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SIMULATION MODELING OF THE THERMAL TREATMENT PROCESS OF MULBERRY SILKWORM COCOONS

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Abstract. *In the development of sericulture, enhancing energy efficiency and the ecological safety of the process at all stages of mulberry silkworm cocoon processing is of significant importance. The effective use of solar energy in thermal treatment processes is one of the promising approaches to reducing energy consumption. This article details the development of a simulation model for the thermal processes occurring within the chamber of an electrotechnical device designed for the heat treatment of mulberry silkworm cocoons, utilizing the Simulink package in Matlab. The parameter values for each block and element comprising the model were determined. This model was then used to investigate the thermal processes within the device's chamber and to assess the influence of various factors on the temperature regime of the cocoons. During the thermal processing of cocoons, the time-dependent changes in the energy consumption indicators of the electrical equipment were determined and analyzed. An analysis of the change in electricity consumption over time enabled an assessment of the device's energy efficiency.*

Key words: *model, device, temperature, cocoon, technological process, energy, consumption.*

INTRODUCTION

In recent years, enhancing energy efficiency and environmental safety across all stages of silkworm cocoon processing has become increasingly important for the development of the sericulture industry. Among these processes, the thermal treatment stage of the cocoons holds a special place. The amount of silk obtained from a cocoon, i.e., the degree of maximum utilization of the cocoon shell, largely depends on the methods used for pupa stifling and cocoon drying [1-4].

Traditional heat treatment methods typically require large amounts of electricity and fuel, leading to higher product costs and lower production efficiency. Utilizing solar energy in the technological processes of sericulture is a promising approach that allows for reduced energy consumption and a smaller negative impact on the environment [5;8-9].

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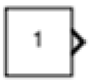
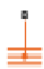
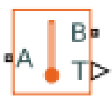
Solar thermal devices are a renewable energy source, and the efficiency of such devices directly depends on their design parameters, climatic conditions, and thermal processing modes [10-12]. In this context, developing a simulation model of an electrotechnical device intended for the thermal processing of mulberry silkworm cocoons is a pressing task. This model makes it possible to study the thermal processes occurring inside the device, as well as to assess the influence of various factors on the temperature regime of the cocoon. The use of simulation modeling allows for conducting numerical experiments without expensive experimental tests, serving to optimize the device's design and operating modes. The purpose of this work is to develop and analyze a simulation model of a solar installation intended for the thermal treatment of mulberry silkworm cocoons, taking into account the thermotechnical properties of the installation's elements and the external environmental conditions. The results obtained can be applied to improve the quality of cocoon processing and ensure energy efficiency in sericulture production [6].

Materials and Methods. An imitation model of the electrotechnical device system for the thermal treatment of mulberry silkworm cocoons will be developed using the mathematical model of the thermal treatment process, as well as the control algorithm and methods of the device system. For this, we will use the Simulink package in Matlab, which is well-suited for scientifically describing the thermal processes occurring in the device's chamber [7]. First, we will determine the parameter values for each block and element that comprises the model. Table 1 presents the blocks and elements selected in the Matlab Simulink package.

Table 1

Blocks and Elements in the Simulink Package of the MATLAB Program

	Block and Element Name	Block and element symbol	№	Block and Element Name	Block and element symbol
	Constant		**10**	Thermal reference	
	Sum block		**11**	Temperature sensor	

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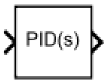
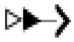
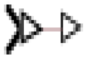
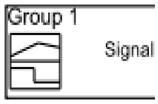
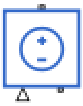
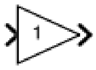
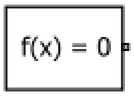
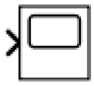
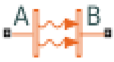
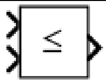
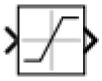
	PID controller		**12**	PS-Simulik converter	
	Simmulik-PS converter		**13**	Signal builder	
	Controlled voltage source		**14**	Gain block	
	Resistor		**15**	Solver configuration	
	Electrical reference		**16**	Scope block	
	Convective heat transfer		**17**	Relational operator	
	Thermal mass		**18**	Saturation block	

1. To maintain the thermal processing temperature for the live cocoons placed in the drum of the insulating chamber of the electro-technical device for thermal processing of mulberry silkworm cocoons, the "Constant" block was selected from the Simulink Sources library. The thermal processing temperature for the live cocoons placed in the drum is set to 95°C.

2. The temperature control within the device's insulation chamber is based on the error principle. Therefore, the system requires a Sum block to calculate the difference between the actually measured temperature and the set temperature. This specific error signal serves as the main input parameter for the PID controller and determines the dynamics of the control process.

3. The temperature change process within the insulation chamber is inherently unpredictable. Therefore, a classic PID controller was selected for temperature regulation in the system. The PID controller manages temperature fluctuations through integral, differential, and proportional actions, ensuring a stable state around 95°C for the thermal processing of silkworm cocoons.

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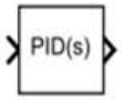
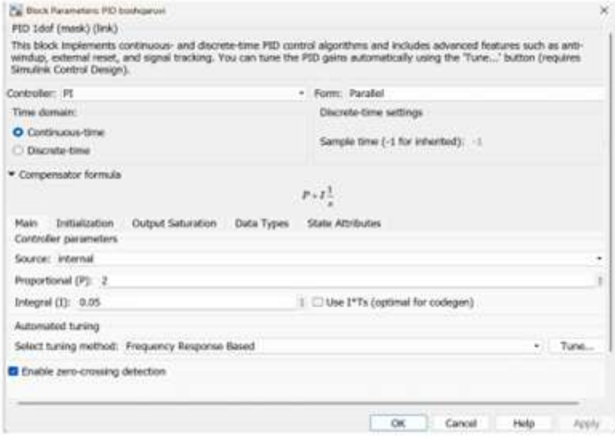


PID controller



4. The output of the PID controller is an abstract control signal that must be converted into physical quantity signals, specifically voltage signals. For this reason, the "Simulink-PS Converter" block was selected, as it enables the conversion of Simulink signals into physical signals.

5. Since the heat supplied to the unit during the thermal processing of the cocoons is also provided by electrical energy, the system requires a controlled voltage source. This unit allows the amount of energy supplied to the heater to be adjusted according to the PID regulator's output. In this way, the temperature is controlled precisely by the electric current.

6. To model the heaters that convert electrical energy into thermal energy, the Resistor block from the Simscape software was chosen. Within the Resistor block, the heating process can be represented according to the Joule-Lenz law: $Q = I^2Rt$. Therefore, this element makes it possible to accurately reflect the heating process inside the device's chamber.

7. In any electrical model, calculation processes are physically meaningless without a common potential point (ground). For this reason, an Electrical Reference is selected as a mandatory element of the calculation to define the initial point of the electrical circuit.

8. Heat transfer within the device's insulation chamber varies depending on humidity. The heat exchange occurs via a convective mechanism, which necessitates the use of convective heat exchange models. The "Convective heat transfer" block models this specific physical process and enables the consideration of humidity's influence.

9. The air within the insulated chamber of the electrical device for thermally processing silkworm cocoons has a specific heat capacity and the ability to store the supplied thermal energy. Consequently, the temperature change inside the chamber does not occur instantaneously but gradually over time, meaning the system possesses thermal inertia. To reflect the real dynamics of the system's temperature changes, the Thermal Mass block was selected.

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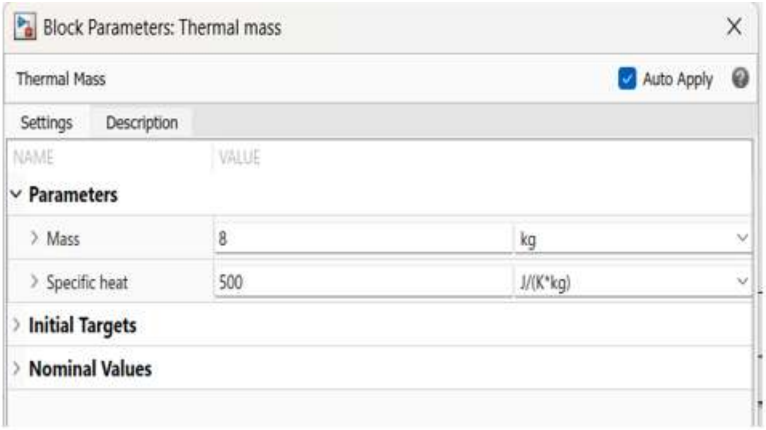
Without this block, the system would not accurately represent the actual dynamics of temperature fluctuations.

10.

Thermal mass



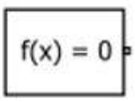
11. The thermal reference block was selected to establish the reference point (zero point) for thermal energy.

12. The selected Temperature sensor feeds the real-time temperature inside the device's chamber back to the system, enabling the operation of the PID regulator.

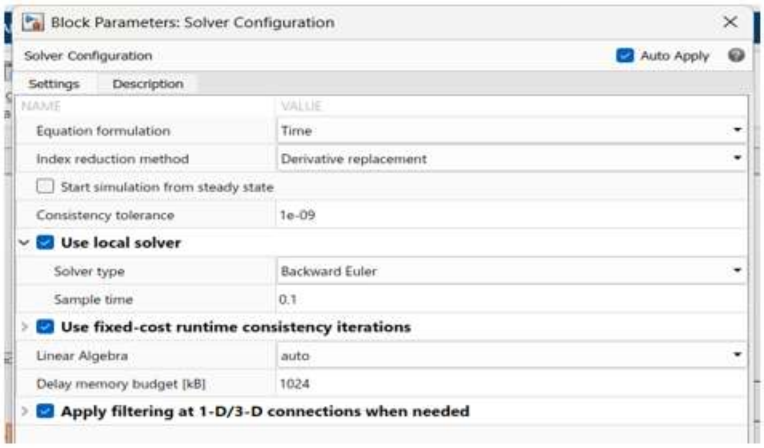
13. The sensor output is in the form of a physical signal. It must be converted to a Simulink signal for it to be processed by the Sum and PID blocks. For this reason, the "PS-Simulink Converter" block was selected.

14. During the thermal processing of cocoons, heat and mass exchange occurs. The release of moisture from the cocoons leads to a decrease in temperature and heat loss inside the device's chamber. To test the system's response to the change in moisture over time, it is necessary to create an artificially variable input signal. The Signal Builder block was used for this purpose.

15. The effect of moisture on the convective heat transfer coefficient is modeled using a linear function. Therefore, the Gain block allows the effect of air humidity to be mathematically incorporated into the control system.



Solver configuration



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16. The system consists of differential, nonlinear equations. A general solver configuration block is required to solve them. Without this block, it is not possible to model the change in temperature over time.

17. Graphical monitoring is necessary to analyze the system's operating dynamics, the PID response characteristics, and thermal inertia. For this purpose, the Scope block was selected.

18. The Relational Operator block performs a crucial control function in the operation of the control system. This block compares the measured temperature or humidity value against specified threshold parameters to generate a logical result.

19. A Saturation block is used to prevent the control signal at the PID controller's output from exceeding the physical limits of the practical system. The Saturation block limits the control signal to the following range: $U_{\min} \leq U(t) \leq U_{\max}$

Where:

$U_{\max}$ — maximum voltage that can be supplied to the heater,

$U_{\min}$ — minimum allowable power rating.

Using the blocks described above, a simulation model for the thermal processing of mulberry silkworm cocoons was created. The simulation model for the thermal processing of mulberry silkworm cocoons is shown in Figure 1.

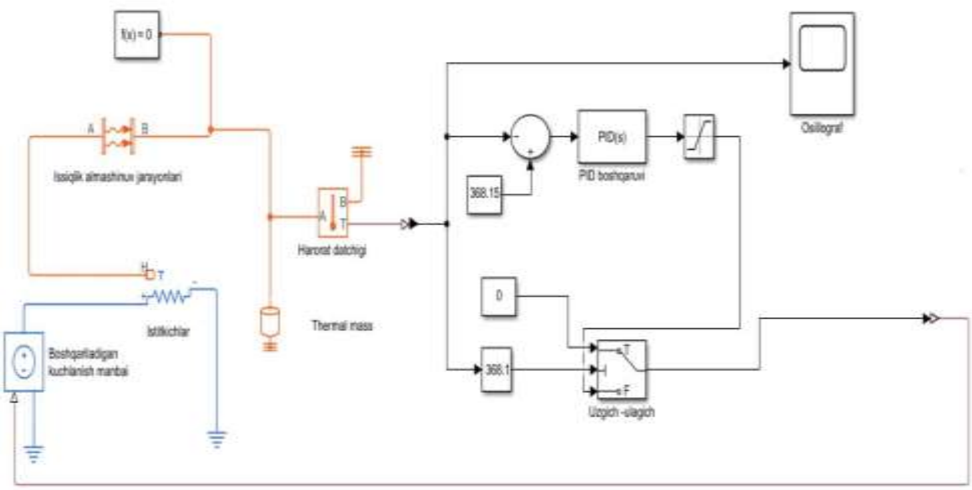

Figure 1. Simulation model of the thermal treatment process for mulberry silkworm cocoons

The Constant block defines the required thermodynamic state within the device's insulation chamber. The thermal processing temperature for the cocoons is set to 95^0 C. This parameter serves as a reference point for the control system.

During the thermal processing, the Temperature Sensor measures the actual temperature inside the device's chamber, and this data is transmitted to the digital control system via the PS-Simulink Converter.

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The summing block calculates the error (difference) between the setpoint and the measured temperature. This value serves as the primary input signal for the control system. The PID Controller generates a control signal by considering the current value of the error, its integrated area, and its rate of change. This regulator prevents oscillations in systems with high thermal inertia and accelerates the attainment of an optimal equilibrium state.The Simulink-PS Converter converts control signals into a physical quantity in the form of voltage. As a result, the control algorithm is adapted for practical temperature control. Based on the PID output, the Controlled Voltage Source controls the electrical energy supplied to the heating element. The Resistor (Heater) generates thermal energy as a result of the controlled voltage. This block functions as the primary heat source inside the vacuum chamber.

The Thermal Mass block represents the thermal capacity of the internal environment, modeling the physical inertia that influences the rate of temperature change. The Convective Heat Transfer block accounts for the effect of heat flow and humidity on thermophysical properties. An increase in humidity leads to a change in the heat transfer coefficient, which in turn indirectly affects the heating process. The Humidity Source (Signal Builder) models the change in humidity over time. Its output is processed through the Gain block and connected to the Convective Heat Transfer block. The Scope and Display blocks reflect the time dynamics of temperature, humidity, and control signals, which allows for an analysis of the system's efficiency. The Solver Configuration block provides a numerical solution for the differential equations across all physical connections and guarantees the model's convergence.

RESEARCH FINDINGS AND ANALYSIS

The dynamic characteristics of the cocoon heat treatment process - specifically, the change in air temperature over time within the device's chamber - were studied. Figure 2 illustrates the temperature change over time inside the chamber of the electrical device used for the heat treatment of mulberry silkworm cocoons.

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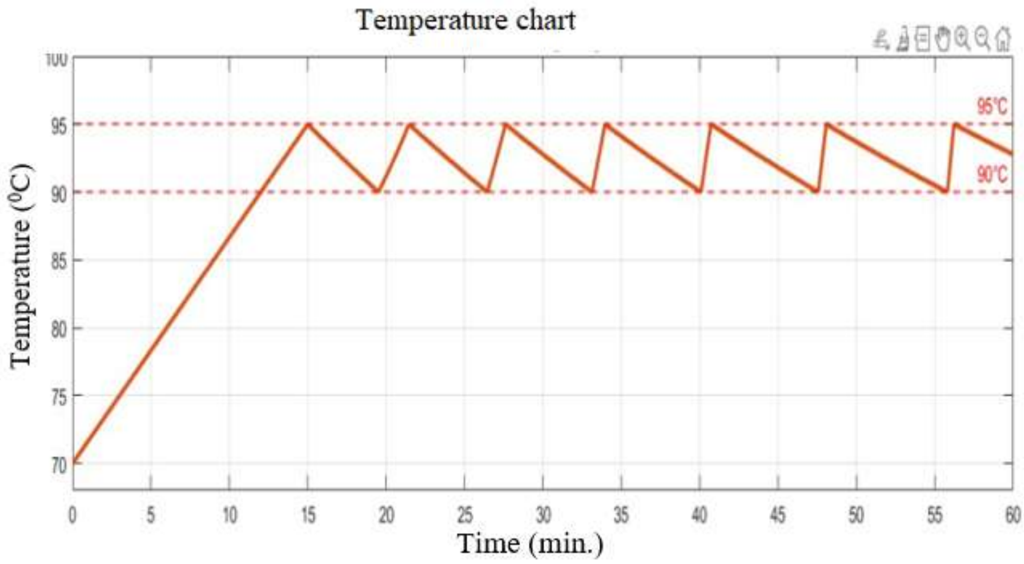

Figure 2. Change in temperature over time within the chamber of the electrotechnical device for thermal processing of mulberry silkworm cocoons.

Energy is consumed to raise the temperature in the device's insulation chamber from 70^0 C to 95^0 C, the established operating mode for the thermal treatment of cocoons. Following this, the process under our investigation begins. According to the developed mathematical model, the energy consumed is 16,079MJ. Theoretically, the amount of heat expended during thermal processing should not be lost. According to the relationship obtained by simulating the process (Fig. 2), the temperature in the device's chamber decreases to 90°C due to heat and mass exchange. Depending on the signal from the thermal sensor, the microcontroller activates the heaters to raise the temperature in the chamber to the set operating temperature, thereby compensating for the lost energy. When the set operating temperature is reached, the microcontroller deactivates the heaters based on the signal from the thermal sensors. As the heat and mass exchange process in the cocoons progresses and its duration shortens, the amount of energy consumed also decreases.

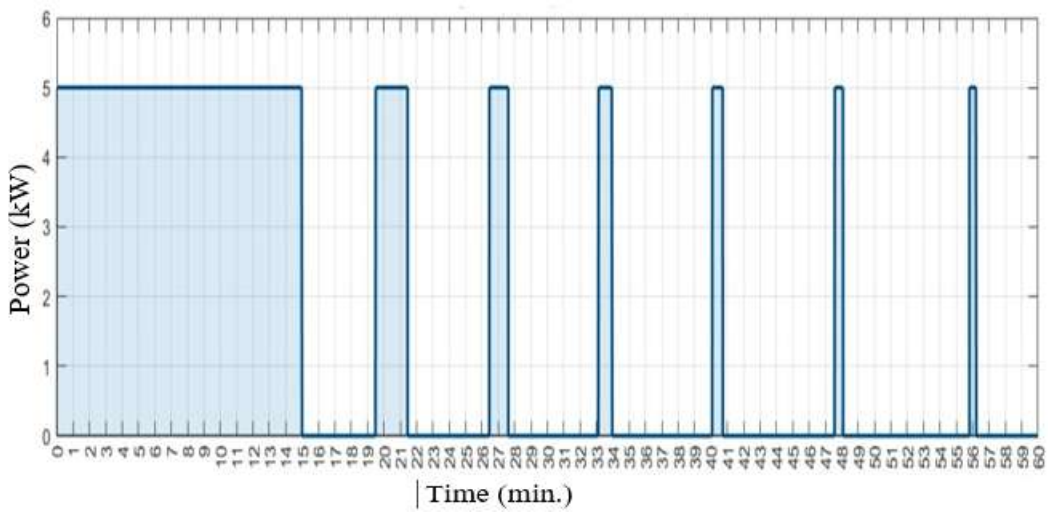

Figure 3. Variation of electricity consumption over time

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Figure 3 illustrates the change over time in the electrical energy consumption of the electrotechnical equipment during the thermal processing of cocoons. The results obtained indicate that the operating time of the heaters is reduced during the thermal processing, which leads to a decrease in energy consumption.

CONCLUSION

A simulation model of the thermal process occurring in the chamber of an electrotechnical device for heat-treating mulberry silkworm cocoons was developed using the Simulink package of the Matlab software.

The dynamics of the air temperature change over time within the device's chamber were determined and analyzed.

The changes in the energy consumption indicators of the electrotechnical device during the cocoon heat treatment process were determined and analyzed over time.

An analysis of the change in electricity consumption over time allowed for an assessment of the device's energy efficiency.

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