ТЕХНИЧЕСКИЕ НАУКИ
И ТЕХНОЛОГИИ

АВТОМАТТАНДЫРУ ЖӘНЕ БАСҚАРУ
АВТОМАТИЗАЦИЯ И УПРАВЛЕНИЕ
AUTOMATION AND CONTROL

DOI 10.51885/1561-4212_2024_1_214
IRSTI 28.23.29

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THERMODYNAMIC MODEL OF STUDYING THE DYNAMICS OF THE TEMPERATURE BALANCE BY CALCULATING HEAT ENERGY IN AGRICULTURAL SECTOR

АУЫЛ ШАРУАШЫЛЫҒЫНДАҒЫ ЖЫЛУ ЭНЕРГИЯСЫ МЕН ТЕМПЕРАТУРА БАЛАНСЫНЫҢ ДИНАМИКАСЫН ЗЕРТТЕУДІҢ ТЕРМОДИНАМИКАЛЫҚ МОДЕЛІ

ТЕРМОДИНАМИЧЕСКАЯ МОДЕЛЬ ИЗУЧЕНИЯ ДИНАМИКИ ТЕМПЕРАТУРНОГО БАЛАНСА С РАСЧЕТОМ ТЕПЛОВОЙ ЭНЕРГИИ В СЕЛЬСКОМ ХОЗЯЙСТВЕ

***Abstract**. This work is the result of the simulation of a thermodynamic model that investigates the dynamics of the temperature balance due to the transfer of thermal energy. A proposed scheme outlines the rheological heat transfer characteristics of an object featuring an insulated surface, along with accompanying graphs illustrating irreversible rheological transformations. The primary equation governing heat exchange, incorporating a chemical reaction, is presented, and the equation dictating the rate of heat energy transfer along the object's length is derived. The subsequent step involves advancing physical-mathematical models to depict the conversion of thermal energy into various states of the object. This advancement aims to facilitate an evaluation of the overall temperature regimen of agricultural entities and optimize the heating procedures. In recent years, the agricultural sector has faced substantial challenges attributed to climate change. Climate change impacts on agriculture encompass elevated temperatures, increased weather variability, shifting agroecosystem boundaries, invasive species, pests, and frequent extreme weather events. These changes possess the potential to disrupt agricultural yields and food security, underscoring the importance of comprehending and managing temperature dynamics within agricultural systems. This research delves into the core of temperature regulation within agricultural objects, employing a thermodynamic model that not only considers heat exchange but also incorporates the influence of chemical reactions. Through the derivation of equations characterizing the speed of heat energy transfer and the development of physical-mathematical models for thermal energy transformation, this study offers* *a robust framework for evaluating and refining the temperature regime of agricultural objects. This research paves the way for further advancements in the comprehension and management of temperature dynamics within agricultural systems. As climate change persists in posing challenges to the sector, the knowledge and models developed here will serve as invaluable tools in optimizing heating procedures, enhancing agricultural resilience, and securing global food production. In summary, this study significantly contributes to our understanding of temperature balance and heat energy transfer within agricultural objects. It represents a crucial stride towards addressing the challenges posed by climate change in agriculture.The suggested thermodynamic model, along with its corresponding equations, lays a robust groundwork for forthcoming investigations and practical implementations. Ultimately, this development stands to enhance the agricultural sector and contribute to global food production.*

***Keywords**: thermodynamic model, thermal thermodynamics, rheological transitions, agriculture, mathematical models.*

***Аңдатпа.** Бұл жұмыс жылу энергиясын беру арқылы температура тепе-теңдігінің динамикасын зерттейтін термодинамикалық модельді модельдеудің нәтижесі болып табылады. Ұсынылған схема оқшауланған беті бар объектінің жылу беруінің реологиялық сипаттамаларын, сондай-ақ қайтымсыз реологиялық өзгерістерді бейнелейтін ілеспе графиктерді сипаттайды. Химиялық реакцияны қамтитын жылу алмасуды реттейтін бастапқы теңдеу ұсынылған және объектінің ұзындығы бойынша жылу энергиясының берілу жылдамдығын анықтайтын теңдеу алынған. Келесі қадам жылу энергиясының объектінің әртүрлі күйлеріне айналуын көрсету үшін физика-математикалық модельдерді жетілдіруді қамтиды. Бұл жетілдіру ауылшаруашылық кәсіпорындарының жалпы температуралық режимін бағалауды жеңілдетуге және жылыту процедураларын оңтайландыруға бағытталған. Соңғы жылдары ауылшаруашылық секторы климаттың өзгеруіне байланысты айтарлықтай қиындықтарға тап болды. Климаттың өзгеруінің ауыл шаруашылығына әсеріне температураның жоғарылауы, ауа-райының құбылмалылығының жоғарылауы, агроэкожүйе шекараларының сысуы, инвазиялық түрлер, зиянкестер және жиі экстремалды ауа райы оқиғалары жатады. Бұл өзгерістер ауылшаруашылық жүйелеріндегі температура динамикасын түсінудің және басқарудың маңыздылығын көрсете отырып, дақылдардың өнімділігі мен азық-түлік қауіпсіздігінің төмендеуіне әкелуі мүмкін. Бұл зерттеу жылу алмасуды ескеріп қана қоймай, химиялық реакциялардың әсерін де қамтитын термодинамикалық модельді қолдана отырып, ауылшаруашылық объектілеріндегі температураны реттеудің мәнін ашады. Жылу энергиясының берілу жылдамдығын сипаттайтын теңдеулерді шығару және жылу энергиясын түрлендірудің физика-математикалық модельдерін әзірлеу арқылы бұл зерттеу ауылшаруашылық нысандарының температуралық режимін бағалау және нақтылау үшін сенімді негіз ұсынады. Бұл зерттеу ауылшаруашылық жүйелеріндегі температура динамикасын түсінуде және басқаруда одан әрі жетістіктерге жол ашады. Климаттың өзгеруі сала үшін қиындықтар туғызуды жалғастыруда, мұнда әзірленген білім мен модельдер жылыту процедураларын оңтайландыру, ауыл шаруашылығының тұрақтылығын арттыру және жаһандық азық-түлік өндірісін қамтамасыз ету үшін баға жетпес құрал ретінде қызмет етеді. Осылайша, бұл зерттеу температуралық тепе-теңдік пен ауылшаруашылық объектілеріндегі жылу энергиясын беру туралы түсінігімізге айтарлықтай үлес қосады. Бұл ауыл шаруашылығындағы климаттың өзгеруіне байланысты мәселелерді шешудегі маңызды қадамды білдіреді.Ұсынылған термодинамикалық модель тиісті теңдеулермен бірге алдағы зерттеулер мен практикалық іске асырудың берік негізін қалады. Сайып келгенде, бұл Даму ауылшаруашылық секторын нығайтады және әлемдік азық-түлік өндірісіне үлес қосады.*

***Түйін сөздер:** термодинамикалық модель, термодинамика, реологиялық ауысулар, ауыл шаруашылығы, математикалық модельдер.*

***Аннотация.** Эта работа является результатом моделирования термодинамической модели, которая исследует динамику температурного баланса за счет передачи тепловой энергии. Предложенная схема описывает реологические характеристики теплопередачи объекта с изолированной поверхностью, а также сопровождающие графики, иллюстрирующие необратимые реологические преобразования. Представлено первичное уравнение, регулирующее теплообмен, включающее химическую реакцию, и выведено уравнение, определяющее скорость передачи тепловой энергии по длине объекта. Следующий шаг включает в себя усовершенствование физико-математических моделей для отображения преобразования тепловой энергии в различные состояния объекта. Это усовершенствование направлено на облегчение оценки общего температурного режима сельскохозяйственных предприятий и оптимизацию процедур обогрева. В последние годы сельскохозяйственный сектор столкнулся со значительными проблемами, связан-*

ными с изменением климата. Последствия изменения климата для сельского хозяйства включают повышение температуры, повышенную изменчивость погоды, смещение границ агроэкосистем, инвазивные виды, вредителей и частые экстремальные погодные явления. Эти изменения потенциально могут привести к снижению урожайности сельскохозяйственных культур и продовольственной безопасности, подчеркивая важность понимания динамики температуры в сельскохозяйственных системах и управления ею. Это исследование раскрывает суть регулирования температуры на сельскохозяйственных объектах, используя термодинамическую модель, которая не только учитывает теплообмен, но и включает влияние химических реакций. Благодаря выводу уравнений, характеризующих скорость передачи тепловой энергии, и разработке физико-математических моделей преобразования тепловой энергии, это исследование предлагает надежную основу для оценки и уточнения температурного режима сельскохозяйственных объектов. Это исследование прокладывает путь к дальнейшим достижениям в понимании динамики температуры в сельскохозяйственных системах и управлении ею. Поскольку изменение климата продолжает создавать проблемы для отрасли, знания и модели, разработанные здесь, послужат бесценными инструментами для оптимизации процедур обогрева, повышения устойчивости сельского хозяйства и обеспечения глобального производства продовольствия. Таким образом, это исследование вносит значительный вклад в наше понимание температурного баланса и передачи тепловой энергии внутри сельскохозяйственных объектов. Это представляет собой важный шаг на пути решения проблем, связанных с изменением климата в сельском хозяйстве. Предложенная термодинамическая модель, наряду с соответствующими уравнениями, закладывает прочную основу для предстоящих исследований и практической реализации. В конечном счете, эта разработка укрепит сельскохозяйственный сектор и внесет вклад в мировое производство продовольствия.

Ключевые слова: *термодинамическая модель, тепловая термодинамика, реологические переходы, сельское хозяйство, математические модели.*

Introduction. Climate change can have varied impacts on agriculture. When temperatures exceed a particular range, the warming trend typically leads to a decline in crop yields due to accelerated crop development, resulting in a reduced overall seed production. Moreover, elevated temperatures negatively affect plants by hindering their capacity to acquire and utilize moisture.

Evaporation from soils accelerates with rising temperatures and increased transpiration, that is, the release of moisture from plant leaves. The combined effect is called evapotranspiration. Because global warming generally leads to increased precipitation, the net effect of higher temperatures on water availability is the result of a "competition" between increased evapotranspiration and increased precipitation. In this competition, evapotranspiration usually wins.

Climate change is a pressing global concern that has far-reaching implications for various sectors, including agriculture. The agricultural industry is particularly vulnerable to the adverse effects of rising temperatures, increased weather variability, and shifting agroecosystem boundaries. These changes can lead to reduced crop yields, disruption of planting and harvesting schedules, the spread of invasive species and pests, and an increased frequency of extreme weather events [1].

In this context, understanding and effectively managing temperature dynamics within agricultural systems have become paramount. Temperature regulation plays a pivotal role in the growth and development of crops and livestock. Moreover, optimizing heating procedures and ensuring agricultural resilience are critical for maintaining global food production and food security.

This research delves into the heart of temperature regulation within agricultural objects, employing a sophisticated thermodynamic model. This model not only considers heat exchange but also accounts for the influence of chemical reactions, which are fundamental in biological systems. By deriving equations characterizing the speed of heat energy transfer and developing physical-mathematical models for thermal energy transformation, this study establishes a robust framework for evaluating and refining the temperature regime of agricultural objects [2].

The findings of this research are poised to make significant contributions to our understanding of temperature balance and heat energy transfer within agricultural settings. As climate change continues to pose challenges to the sector, the knowledge and models developed here will serve as invaluable tools for optimizing heating procedures, enhancing agricultural resilience, and safeguarding global food production.

Hence, the agricultural sector faces direct consequences of climate change, encompassing heightened temperatures, fluctuations in weather patterns, alterations in agroecosystem boundaries, the advent of invasive species and pests, and a rise in the frequency of extreme weather events [3].

Air-heat treatment of agricultural seeds is often used. This is one of the ecological methods of pre-sowing seed treatment, promoting their maturation. Due to this, germination energy increases and the emergence of seedlings accelerates.

The goal of our work is to create a thermodynamic model to study the dynamics of temperature balance due to thermal energy.

Materials and methods. Since the change in temperature is the driving force, it leads, first of all, to a change in the rate of mass transfer and chemical processes in the object.

The processes of heat and matter transfer in seeds are similar. Molecular diffusion corresponds to heat transfer by molecular heat conduction, and convection diffusion corresponds to heat transfer by convection. All theoretical and experimental results obtained in the study of heat exchange processes [4-9] can be directly applied to diffusion processes. The experimental study of heat exchange is complicated by the need to carry out measurements in seeds with a variable temperature. At the same time, the results are affected by the temperature dependence of the physical and chemical constants. In the case of a stationary medium, the fundamental principle governing heat transfer is the Fourier law, which states that the heat flow is directly proportional to the temperature gradient, reflecting either molecular thermal conductivity or thermal conductivity [10]

$$[q] = -\lambda gradT \equiv -\lambda \frac{dT}{dy} \quad (1)$$

Here, q - represents the heat flow, indicating the quantity of heat transferred per unit surface area per unit time. The term grad$T$ - denotes the temperature gradient, while λ - corresponds to the thermal conductivity coefficient.

When the driving force for the movement is a temperature disparity causing heat transfer within the seed, it is classified as free or natural convection [11]. Conversely, if external forces induce the movement, the process is termed forced convection. A more comprehensive description of transport processes is achieved by not segregating molecular flows from convective flows and incorporating mediated velocities of individual components, encompassing both molecular and convective transport. In this context, the law of thermal diffusion in the form of Maxwell-Stefan [9] is derived, and for intricate scenarios, a system of equations incorporating forces of mutual friction is established. In the framework of independent thermal diffusion approximation, it proves convenient to retain the structure of Fourier's laws while augmenting them with convection components that articulate the convection transport linked to the overall movement of matter. If the linear velocity of the latter is represented by v, then the modified Fourier law is expressed as follows [9]

$$q = -\lambda \ grad \ T + c_P \rho v T \quad (2)$$

where *cp* - represents the heat capacity at constant pressure, and ρ - denotes density.

In the heat transfer process, a coefficient of thermal conductivity, denoted as *a*, is introduced. This coefficient is related to the conventional coefficient of thermal conductivity by the ratio

$a = -\lambda/c_P\rho$, where λ is the usual coefficient of thermal conductivity, ρ is density, and *cp* is the heat capacity at constant pressure. The equation for thermal conductivity in a stationary medium is expressed as follows [6]

$$c_P\rho\frac{\partial T}{\partial \theta} = div\ \lambda gradT + q' \quad (3)$$

Where *q'* - represents the density of heat sources, indicating the amount of heat released due to chemical reactions in a unit of volume per unit of time, and *Θ* - denotes the heat transfer time.

If the thermal conductivity coefficient λ can be treated as constant, then equation (3) assumes the following form

$$\frac{\partial T}{\partial \theta} = a\Delta T + \frac{1}{c_P\rho}q' \quad (4)$$

In the presence of convection, equation (4) needs to be augmented with a convection component, represented as $vgradT$, where v is the flow rate. In the context of biochemical processes, the source of heat is the heat released from a chemical reaction, whose key characteristic is the temperature-dependent rate described by the Arrhenius law. Consequently, the density of heat sources is expressed as

$$q' = Qz\ exp\ exp\ (-E/RT_{\mathrm{P}}), \quad (5)$$

In this expression, Q stands for the thermal impact of the reaction, z is a constant, E - represents the activation energy (assumed to be sufficiently high), R - is the universal gas constant, and Tp - denotes the temperature at which the biochemical reaction occurs.

Due to the adopted assumptions, the fundamental equation for heat exchange involving a chemical reaction is derived as follows

$$c_P\rho\frac{\partial T}{\partial \theta} = div(\lambda gradT - c_P\rho vT) + Qz\ exp\ exp\ (-E/RT_{\mathrm{P}}). \quad (6)$$

In a state of equilibrium, the products of a chemical reaction disperse at a constant rate denoted as v_0. In such a scenario, the heat transfer is characterized by the following equation

$$\frac{\partial}{\partial x}\lambda\frac{\partial T}{\partial x} - c_P\rho v_0\frac{\partial T}{\partial \mathrm{x}} + Qz\ exp\ exp\ (-E/RT_{\mathrm{P}})\ = 0, \quad (7)$$

where x - represents the direction of thermal energy propagation.

If we assume that the variation of thermal conductivity with temperature can be neglected (within an acceptable range of temperature changes), equation (7) simplifies and is expressed as

$$a\frac{\partial^2 T}{\partial x^2} - v_0\frac{\partial T}{\partial x} + \frac{Q}{c_P\rho}z\ exp\ exp\ (-E/RT_{\mathrm{P}})\ = 0 \quad (8)$$

Derived from the heat balance equation for the temperature field, we obtain

$$c_P\rho\frac{\partial T}{\partial \theta} = -\frac{\partial q_x}{\partial x}. \quad (9)$$

Let's replace q_x with the following expression

$$q_x = -\lambda\frac{\partial T}{\partial x} - \tau_P\frac{\partial q_x}{\partial \theta}, \quad (10)$$

where $\tau_P = \mathrm{c_P}\rho$ is the time constant of the heat transfer process.

Assuming that λ and τ_{P} are constants, after differentiating with respect to time (*t*), we have

$$\tau_P\frac{\partial^2 T}{\partial \theta^2} + \frac{\partial T}{\partial \theta} - a\frac{\partial^2 T}{\partial x^2} + v_0\frac{\partial \mathrm{T}}{\partial \mathrm{x}} - \frac{Q}{c_P\rho}z\ exp\ exp\ (-E/RT_{\mathrm{P}})\ = 0, \quad (11)$$

Dividing equation (11) by the coefficient of thermal conductivity a, we obtain

$$\tau_P \frac{\partial^2 T}{\partial \theta^2} + \frac{\partial T}{\partial \theta} - \left(a \frac{\partial^2 T}{\partial x^2} - \nu_0 \frac{\partial T}{\partial x} + \frac{Qz}{c_P \rho} exp\ exp\ (-E/RT_P) \right) = 0. \quad (12)$$

If we examine the heat energy transfer process of a seed in a scenario where the seed is within an environment featuring a constant temperature field [4]. Fig. 1 illustrates the seed as a conventional rod surrounded by a uniformly insulated external environment. The non-insulated segment represents a liquid or air serving as a heat source with a temperature of T_0. We'll partition the length of our object into conventional sections (n) of infinitesimal thickness $\Delta x \to 0$.. It is assumed that heat is transferred to each successive section Δx_i only after the preceding one has reached the temperature of the heat source.

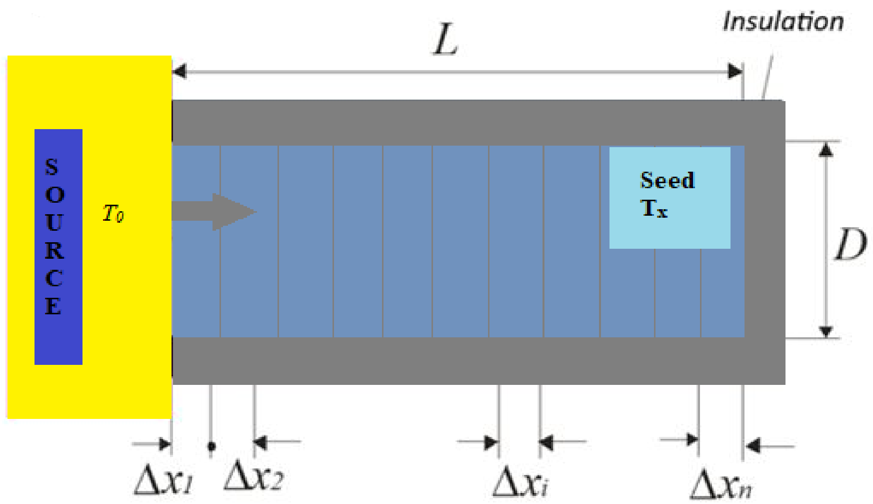

Figure 1. Diagram illustrating the rheological transformation of heat in an object with an insulated surface

Each element of such a body undergoes a process of rheological transformation (heating), which, according to [5], can be described by equation (12). In the initial section $\Delta x \to dx$, there is a rheological transfer of thermal energy from the source to the first section, as shown in Fig. 2, curve 1. This transfer results in the accumulation of heat in the object, causing it to reach a temperature of $T_{xi} = T_0$. The heating process for the section $\Delta x_1 \to dx_1$ is depicted in Fig. 2, curve 2. The Dirac delta function integral pulse represents a rectangle with a width of Δx_1. Given that, according to the problem's conditions, there is no thermal energy flow through the surface, the task of transferring heat and heating the object is symmetrical for each section. Thus, the heat transfer process from the source to section 1 of the object can be described by a differential equation of type (12). The time for the transfer of thermal energy from one section to another (flow time) is denoted as $\Delta t_i = \theta_i - \theta_{i-1}$. When $\Delta t_i \to 0$, we can write [4] that

$$\tau_C \frac{dT_x}{dt} = kT_d(x,\ \theta), \quad (13)$$

where $\tau_C = \Pi L/a$ - is the thermal energy flow time constant; Π - seed perimeter; k - thermal energy transfer coefficient.

Equation (13) delineates the flow of thermal energy along the object. Consequently, under the assumption that ∂θ≈dt, equation (12) can be expressed as [4]

$$\tau_P \frac{\partial^2 T}{\partial \theta^2} + \frac{\partial T}{\partial \theta} - \left(a \frac{\partial^2 T}{\partial x^2} - \nu_0 \frac{\partial T}{\partial x} + \frac{Qz}{c_P \rho} exp\,(-E/RT_P) \right) = \gamma(t), \quad (14)$$

where γ(t) represents the speed of heat energy transfer along the length of the object, which is the flow of heat energy.

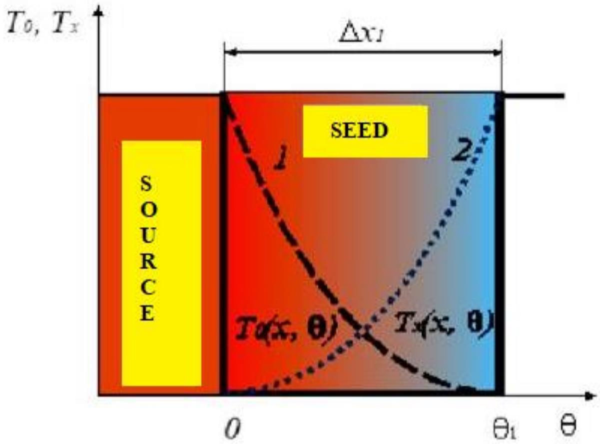

Figure 2. Plots depicting irreversible rheological transformations (designated as curves 1 and 2) alongside the Dirac delta function integral pulse

Biochemical processes taking place in the biological environment are inherently irreversible [12]. As a result, we will introduce a physical model and visually represent graphs depicting Irreversible Rheological Transformations (IRP) to illustrate rheological transitions (see Figure 3).

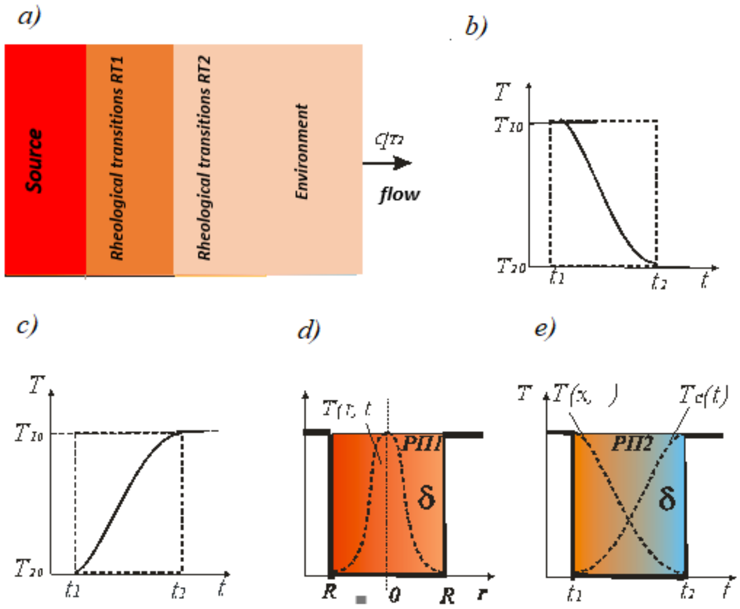

Figure 3. Physical model (a) and IRP plots for rheological transitions; b) graph of the IRP of temperature transfer from the source to the biological object; c) IRP graph of temperature transfer to the core of the environment; d) graph of the δ-function of the integral Dirac momentum for the first rheological transition RT1; e) graph of the integral δ-function of the Dirac momentum for the second rheological transition

RT2

The heat balance equation for the heat energy transfer process in the x direction is formulated as [5]

$$\frac{\partial T(x,\ \theta)}{\partial \theta} = a\frac{\partial^2 T(x,\ \theta)}{\partial x^2} - [\gamma_1(x,\ \theta) + \gamma_2(r,\ t)] \tag{15}$$

Where $\gamma_1(x,\ \theta)$ represents the flow of thermal energy in the direction of the length of the conventional rod, and $\gamma_2(r,\ t)$ is the flow of thermal energy during time *t* in the transverse direction with radius *r*.

The accumulation of heat in the conditional rod, as per the heat balance equation, is performed using the formula

$$\gamma_1(x,\ \theta) = \tau'\frac{d^2T(x,\ \theta)}{d\theta^2} + \frac{dT(x,\ \theta\ )}{d\theta} - k'\frac{dT(r,\ t)}{dt}, \tag{16}$$

where τ' is the time constant of rheological transfer; k' - transmission coefficient; $T(r,t)$ - distribution of temperature by radius r by time t.

The distribution of thermal energy along the radius of a conventional rod can be expressed by the equation [13]

$$\gamma_2(r,\ t) = \tau''\frac{d^2T(r,\ t)}{dt^2} + \frac{dT(r,\ t\ )}{dt} - k''\frac{dT(x,\ \theta)}{dt}, \tag{17}$$

where $\tau''$is the time constant; k''- gear ratio.

Results. The operation of the thermodynamic information processing block is illustrated in Figure 3. In Block 1, control is executed through the LPT1 input/output port. Connected to the computer via the LPT1 port through X1, Block 1 operates in various I/O modes. The DD1 741S245 (555AP6) chip functions as a buffer for transferring data from the port data bus to the device's internal data bus [13]. The DD2 741S374 (555IP23) chip acts as a latch for the DD4 741S138 (555ID7) decoder, facilitating the selection of the required DD5-DD10 latch chip. The DD3 741S257 (555KP11) multiplexer chip transmits the device data bus to the LPT1 X1 port in two passes, organized through the A/B control channel. The selection of channel A or B is determined by transmitting the lower four bits of the data bus D0-D3 with a low-level signal and the higher four bits of the data bus D4-D7 with a high-level signal to channel A/B. The PM1-PM2 micro assembly prevents the high-level voltage from falling below the operating range. The DD5 chip captures information from the internal data bus and concurrently transfers control to the DA1 572PA1A digital-to-analog converter. The DA1 chip influences the signal level from one of the channels of the switching group of the DA5, DA7-DA9 590KN5 chips [14].

In Block 2, the signal passes through the source follower VT1 and enters the amplifier stage (with a gain factor of 10) through the transistor. The cascade mode ensures that the input bipolar signal is shifted to the region of negative voltages necessary for the operation of the ADC DA1. Given the 300 pF input capacitance of the latter, a robust emitter follower on transistor VT3 is connected between the amplifier and the ADC. The DAC DA2 572PA1A from Block 1 is used to adjust the offset of the operating point of transistor VT1, thereby adjusting the constant shift at the emitter of transistor VT3. Resistor RP1 can be utilized to fine-tune the operating point. In the event of overload, transistor VT2 enters limiting mode, and the signal at the ADC input stays within the range of –4 to +1V. Using the DA2 572PA1A DAC from Block 1, the reference voltage for the ADC is regulated, formed by a divider on resistor RP2, R10, an emitter follower on transistor VT4, and varies from –1 to –3V. The digitized information from the ADC is transmitted via the data bus to the buffer DD1 555AP6 chip. The microcircuit is clocked during the writing process to the decryption register of Block 1 by the DD2 signal from port 14P and is then transmitted to Block 2. This device enables the connection of up to 12 measuring transducers for monitoring parameters of the physiological state of plant biosystems, including biopotentials. Subsequently, the received information is processed using a developed program on a PC.

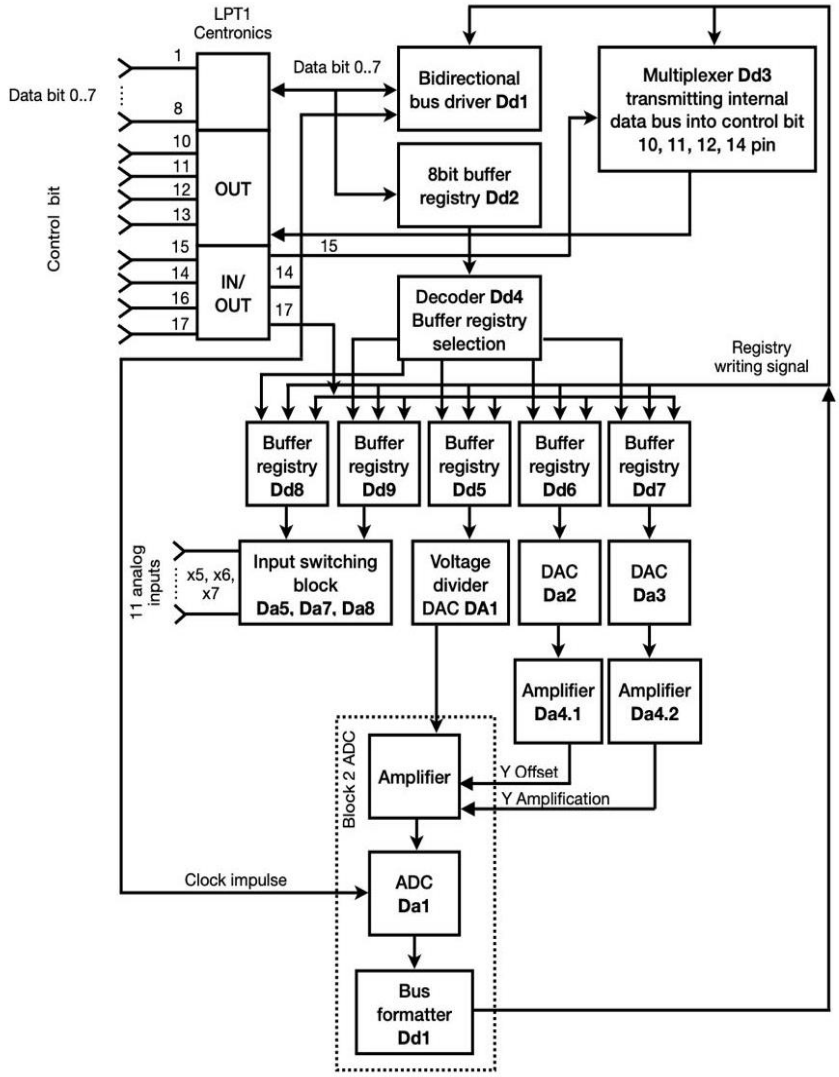

Figure 4. The block diagram of the thermodynamic information processing unit illustrates the functional components and their interconnections within the system

The outcome of developing the experimental algorithm and the class diagram model is the simulation of the experiment, as outlined below:

We conducted an experiment with four containers containing soil and planting material, with three of them subjected to irradiation and one serving as a control sample. The input data include:

- temperature of the environment (*T*);
- irradiation time (*t*);
- irradiation spectrum (*Si*);
- experiment result (*Rex*).

The experiment can be controlled both automatically and manually. The irradiation time has two variants: 12 hours of exposure followed by 12 hours of break, or 24 hours of exposure followed by 24 hours of break. Temperature measurements near the containers are taken every 12 and 24 hours. Three possible radiation spectra are considered [15].

The experiment is deemed complete when stairs (presumably indicating plant growth) appear in any of the containers. The results are documented and stored in the database.

The simulated experiment is outlined in the form of an algorithm (refer to Figure 5). The algorithm encompasses all input and output data, illustrating two operational modes: manual and automatic.

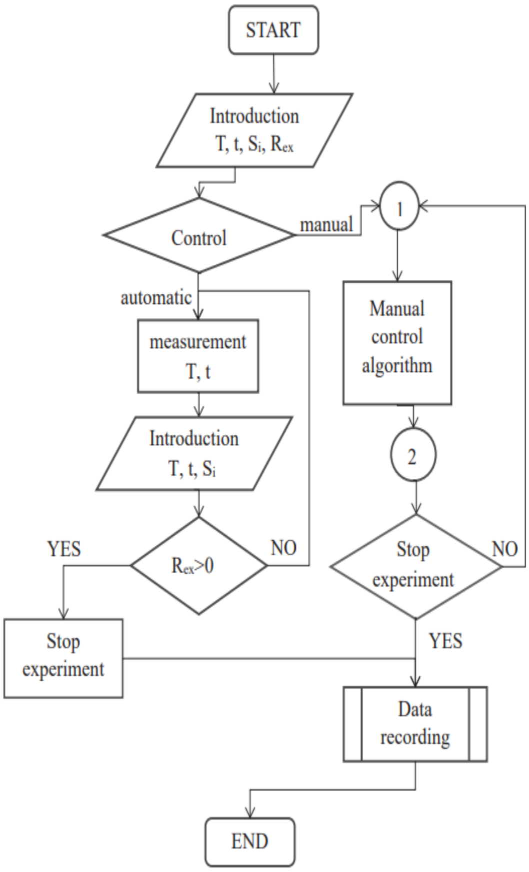

Figure 5. The procedural steps and instructions outlining the future experiment

The experiment's visualization utilized UML, employing a class diagram as depicted in Figure 6. This simulation also utilized a class diagram, illustrated in the same figure. The choice of a class diagram proves advantageous for visualizing the experiment due to several key factors:

- data structure definition: clearly outlining the system's classes (e.g., Container, ExperimentResult), along with their respective attributes and methods.

- representation of relationships: illustrating how classes interact, with the Experiment having aggregation relationships with multiple containers in our specific scenario.

- clear visual representation: providing a graphical representation that enhances comprehension of the system's structure and components for all project stakeholders.

- development support: serving as a valuable reference for developers, offering a foundation for code creation if needed in future development efforts.

By employing the class diagram, we have achieved a more lucid visualization of our experiment. This clarity facilitates analysis, improvement, and the ability to implement changes as required.

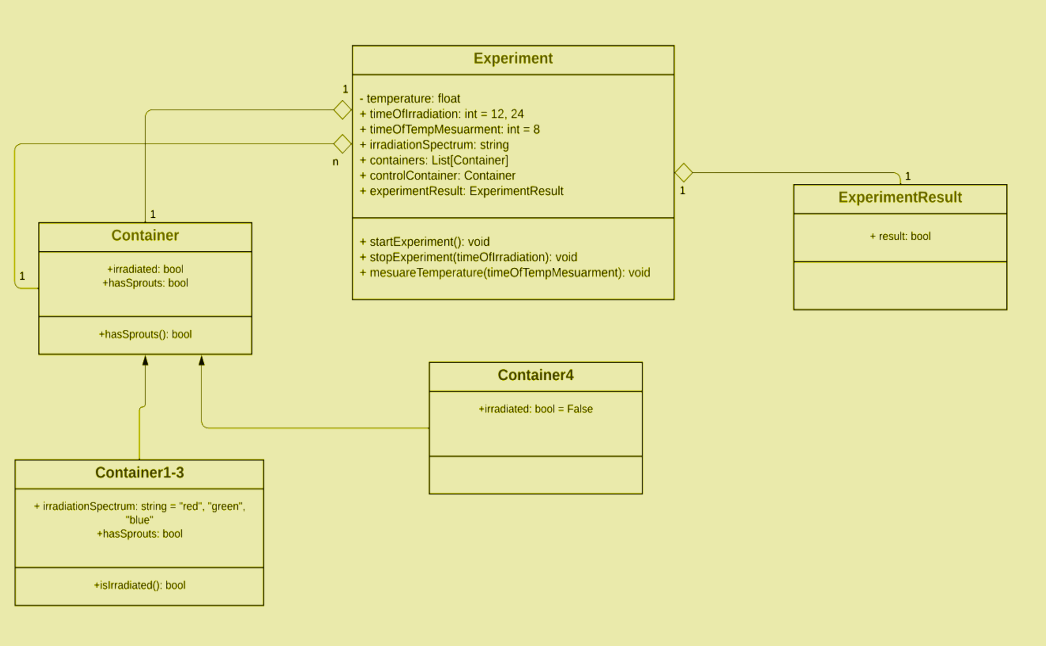

Figure 6. The class diagram of the forthcoming experiment, utilizing specific symbols for access modifiers: "– private" denotes private access, limited to within the class; "+ public" indicates public access, available both inside and outside the class; "# protected" signifies protected access, accessible within the package and its subclasses

The outcome of modeling a thermodynamic system, investigating temperature dynamics resulting from thermal energy transfer, is expressed through equations (11) and (12). These equations serve to evaluate the overall temperature state of a biological object [16]. The nonlinearity observed in the distribution of the temperature field within a biological object allows for the optimization of heating processes, considering both time and thermal radiation power (as indicated in equation (16)). Furthermore, this demonstrates the feasibility of warming a biological organism by dissipating thermal energy.

The mathematical models presented describe the temporal and spatial temperature [17] distribution solely during the transfer of thermal energy through the rheological transition zone (refer to Fig. 2, 3). Currently, thermodynamic processes in a biological object are employed to heat or cool specific elements situated at a distance from the heat source. In practice, the dissipation of thermal energy that has traversed the rheological transition zone during the examination of real processes of energy and mass transfer in the object is effectively utilized.

The implications of our research are profound for the agricultural sector, especially in the context of climate change challenges. Our thermodynamic model offers a powerful tool for optimizing heating procedures, enhancing the resilience of agricultural systems, and ensuring global food production. Farmers and agricultural practitioners can use our findings to fine-tune temperature control measures, ultimately improving crop yields and resource efficiency [18].

Conclusions. The construction of a thermodynamic model for examining temperature balance dynamics was justified, taking into account crucial parameters that contribute to the accuracy and suitability of the model. Exploration of temperature balance dynamics due to thermal energy transfer revealed a nonlinear distribution of the temperature field in a biological object. This nonlinearity allows for the optimization of heating processes in terms of both time and thermal radiation power, as indicated by Equation (16). The mathematical modeling results will aid in the development of an effective, energy-saving, and environmentally friendly technology to enhance greenhouse crop yield and quality. Additionally, technical means for pre-sowing treatment of greenhouse crop seeds with photon radiation are proposed. A block diagram of the thermodynamic information processing unit was designed, offering the capability to connect up to 12 measuring transducers for assessing physiological parameters of plant biosystems. The obtained information is then processed using a developed program on a PC. An experiment conduct algorithm was presented along with a class diagram, providing a clearer visualization of the experiment. This visual representation allows for analysis and improvement, facilitating necessary adjustments as needed.

Acknowledgement: This research has been funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP 19677201).

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