0025 in increments of 0.0002 Cal/(sm²·s°C). At the same time, the width of the central passage will vary from 500 to 1500 in increments of 200 mm.

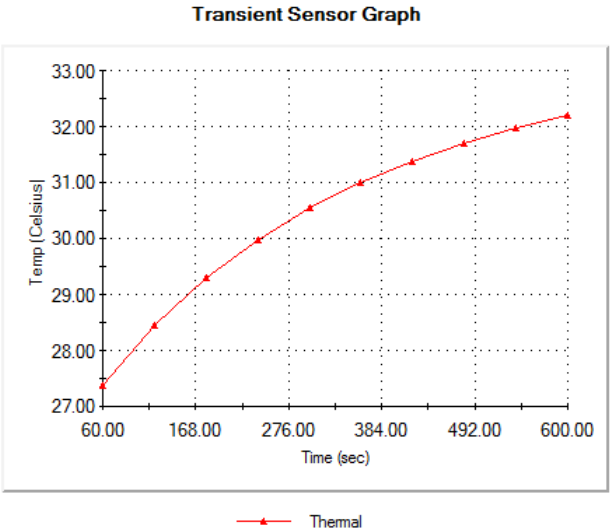

Fig. 5. Graph of temperature distribution in the sensor during 10 iterations (600 seconds)

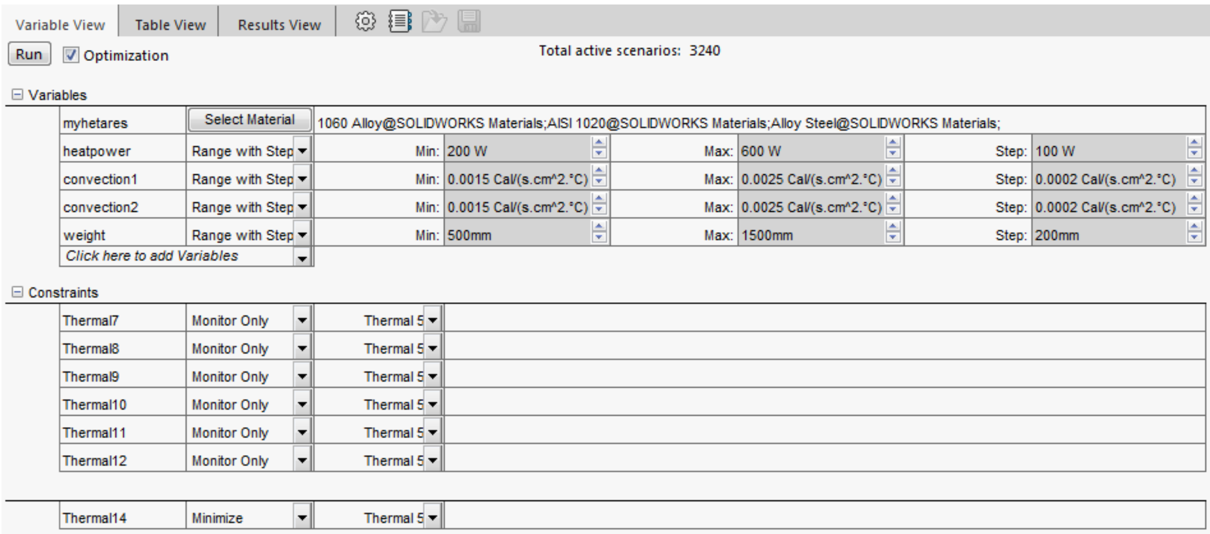

Fig. 6. Window for entering optimization parameters and entering their limits

		Current	Initial	Optimal (1)	Scenario 2918	Scenario 2919
heatpower		400 W	200 W	300 W	400 W	500 W
convection1		79.496000	62.760000	71.128000	71.128000	71.128000
convection2		79.496000	62.760000	71.128000	71.128000	71.128000
weight		1100mm	500mm	1300mm	1300mm	1300mm
myhetares	List of Materials	Alloy Steel @SOLIDWORKS Materials	1060 Alloy @SOLIDWORKS Materials	1060 Alloy @SOLIDWORKS Materials	Alloy Steel @SOLIDWORKS Materials	Alloy Steel @SOLIDWORKS Materials
Thermal7	Monitor Only	32.2502°C	26.9788°C	27.67°C	27.8066°C	29.4266°C
Thermal8	Monitor Only	30.1393°C	26.8251°C	27.4621°C	27.3169°C	28.0898°C
Thermal9	Monitor Only	28.515°C	26.909°C	27.2112°C	27.2209°C	27.8676°C
Thermal10	Monitor Only	27.6237°C	26.8833°C	27.006°C	27.1893°C	27.7892°C
Thermal11	Monitor Only	27.1231°C	26.8913°C	26.86°C	27.1875°C	27.7686°C
Thermal12	Monitor Only	26.8863°C	26.887°C	26.711°C	26.8501°C	26.8503°C
Thermal14	Minimize	26.8863°C	26.9427°C	26.711°C	26.8501°C	26.8503°C

Fig. 7. Selection of optimal parameters for thermal study

In summary, the program offers 3240 possible sets of study parameters. On weak computers, such calculations can take a long time, so in this case, the calculations were performed on a computer with a 20-core INTEL Core™ i7 14700K processor (BX8071514700K) with a base frequency of 3400 MHz. The calculations lasted about 6 hours. As a result of the calculations, the following optimal parameters were established (see Fig. 7): the power of the heaters should be 300 W each, the convection value should be 0.0017 Cal/(sm²s°C), which is equal to 71.12 W/(m^2°C), and the width of the central passage should be 1300 mm. In this case, the best material for heaters is "1060 Alloy". It is also worth noting that during the calculations, the temperature values in different places of the stack were displayed in the view mode ("Thermal7" – "Thermal12"). The locations were selected according to the row of materials in the stack. For example, "Thermal7" is located on the top of the stack and at the start of the optimization, the temperature in it was 32.2502 °C. As a result of using the optimal parameters, it was found that the temperature difference between the upper and lower rows of materials would not exceed more than 1 °C, and their values would be 27.67 °C and 26.711 °C.

Automating the research process using the SolidWorks Simulation API

In recent years, more and more engineers and researchers have been using the SolidWorks Simulation API to automation their research in SolidWorks Simulation. This work is no exception. To use it in this work, specialized software has been developed that allows us to enter input data for modeling and transfer them to SolidWorks [14]. In addition, the software makes it possible to transfer modeling results and display them in a special window. This approach has a number of significant advantages over traditional non-automated research. Firstly, the use of software (see Fig. 8) speeds up the research process and, secondly, simplifies the user's work. At the same time, in this case, the user doesn't need to have skills in using the SolidWorks program, since all calculations in it will be performed exclusively in the background and the user will only enter input parameters and get the completed result.

The developed software also makes it possible to work with the geometry of the 3D model of the drying chamber. For this purpose, separate tabs are provided. It is worth noting that due to this program, the user can automatically design a 3D model of the drying chamber and its components, conduct a thermal study and obtain results. There were also attempts to use the SolidWorks Simulation API for Design Study, but they were unsuccessful. This can be explained by the fact that the developers haven't yet provided for this possibility, as mentioned on the official website [15]. In this regard, the optimization of the parameters of a new automated 3D model of the drying chamber is possible only manually when opening the SolidWorks program.

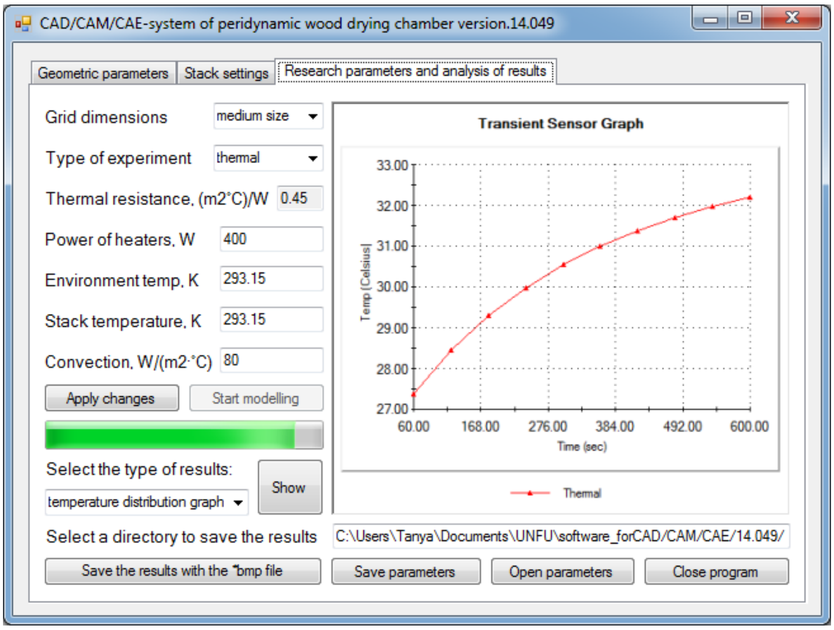

Fig.8. Window of the developed software for entering the parameters of a thermal study

Conclusions

In this study, a comprehensive analysis of the thermal processes occurring in the drying chamber was conducted using SolidWorks Simulation thermal analysis. According to the results of the simulation, it was found that the heat flow in the drying chamber showed an irregular distribution, with the highest value on the top row of the stack. Such heat distribution can negatively affect the quality of drying materials and requires further optimization of the system parameters. In this regard, the study parameters were optimized using SolidWorks Design Study, including the power of the heaters, convection, and the width of the central passage. As a result of the optimization, the optimal values of these parameters were set at 300 W, 71.12 W/(m^2°C) and 1300 mm, accordingly.

In addition, specialized software was developed to automation input data entry, modeling, and analysis of results. This software greatly simplifies the work with the study and allows to speed up the process of analyzing thermal processes in the drying chamber. It is worth noting that irregular heat distribution in the drying chamber may be due to differences in heat transfer between the upper and lower rows of materials. However, due to the optimization of the input parameters, it was possible to reduce this difference to an acceptable level, which confirms the effectiveness of using SolidWorks Simulation in the development and analysis of thermal processes in drying chambers.

Overall, the obtained results demonstrate the effectiveness of modeling thermal processes in complex systems, including drying chambers, using SolidWorks Simulation. The high level of accuracy and the ability to automate this process makes this software a powerful tool for engineering and scientific research. In addition, it was found that any irregular heat distribution in the drying chamber requires optimization of the input parameters of the study to achieve more uniform heating of the materials.

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