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RESEARCH TO SUBSTANTIATE THE MAIN PARAMETERS AND OPERATING MODES OF THE SOLAR DRYING MODULE AS PART OF A GREENHOUSE FACILITY

Abstract

The use of solar energy and energy-saving technologies has always been relevant. However, in recent years, due to a sharp increase in energy prices (by 2–4 times) and the tightening of environmental regulations, these issues have become especially important.

This article is devoted to the development of a solar drying module integrated into a greenhouse facility for horticultural production, a topic that is both timely and relevant.

The study of the drying process aims to provide a scientific basis for selecting optimal methods and operating modes, as well as determining the necessary formulas and calculation expressions for designing drying units. This paper examines a solar drying module placed in the dome of a greenhouse structure. The main purpose of placing the solar drying module in the upper part of the greenhouse is to eliminate shadowing throughout daylight hours. Since the air inside the greenhouse has high humidity, the drying chamber of the helio-drying module receives air from the atmosphere in a heated form, serving as the drying agent.

The proposed improvement in greenhouse design, achieved by integrating a solar drying module during the summer period-when solar activity is at its peak- offers several advantages. The southern regions of the Republic of Kazakhstan provide favorable conditions for the widespread use of solar energy in greenhouses and drying systems, as they experience high solar activity during summer, as well as spring and autumn.

Theoretical and experimental research has been conducted to justify the key parameters and operating modes of the proposed helio-drying module, which is designed for drying various agricultural crops in the Southeastern regions of Kazakhstan.

Keywords: *greenhouse, solar dryer, solar drying module, humidity, solar energy, drying, convection, heat exchange, heat capacity, enthalpy.*

Introduction

Drying of plant products is a very complex technological process. Drying is a heat and mass transfer process designed to dehydrate various materials and products. The drying process is carried out by supplying heat to the product to be dried. As a result of the heat applied to the product, moisture evaporates. Depending on the type of products, different ways of increasing the efficiency of drying plants are used. The creation of highly efficient drying plants is based on a limited connection of theory, technology and technique of drying. In this direction a great contribution was made by scientists like P.A. Rebinder, D.V. Lykov, A.S. Ginzburg and others.

Known methods of production of dried products have a number of disadvantages. Drying apparatuses for the production of dried products of plant origin, working on liquid or gaseous fuel, are inefficient, because of the high energy costs of installations that affect the cost of production. In addition, when the products of fuel combustion get in, the quality indicators are reduced, reducing the biological value of the products.

Heat treatment of products of plant origin in solar drying plants is more acceptable in conditions where there is a sufficient amount of solar radiation. There are no costs for heat energy production in these units, but the heating of the drying agent (air) is limited due to the temperature conditions of the area. In principle, such temperature is more acceptable for drying of seed material, in which it is necessary to preserve biological indicators of a living organism. In addition, solar-powered drying plants have low productivity due to the low temperature of the drying agent and high material intensity. Therefore, there is no production of solar dryers on an industrial basis [1].

With the advent of more affordable materials in the market, solar dryers for limited volume of production for small and medium-sized farms are becoming profitable. The most promising is the use of solar dryers for producers of vegetable and horticultural products that have greenhouse equipment in their plot. Combination of greenhouse equipment and solar drying module, during the period of preventive maintenance of greenhouses will reduce the cost of the structural part of the solar dryer [2].

By mounting the solar drying module on the supporting part of the greenhouses, it is possible to achieve a more efficient use of solar energy, eliminating the shadow effect of the structure, since the drying module will be located near the dome of the greenhouse [3].

Methods and materials

The main parameters of the drying regime include temperature, air velocity, and humidity. These factors influence both the nature of the drying process and the properties of the material being dried. The drying process is divided into three stages: the initial stage (heating), the first drying period, and the second drying period.

In the initial stage, the temperature of the material rises until it reaches the saturated water vapor temperature. During the first drying period, moisture evaporates in a manner similar to evaporation from an open surface. At this stage, the temperature of the material, the drying agent, and the drying rate remain constant. The intensity of the process is largely determined by the temperature, mode parameters, and the velocity of the drying agent.

In the second drying period, the product temperature gradually increases until it reaches ambient temperature, at which point the drying process is complete. The drying rate decreases progressively and eventually reaches zero when equilibrium is established between the drying agent and the product. The drying intensity is characterized by the moisture flux density, which refers to the amount of moisture evaporating per unit time per unit area of mass transfer.

An increase in air temperature leads to a higher drying rate. According to several researchers, this also enhances the heat transfer coefficient between the material surface and the moist air. However, the temperature increase is limited by the thermal sensitivity of most fruits and vegetables, as excessive heat can cause irreversible changes in the colloidal structure of tissues [4-7]. Additionally, excessive heating can increase heat losses and reduce system efficiency [8].

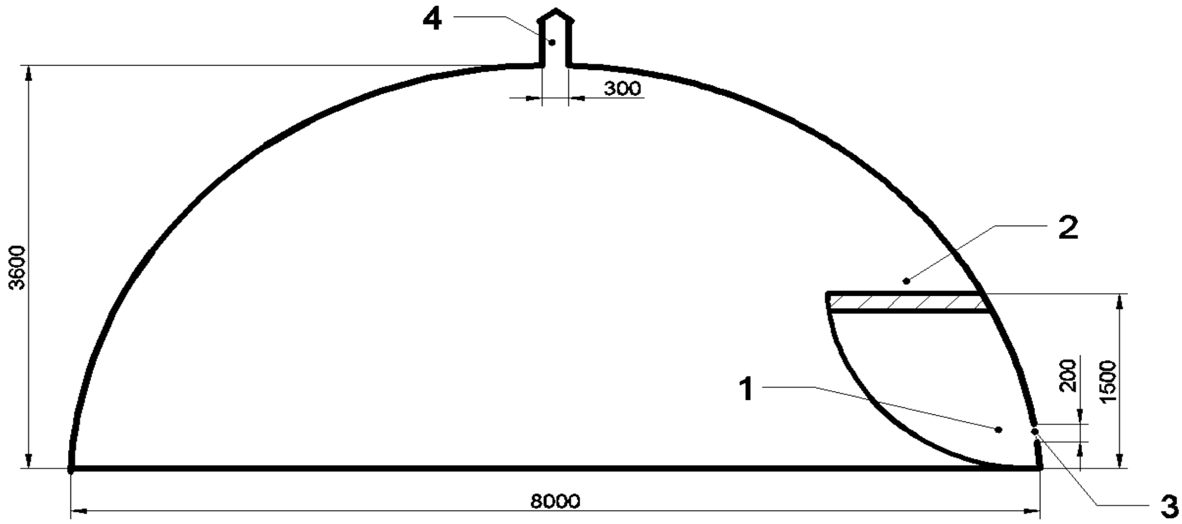
In the system under consideration, elevated temperatures are not present, as such phenomena do not occur when using solar energy as the heat source.

The relative humidity of the drying agent serves as a key parameter that determines the direction of the driving forces of the process.

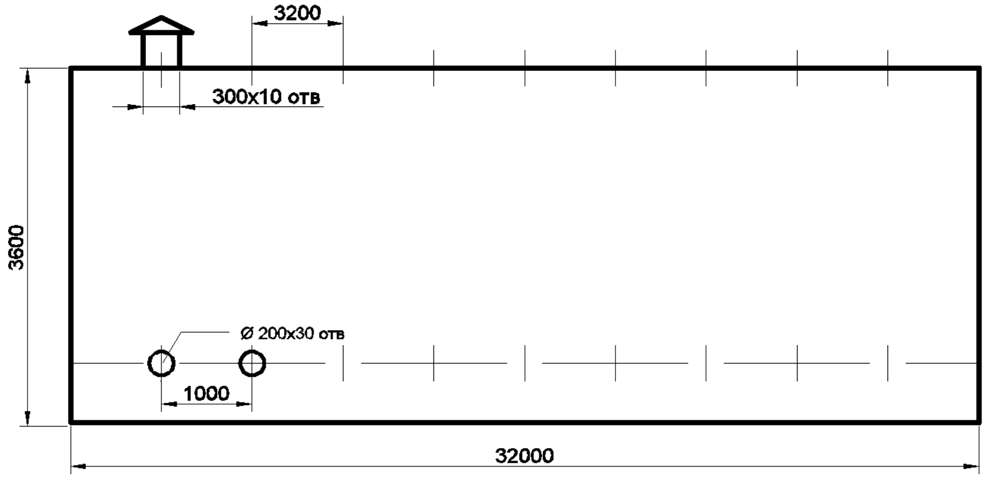
Air velocity is another crucial parameter in the drying process, especially during the first drying period. A high drying agent velocity enhances moisture transfer density, which aligns with Dalton's law.

In the second drying period, the drying rate is primarily influenced by internal heat and mass transfer, which reduces overall energy consumption.

The determination of the parameters for the mixing point of two moist airflows with different characteristics is carried out in accordance with the methodology [9]. Sampling locations for measuring humidity and temperature in the greenhouse facility are shown in Figure 1.



Left view



Top view

Figure 1 - Scheme of measurement points in the research of humidity and temperature in the solar drying module

1 - inlet measuring point; 2 - outlet measuring point; 3 - inlet opening; 4 - outlet opening

Meteometer MES-200 was used to measure air temperature and humidity. Meteometer MES-200 is a modern device that allows simultaneous measurement of all microclimate parameters. This device for monitoring air environment parameters, including atmospheric pressure, relative humidity, air temperature and air velocity, can be used both indoors and in ventilation ducts.

The external appearance of the MES-200 meteometer is shown in Figure 2.

Figure 2 - Meteometer MES-200

When measuring air velocity between 0 and 5 m/s, the temperature inside the touch probe may increase by 2 °C relative to the ambient temperature. The temperature should be measured with a standardized error after 30 minutes after the air velocity measurement [10].

Results and discussion

The obtained results on determination of air temperature and humidity in the solar drying module that are presented in the form of graphs (Figures 3 and 4).

According to the data obtained:

- outside air temperature t_0 = 27^0C;
- temperature of heated air t_1 = 43^0C;
- air temperature after drying t_2 = 29^0C;
- humidity of outside air W_0 = 34,0%;
- humidity of heated air W_0 = 34,2%;
- humidity of air after drying W_0 = 50,5%.

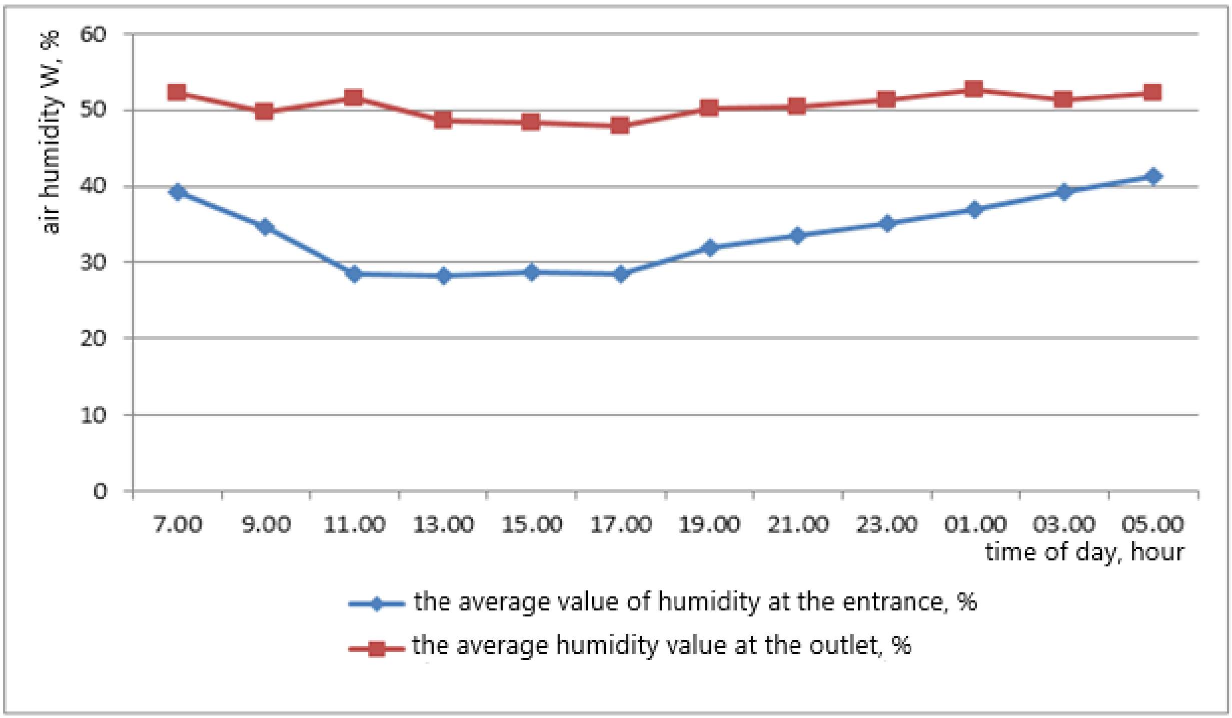


Figure 3 - Variation of air temperature at the inlet (t_1 ^0C) and outlet (t_2 ^0C) of the solar drying module

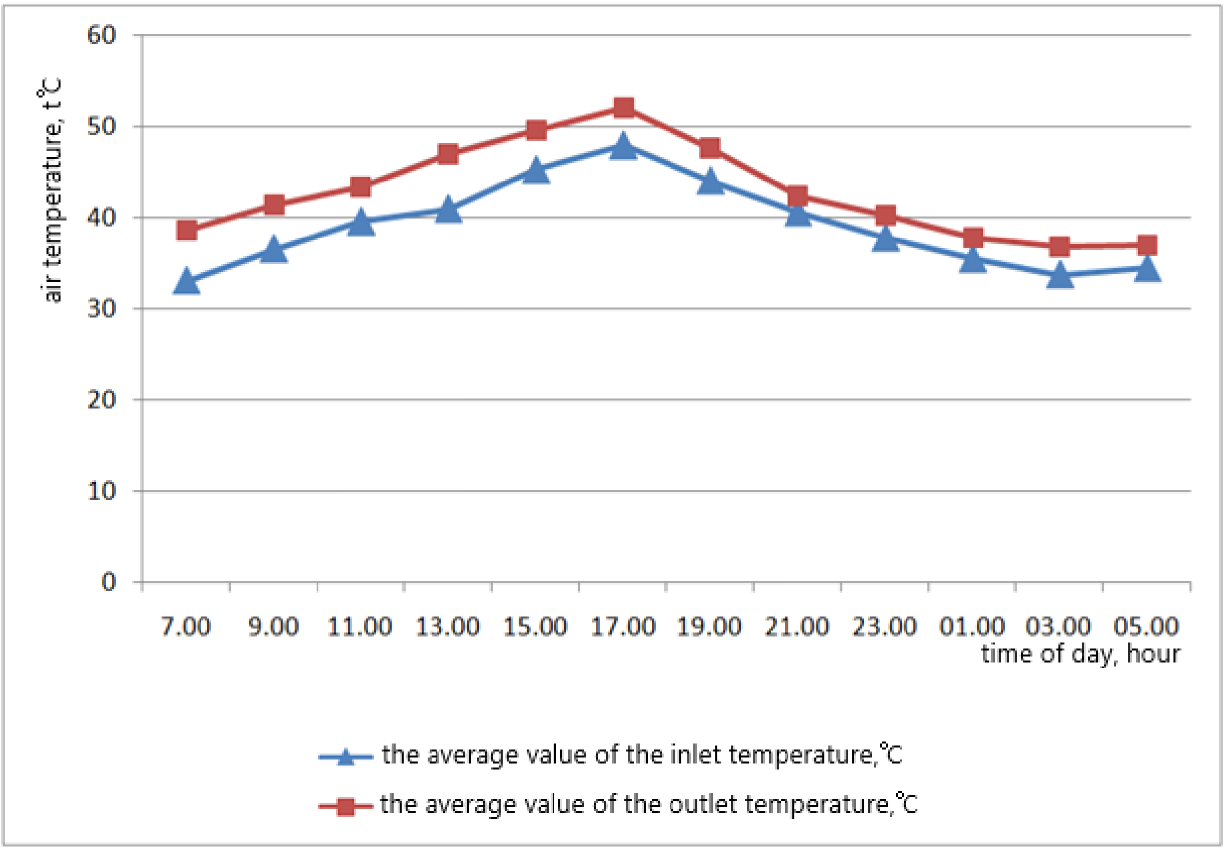


Figure 4 - Change of air humidity at the inlet (W_1,%) and at the outlet (W_2 ,%) of the solar drying module.

Moist material with mass (M_1) at temperature (θ_1) and humidity (W_1) enters the drying chamber. Its parameters after the drying chamber are respectively equal to M_2 θ_2 W_2 (Figure 5).

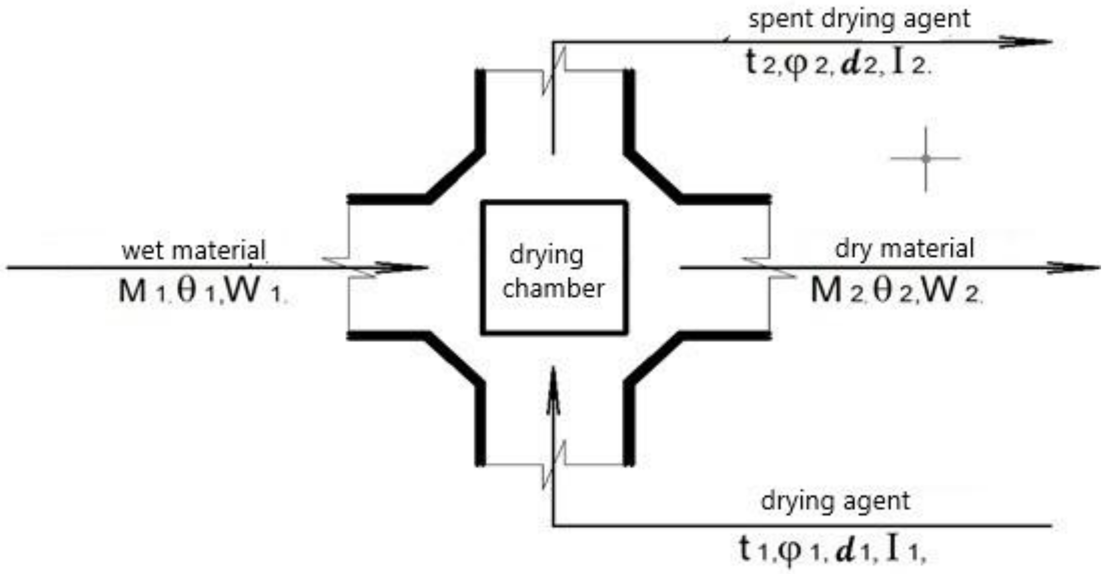


Figure 5 - Schematic diagram of the drying process

The mass of removed moisture in the drying chamber is equal to the difference between the mass of the substance before and after drying.

$$W = \Delta M = M_1 - M_2. \tag{1}$$

During the drying process, the mass of absolutely dry material (M_0) is constant

$$M_0 = M_1 \frac{100 - W_1}{100} = M_2 \frac{100 - W_2}{100} = const. \tag{2}$$

Then the mass of the material after drying can be expressed as follows

$$M_2 = M_1 \frac{100 - W_1}{100 - W_2}. \tag{3}$$

Then using this expression it is possible to find the dependence of removed moisture on the initial mass of the material and humidity

$$W = M_1 - M_1 \frac{100 - W_1}{100 - W_2} = M_1 \frac{W_1 - W_2}{100 - W_2} \tag{4}$$

or on the final mass

$$W = M_2 \frac{100 - W_2}{100 - W_1} - M_2 = M_2 \frac{W_1 - W_2}{100 - W_1}. \tag{5}$$

Moisture balance with regard to moisture content is determined under the steady state drying regime by making an equality between the moisture supplied with the material and with the drying agent and the amount of moisture removed from the drying chamber.

$$M_1\frac{W_1}{100}+L\frac{d_1}{1000}=M_2\frac{W_2}{100}+L\frac{d_2}{1000}\ , \qquad (6)$$

where, L - dry mass of drying agent, kg/s;

d_1 and d_2- moisture content of the drying agent before and after the drying chamber, g/kg of dry air or gas-air mixture.

From equation (6) after transformation it is possible to express the mass of removed moisture

$$L\frac{d_2-d_1}{1000}=\frac{M_1W_1-M_2W_2}{100}=W\ . \qquad (7)$$

From equation (7) the drying agent flow rate is determined.

$$L=\frac{1000W}{d_1-d_2}.$$

Then specific consumption of drying agent per 1 kg of evaporated moisture is as follows

$$l=\frac{L}{W}=\frac{1000}{d_2-d_1}\ . \qquad (8)$$

The heat balance equation is written as follows

$$Q+LH_1+C_\beta\cdot\theta_1W=LH_2\ , \qquad (9)$$

where, H_1 and H_2 - enthalpy of drying agent before and after the drying chamber;

C_β - specific heat capacity of water , kJ/kg^{0}C

Heat consumption is equal to

$$Q=L(H_2-H_1)-C_\beta\cdot\theta_1W\ ,$$

Dividing by the amount of moisture removed, we determine the specific heat consumption

$$g=\frac{Q}{W}=l(H_2-H_1)-C_\beta\theta_1\,.$$

Investigation by experimental method of temperature-humidity regime of solar drying module is reduced to the construction of the actual drying process in *I* - *d* diagram. As it is noted in the actual drying process enthalpy of the drying agent during the period of moisture removal from the material at the beginning and at the end are not equal ($I_1 \neq I_2$) [11], but differs by the value *Δ*.

As a result of *I* - *d* diagram construction, the initial (d_1) and final moisture content of air is determined and the difference of which (*Δ*d) shows the amount of moisture removed from the raw material. As a result, the amount of air and the duration of the drying process for a given volume of material is determined.

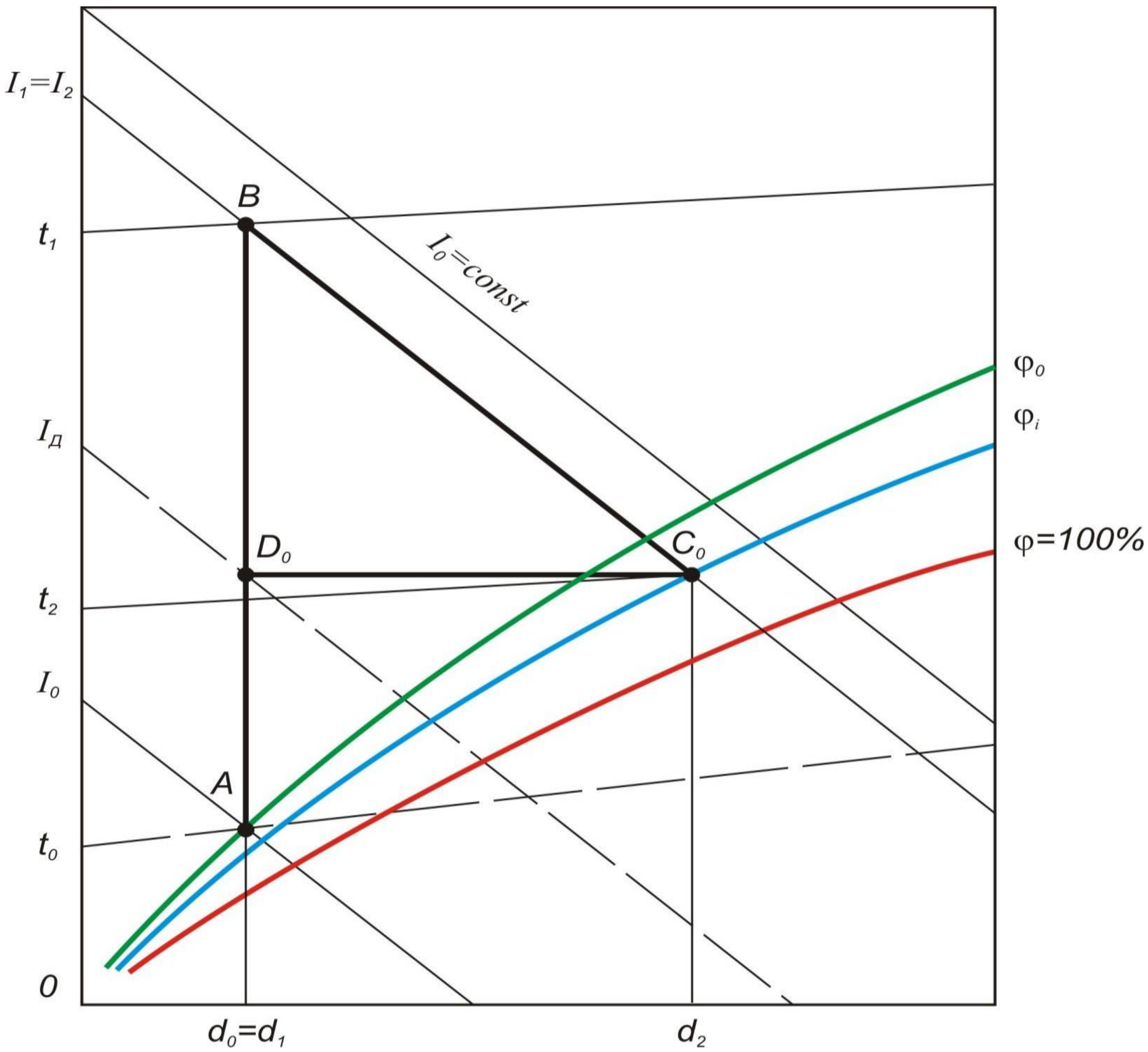


Figure 6 – Scheme of theoretical drying in *I – d* diagram

The diagram was constructed as follows (Figure 6). Parameters of heated air - drying agent (point B) with parameters t_1, $d_1 = d_0$, I_1 enters the chamber, assimilates moisture from the material and with parameters t_2, d_2, I_2, $φ_2$ (point C) is exhausted by the exhaust device into the atmosphere.

Outdoor air with parameters t_0, d_0, I_0, $φ_0$,, which corresponds to point A. When the air is heated without moisture to temperature t1, its moisture content does not change ($d_0 = d_1$). Consequently, heating of the outside air goes I - d diagram vertically upward along the line of constant moisture content up to the intersection with the isotherm t_1. At the intersection of these lines we obtain point B. The parameters of point B will be t_1, $d_1 = d_0$, I_1 respectively, since φ in this region is insignificant (i.e. up to 5%) it is not shown for point B.

According to the definition of the relative humidity of the drying agent, at the intersection of the iso enthalpy line drawn from point B and φ = 100% lies the point characterizing the maximum ability of the drying agent to retain water vapor.

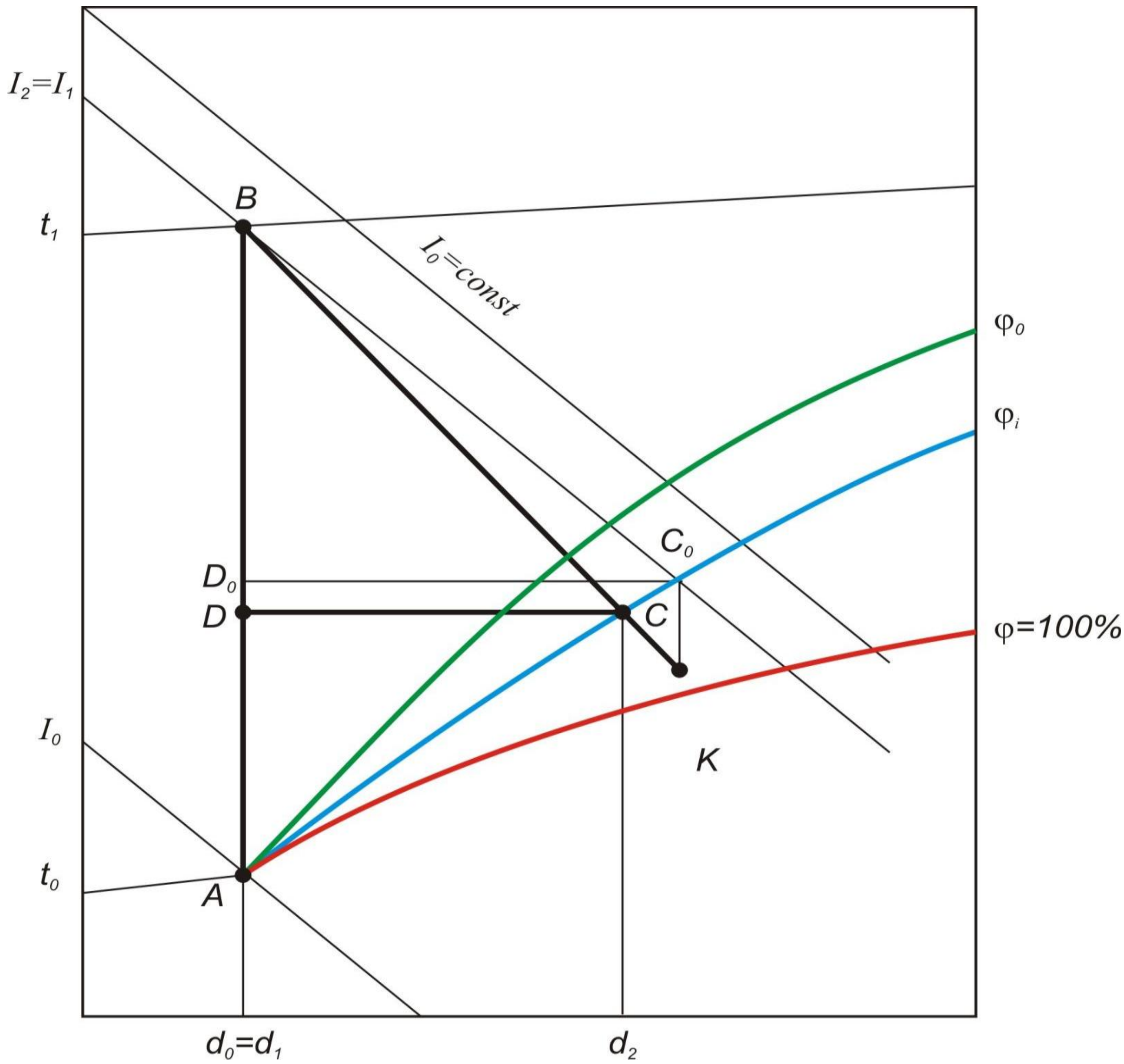


Figure 7 - Schematic of the actual drying process in the *I* - *d* diagram

Consequently, the line BC_0 of the theoretical dryer characterizes the work of the drying agent in assimilating moisture from the material. The drying agent working in the chamber of the solar drying module increases its moisture content from $d_0 = d_1$ t_o d_2. If draw a line from the point C_0 parallel to the axis d_1 up to the intersection with the line AB and find the point D_0. The line C_0D_0 in the scale I - d of the diagram expresses the difference of moisture content $d_2 – d_0$.

In the diagram of the actual process, the theoretical process is also repeated and denoted by the same letters ABC_0D_0 (Figure 7). Next, we find the segment, postponing from the point C_0, at which the polytropic of the process will pass below the isoenthalp of the theoretical process. This segment is labeled as C_0K or in the scale of the diagram $C_0K \cdot \mu_i$. This segment is numerically equal to the difference $V_1 – I_2$. From point B through point K we draw the polytropic of the actual process. The physical meaning of the polytropic BK is the work of the drying agent on moisture assimilation taking into account the calculated losses real for a given solar drying module. At the intersection of polytroph BK with the line φ = 50,5% of the theoretical dryer we will find the point C, characterizing the parameters of the spent drying agent. Further, also by analogy of the theoretical process a line is drawn from point C parallel to the axis d1 and at the intersection with the segment AB point D is obtained.

Thus, for preparation of the drying agent the amount of heat equal to the segment $AB \cdot \mu_i$ is consumed. This drying agent assimilates moisture (segment BC), the amount of which is characterized by the segment CD·μ_d. Hence, by analogy with the theoretical process, the specific flow rate of the drying agent td in the actual process was [11, p.21].

$$t_d = \frac{1000}{CD \cdot \mu_d} \quad (10)$$

Specific heat consumption in the actual process [11, p.143]

$$q_d = 1000 \cdot (\frac{\mu_i}{\mu_d}) \cdot (\frac{AB}{CD}) = \frac{AB}{CD} \cdot m \quad (11)$$

where, $m = 1000 \cdot (\frac{\mu_i}{\mu_d})$ – is the scale factor I - d of the diagram.

Conclusion

The drying process in the solar drying module is described by a mathematical model according to formula (3). The most significant factor influencing moisture reduction is the thickness of the slices. Based on drying dynamics, the optimal temperature range for the drying agent is 40–45°C.

When using the *I - d* diagram the main process parameters looked as follows: outside air temperature - 27^{0}C; heated air temperature - 43^{0}C; air temperature after drying - 29^{0}C; air humidity at the inlet and outlet, respectively - 34% and 50, 52%. Additionally, the moisture content difference (Δd) was approximately 4 g/kg.

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ЖЫЛЫЖАЙ ҚҰРАМЫНДАҒЫ ГЕЛИОКЕПТІРГІШ МОДУЛІНІҢ НЕГІЗГІ ПАРАМЕТРЛЕРІ МЕН ЖҰМЫС РЕЖИМДЕРІН НЕГІЗДЕУ БОЙЫНША ЗЕРТТЕУЛЕР

Аңдатпа

Күн энергиясын пайдалану және энергияны үнемдеу барлық уақытта өзекті болды, бірақ қазіргі уақытта энергия бағалары 2-4 есе өсіп, экологиялық талаптар күшейтілген кезде қажет болып отыр. Жеміс-көкөніс өнімдерін өндіруге арналған жылыжай құрылымының құрамында гелиокептіру модулін жасауға арналған мақала өзекті болып табылады.

Кептіру процесін зерттеу - процестің ұтымды әдістері мен оңтайлы режимдерін, сондай-ақ кептіру қондырғыларын жобалау және есептеу үшін қажетті формулалар мен теңдеулер таңдауды ғылыми негіздеу мақсатында жүргізіледі. Бұл жұмыста жылыжай құрылымының жоғарғы жағында орналастырылған гелиокептіру модулі қарастырылады. Құрылымның жоғарғы жағында гелиокептіру модулін орналастырудың мақсаты күндізгі уақытта көлеңкелі әсерді болдырмау болып табылады. Жылыжайдың ішінде ауаның ылғалдылығы жоғары болғандықтан, гелиокептіру модулін камерасына кептіргіш түріндегі ауа құрылымнан ыстық түрде шығады.

Күн энергиясы шегіне жеткен жаз мезгілінде жылыжай құрылымының гелиокептіру модулімен біріктіру арқылы белгілі бір артықшылықтарға жетуге болады. Қазақстан Республикасының оңтүстік өңірлері жылыжайларда және кептіру құрылғыларында күн энергиясын кеңінен қолдану үшін қолайлы мүмкіндіктерге ие. Бұл жазғы және көктемгі-күзгі уақыттарда күн белсенділігінің жоғары болуына ықпал етеді.

Қазақстанның оңтүстік-шығысында әртүрлі ауылшаруашылығы дақылдарын кептіруге арналған ұсынылатын гелиокептіргіш модулінің негізгі параметрлері мен жұмыс режимдерін негіздеу бойынша теориялық және эксперименттік зерттеулер жүргізілді.

Кілт сөздер: жылыжай, гелиокептіргіш, гелиокептіргіш модуль, ылғалдылық, күн энергиясы, кептіру, конвекция, жылу алмасу, жылу сыйымдылығы, энтальпия.

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ИССЛЕДОВАНИЯ ПО ОБОСНОВАНИЮ ОСНОВНЫХ ПАРАМЕТРОВ И РЕЖИМОВ РАБОТЫ ГЕЛИОСУШИЛЬНОГО МОДУЛЯ В СОСТАВЕ ТЕПЛИЧНОГО СООРУЖЕНИЯ

Аннотация

Использование солнечной энергии и энергосбережение было актуальным во все времена, однако стало более востребованной в настоящее время, когда возросли цены на энергоносители в 2-4 раза и ужесточились экологические требования. Статья, посвященная к разработке гелиосушильного модуля в составе тепличного сооружения для производства плодоовощной продукции, является своевременной и актуальной.

Исследование процесса сушки проводится с целью научного обоснования выбора рациональных методов и оптимальных режимов процесса, а также необходимых формул или выражений для проектирования и расчета сушильных установок. В данной работе рассматривается гелиосушильный модуль, расмещенный в куполе тепличного сооружения. Цель размещения гелиосушильного модуля в верхней части сооружения заключается в исключении теневого эффекта в течение светового дня. Поскольку внутри теплицы воздух имеет высокую влажность в камеру гелиосушильного модуля, воздух в виде сушильного агента поступает из атмосферы в горячем виде.

Предлагаемое усовершенствование конструкции тепличного сооружения путем совмещения с гелиосушильным модулем в летний период, когда солнечная энергия достигает своего пика, будет иметь определенные преимущества. Южные регионы Республики Казахстан, имеют благоприятные возможности для широкого применения солнечной энергии в теплицах и сушильных устройствах. Этому способствует с достаточно высокой солнечной активностью в летнее и весенне-осеннее время.

Проведены теоретические и экспериментальные исследования по обоснованию основных параметров и режимов работы предлагаемого гелиосушильного модуля для сушки различных сельскохозяйственных культур в условиях юго-востока Казахстана.

Ключевые слова: теплица, гелиосушилка, гелиосушильный модуль, влажность, солнечная энергия, сушка, конвекция, теплообмен, теплоемкость, энтальпия.

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ОБОСНОВАНИЕ ПАРАМЕТРОВ МАЛОГАБАРИТНОГО РАЗДАТЧИКА-СМЕСИТЕЛЯ КОРМОВ

Аннотация

В статье представлены результаты теоретических и экспериментальных исследований, направленных на обоснование параметров малоразмерного раздатчика-смесителя кормов. Теоретические исследования позволили разработать аналитические выражения для определения производительности выгрузки кормосмеси и расчета массы выгружаемого корма на одном метре кормового стола. Эти выражения являются основой для оптимизации работы устройства.

В ходе эксперимента были получены данные о таких параметрах, как частота вращения горизонтального шнека, продолжительность процесса смешивания, площадь выгрузного окна, а также степень равномерности распределения кормосмеси по длине кормового стола

При этом оптимальная частота вращения горизонтального шнека составила 26 мин$^{-1}$, что обеспечило стабильную и эффективную работу устройства. Время смешивания для овец было определено в пределах 3–5 минут, а для крупного рогатого скота (КРС) — 8–9 минут, что способствовало лучшему качеству кормосмеси. Однородность выгрузки корма по длине кормового стола составила 92,4%, что является важным показателем равномерности кормления животных. Полученные результаты позволяют рекомендовать данные параметры для улучшения эффективности работы раздатчиков-смесителей кормов в