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MODELING OF HEAT-PHYSICAL PROCESSES IN SOLAR DRYERS

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Abstract – In this article, the process of a solar drying installation is described thermophysical characteristics and their design formulas in the possibility of an algorithm of mathematical modeling.

Keywords: Solar dryer, physical process, mathematical model, heat balance equation, temperature, moist air.

I.Introduction

A sharp increase in energy demand will lead to the use of alternative energy sources. The relatively low efficiency of power plants operating with such energy sources complicates their use. The growing population of the world is also leading to an increase in demand for dried food products. The role of solar dryers in the uninterrupted supply of dried food to the population is invaluable.

Solar dryers mainly consist of a transparent layer, air circulation openings, space for the product to be dried and walls. The working principle of the dryer is that sunlight passes through a transparent layer and is absorbed by the indoor air as well as the drying elements. The absorbed energy is converted into heat. The dryer temperature is formed due to this energy. An inflow of low-temperature air from the lower slits of the device enters the dryer; the temperature rises and at the same time evaporates the moisture of the product intended for drying from the upper slits.

II.Literature review

Research in the field of design and improvement of solar dryers has been conducted by many scientists. So far, no perfect devices have been created among the solar dryers created. There are some devices whose performance has improved due to the design. There is no single device that combines the performance of all the devices created. There is a need for such devices today. Fruits and vegetables grown in Uzbekistan are distinguished by their unique taste. Therefore, the similarity of dried fruits and dried vegetables made from them is not found in the world market. Therefore, such products are in great demand in the world market.

III.Analysis

The development of effective solar fruit dryers and its implementation requires the study of heat-mass exchange, thermal-physical processes that occur during the drying of fruits. Determining the construction mode of each fruit dried in dryers, the study of construction kinetics, technological processes related to the quality of dried fruits is one of the current tasks. The quality and appearance of the dried product (moisture-heat regime of the dryer) depends not only on the drying modes of the fruit, but also on the technology of pre-treatment and drying of the fruit before drying.

In the mathematical modeling of the thermal regime of solar dryers, we write the heat balance equations for each element of the system under consideration (Figure 1):

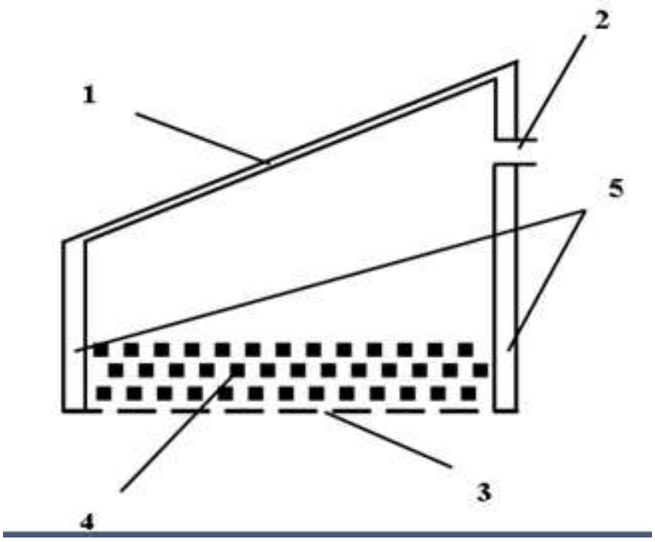

Figure 1. General view of the solar dryer:

1-transparent glass; 2,3-air circulation hole; 4-space for drying product; 5-side walls
- for the amount of water in the product placed in the device

$$h_{af}(T_a - T_f) = h_{fc}(T_f - T_c) \quad (1)$$

- for air inside the dryer

$$(h_{cc} + h_{ec}) \cdot (T_c - T_{ch}) \cdot A_p = h_s \cdot A_s \cdot (T_{ch} - T_a) + C_d \cdot A_V \cdot \sqrt{2 \cdot g \cdot \Delta H} \cdot \Delta P \quad (2)$$

In this, $$\Delta P = [P(T_{ch}) - \gamma P(T_a)] \quad (3)$$

$$\Delta H = \frac{\Delta P}{\rho_a g} \quad (4)$$

- for products intended for drying

$$M_c \cdot C_c \cdot \frac{dT_c}{dt} + h_{cc} \cdot A_p \cdot (T_c - T_{ch}) + h_{ec} \cdot A_p \cdot (T_c - T_{ch}) = h_{fc} \cdot A_p \cdot (T_f - T_c) + \tau \cdot \alpha \cdot I_T \cdot F_c \quad (5)$$

The parameters and sizes given in the above equation and in the thermal scheme of the device in Figure 2 are:
h_{fc}- coefficient of convective heat exchange of products relative to each other;
h_{cc} - the coefficient of heat exchange between the air inside the box and the product;
h_{fa}- the coefficient of heat exchange of the fruit with the environment;
h_{ec}- heat transfer coefficient by evaporation;
Cd-diffusion coefficient;
A_v-crack surface;
A_s- surface of side walls;
ΔP- the difference in pressure inside and around the device;
ΔH- distance between holes;
C_c-specific heat capacity of the product;

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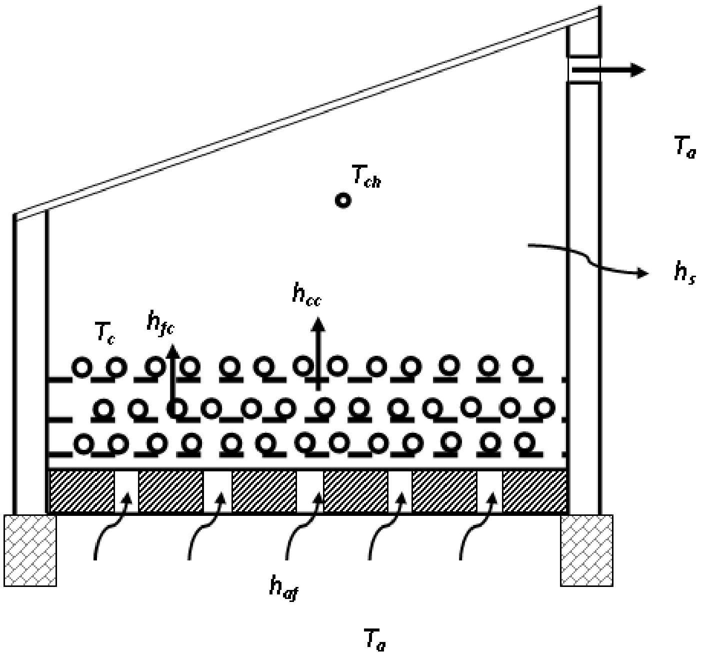

Figure 2. Thermal scheme of the device

We bring the given equations to differential schemes:

From expression (1) T_f is found:

$$T_f = \frac{h_{af}T_a}{h_{af}+h_{fc}} + \frac{h_{fc}T_c}{h_{af}+h_{fc}} \tag{6}$$

From expression(2) we find T_{ch}

$$T_{ch} = \frac{h_{cc}T_cA_p + h_{ec}T_cA_p + h_sA_sT_a - C_dA_v\sqrt{2g\Delta H}\Delta P}{h_sA_s + h_{cc}A_p + h_{ec}A_p} \tag{7}$$

(7)The notation is added to the equation:

$$h_{cc}A_p + h_{ec}A_p = B \tag{8}$$

Once the notation is introduced, Equation (7) looks like this:

$$T_{ch} = \frac{BT_c + h_sA_sT_a - C_dA_v\sqrt{2g\Delta H}\Delta P}{h_sA_s + B} \tag{9}$$

Equations (9) and (6) are expressed in (5):

$$M_cC_c\frac{dT_c}{dt} = h_{fc}A_pT_f - (h_{fc}A_p + h_{cc}A_p + h_{ec}A_p)T_c + (h_{cc}A_p + h_{ec}A_p)T_{ch} + \tau\alpha \cdot I_TA_c \tag{10}$$

$$M_cC_c\frac{dT_c}{dt} = \frac{h_{af}h_{fc}A_p}{h_{af}+h_{fc}}T_a + \frac{h_{fc}{}^2A_p}{h_{af}+h_{fc}}T_c - (h_{fc}A_p + B)T_c + \\ + \frac{T_cB^2 + h_sA_sT_aB - C_dA_v\sqrt{2g\Delta H}\Delta PB}{h_sA_s + B} + \tau\alpha \cdot I_TA_c \tag{11}$$

We differentiate the last equation and determine $T_c^{\tau+\Delta\tau}$:

$$T_c^{\tau+\Delta\tau}=\frac{T_c^{\tau}+\dfrac{\left(\dfrac{h_{af}h_{fc}A_p}{h_{af}+h_{fc}}+\dfrac{h_sA_sB}{h_sA_s+B}\right)\cdot\Delta t}{M_cC_c}\cdot T_a-\dfrac{C_dA_v\sqrt{2g\Delta H}\Delta P\Delta t}{M_cC_c(h_sA_s+B)}+\dfrac{\tau\alpha I_TA_c\Delta t}{M_cC_c}}{1-\dfrac{\left(\dfrac{h_{fc}^2A_p}{h_{af}+h_{fc}}-h_{fc}-B-\dfrac{B^2}{h_sA_s+B}\right)\cdot\Delta t}{M_cC_c}} \quad (12)$$

From expression (12) the change in temperature of the product during the day is determined. It can be seen from the expression that the temperature of the fruit placed inside the device depends on the ambient temperature, the heat of the falling solar radiation, and a number of other parameters [3].

IV.Discussion

Currently, research on the reuse of drying agent (air) used in solar dryers to increase the efficiency of dryers is becoming increasingly important.

It is known that in the initial stage of drying fruits in the recirculation mode, if moist air is not expelled from the drying chamber in time, it leads to saturation of air in the construction chamber, which adversely affects the construction process. Also, the continuous removal of moist air from the chamber leads to a decrease in the air temperature in the dryer and heat loss. Therefore, the modeling of processes such as changes in the vapor concentration inside the chamber, temperature-humidity regime, as well as heat-mass transfer, as well as the study of physical processes occurring in the construction chamber are of scientific and practical importance [3], [4].

Suppose the transparent surface of a solar dryer of a certain size is facing south. Let the mass of dried fruit in the dryer be equal to *M*. Once the solar radiation passes through the transparent surface of the dryer, it is absorbed into the walls of the fruit and dryer and converted into heat radiation. A certain amount of heat escapes to the environment through the transparent surface of the dryer and the outlet window.

In developing a mathematical model of the physical processes that take place during the drying of fruits in the dryer, we used the following assumptions:

1. The temperature is the same at all points in the drying chamber.
2. The pressure in the dryer is equal to the external atmospheric pressure $P = P_A$
3. The pressure inside the dryer does not depend on the temperature of the air and the thermal and physical parameters of the dried fruit are constant. Also, the model does not take into account the difference between the fruit temperature and the air temperature in the chamber. Suppose the dryer enters. Regardless of the air flow rate G^+ and the air flow rate G_-, the air mass balance in the dryer is written as follows:

$$\frac{Vd\rho}{d\tau}=-\frac{dM}{d\tau}+G_+-G_- \quad (13)$$

The following equation can be written for the vapor concentration inside the chamber.

$$V\rho\frac{dC}{d\tau}=-\frac{dM}{d\tau}+G_0-G_+ \quad (14)$$

Considering (14), (13) can be written as follows.

$$V\rho\frac{dC}{d\tau}=-\frac{dM}{d\tau}(1-C)-G_-\left(C-C_0\right) \quad (15)$$

As mentioned above, $P > P_A$, thus we write the following using the gas state equation.

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$$P = \rho RT\left\{\frac{C}{\mu_\delta} + \frac{1-C}{\mu_8}\right\}\ ;\ P_a = \rho_a RT\left\{\frac{C_a}{\mu_\delta} + \frac{1-C_a}{\mu_8}\right\}$$

$$\rho T\left(\frac{C}{\mu} + \frac{1-C}{\mu}\right) = \rho_a T_A\left(\frac{C_a}{\mu_\delta} + \frac{1-C_a}{\mu_8}\right)$$

we enter the definition as follows

$$C_P = \frac{KR}{K-1}\left(\frac{C}{\mu_\delta} + \frac{1-C}{\mu_8}\right);C_{P_a} = \frac{KR}{K-1}\left\{\frac{C_a}{\mu_\delta} + \frac{1-C_a}{\mu_8}\right\}$$

$$C_P \rho T = C_{\rho_a} \rho_a T_a \tag{16}$$

We now derive the energy equation. The air flow $G_+ C_P T_a d\tau$ entering the dryer carries heat energy. The energy emitted from the camera is equal to $G\_C_P dT\tau$.

In addition, solar radiation is the main factor influencing the change in chamber temperature, and its share is equal to $AJSd\tau$. There will be an amount of heat transferred to the outside environment due to $Q = \alpha F(T - T_a)d\tau$ heat exchange.

Thus

$$\frac{dC_P \rho TV}{d\tau} = C_P G_+ T_a - C_P G\_T + JAS + \alpha F\left(T_A - T\right) \tag{17}$$

But $C_P \rho TV = PV\dfrac{K}{K-1} = const$ for this

$$C_{P_a} G_+ T_a - C_P G\_T + AJS + \alpha F\left(T_a - T\right) = 0$$

$$G\_ = \frac{C_{P_a} G_+ T_a + JAS + \alpha F\left(T_a - T\right)}{C_P T} \tag{18}$$

To close the system of equations, it is necessary to determine the amount of moisture that evaporates from the dried fruit.

In developing such a model, we use the following assumptions. Firstly, the transfer of heat from the fruit to the external environment occurs due to moisture exchange (evaporation).

Secondly, the wet migration in the fruit (its diffusion) occurs through the fruit peel, which has a diffusion coefficient *D* and thickness ℓ. According to the first hypothesis, the flow of the wet mass is equal to $j = \dfrac{q}{r}$. The diffusion coefficient is

$$D = \frac{\lambda}{C_P \rho} \tag{19}$$

Here λ_1 and ρ the thermal conductivity and density of the fruit accordingly.

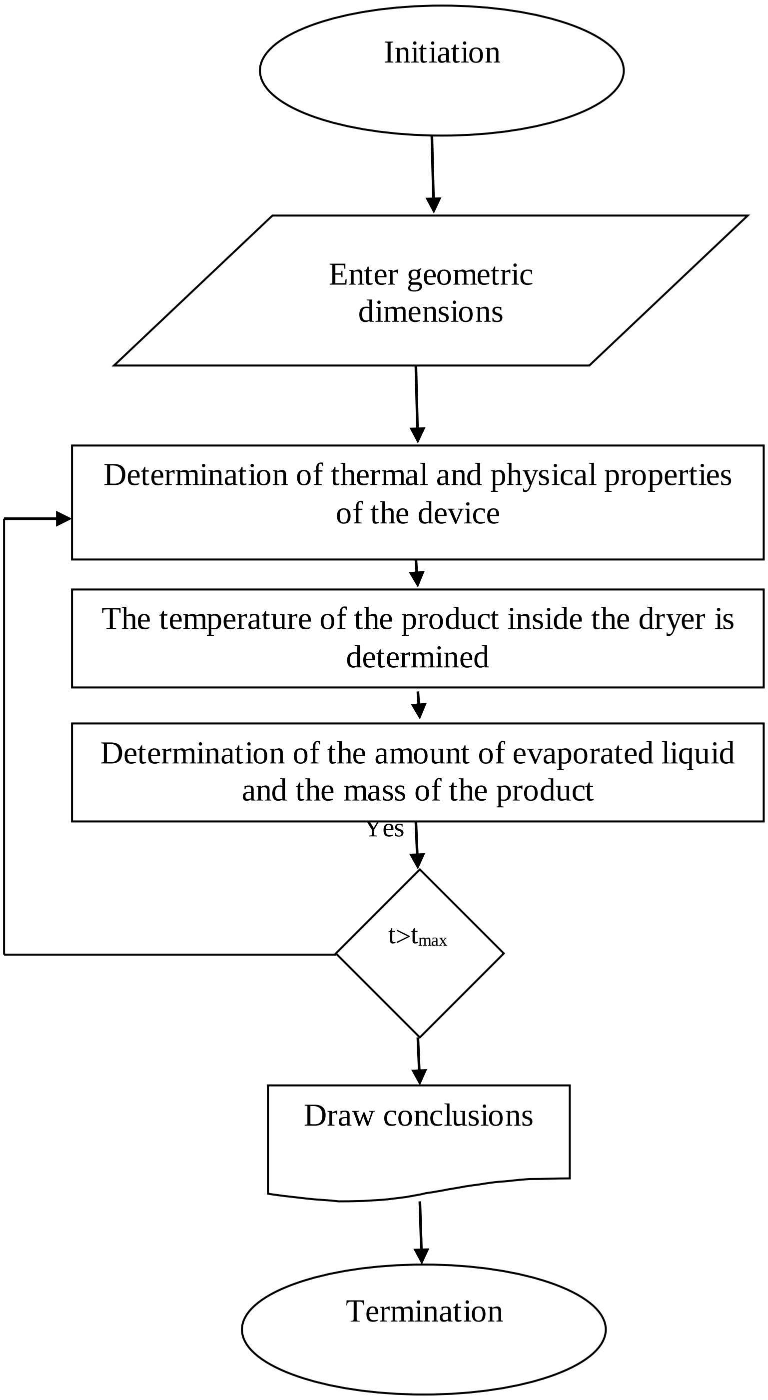

Figure 3. Algorithm in the form of a block diagram

To build a computational algorithm, we use a block diagram view of the algorithms. Figure 3 shows the algorithm for calculating a mathematical model constructed for a dryer.

Based on the created algorithm, the software was created in MathCAD environment [4].

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V.Conclusion

A block diagram of an algorithm for mathematical modeling was constructed using numerical methods for thermal conductivity and mass-transfer processes of solar fruit dryers. Using this block diagram, high efficiency of thermal-physical, technical parameters of the device was achieved. These results will be the basis for the creation of new variants of dryers in optimal appearance.

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