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Method for determining the sizes of structural elements and semi-empirical formula of thermal characteristics of solar dryers

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Abstract. By choosing the initial dimensions of flat solar collectors, and by measuring the temperature of the incoming and outgoing air from the collector, it is possible to determine the linear dimensions of the drying cabinet attached to the collector. It is also possible to establish the basic semi-empirical formulas for determining the thermal characteristics of solar dryers. This calculation method was applied to design and build a study of an indirect solar dryer with natural air convection for drying apricots.

1. Introduction

Concern about climate change and food insecurity is one of the top pressing issues from a global perspective.

In particular, the need to minimize the use of fossil fuels currently requires scientists around the world to conduct extensive research on the use of renewable energy sources.

Solar energy is the most reliable, environmentally friendly and renewable source of energy. It is preferable to other sources because it does not require the high cost of fossil fuels and does not pollute the environment [1].

The issue of obtaining quality products by drying them on site using efficient solar dryers in order to significantly reduce losses after harvesting agricultural products remains an important problem for scientists around the world [2].

Basically, world scientists [1-5] recommend indirect types of solar dryers with natural air convection to solve this problem.

In order to further improve the efficiency of obtaining high-quality products in such devices, scientists will focus on the complete modernization of the elements of building models based on programs created on modern computer technologies.

They focus their scientific activity on conducting experimental research by using additional new equipment and adjusting the geometric dimensions of structural elements not only on an empirical form, but at least on a semi-empirical form.

Based on the above problems, in the field of creating and researching efficient indirect solar drying plants with natural air convection, this article sets the goal: to develop a method for determining the optimal geometric dimensions of the main structural elements and, on its basis, establish semi-empirical formulas for determining the main thermal characteristics [6-7].



2. Materials and methods

Indirect type solar dryer with natural air convection consists mainly of two parts: a flat solar collector and a drying cabinet (figure 2) [1].

The solar flat collector is made in the form of a hot box and a rectangular parallelepiped, its bottom and sides are protected from heat transfer to the environment. A thermal accumulator is installed in the lower part of the collector to reserve heat. Covers are cut out on two sides (bottom and top sides) of the collector: a cover (A) for the entry of air from the environment and a cover (B) for transferring heated air from the collector to the drying cabinet (figure 2). The part of the hot box facing the sun is covered with glass. The internal and external parts of all the remaining side walls, the bottom, are enclosed with plywood, between which the heat is isolated from the external environment [3-5].

The drying cabinet was also made in the form of a rectangular parallelepiped, and all its walls were protected from heat transfer to the environment. On the side of the cabinet facing the North Pole, there is a thermally protective door for placing products in it [8-10].

To ensure the supply of heated air from the flat collector to the drying cabinet, a hole (B) is installed in the lower part of the cabinet, a hole (D) is installed on the roof of the cabinet to discharge the vapor-air mixture into the environment (figure 2).

Solar radiation falls on the transparent surface of a flat collector, part of the solar radiation is reflected from the transparent surface and part is absorbed by it, the rest is passed through the air inside the collector and hits the surface of a heat accumulator, which is installed at the bottom of the collector.

The air and the battery that have received solar radiation heat up. At the same time, the heated battery also transfers its thermal energy to heat the air around it. The elevated air temperature rises to the outlet (B) of the collector and enters the oven. At the same time, air from the environment enters the manifold through opening (A).

The heated air moves vertically and is discharged into the environment through an opening (D) installed at the top of the cabinet. In the event that a dried product is placed in a cabinet, heated air, transferring its heat, evaporates the water contained in it. Then through the hole (D), the steam-air mixture is released.

In the nodes of the drying device, we determine the temperatures: the temperature of the incoming air from the environment to the collector $-T_a$, collector outlet temperature $-T_c$, temperature of the steam-air mixture leaving the oven $-T_d$. Determining the dimensions of the dryer: installation height $-H$, collector height $-h_c$, drying cabinet height h_{uk} . (figure 1).

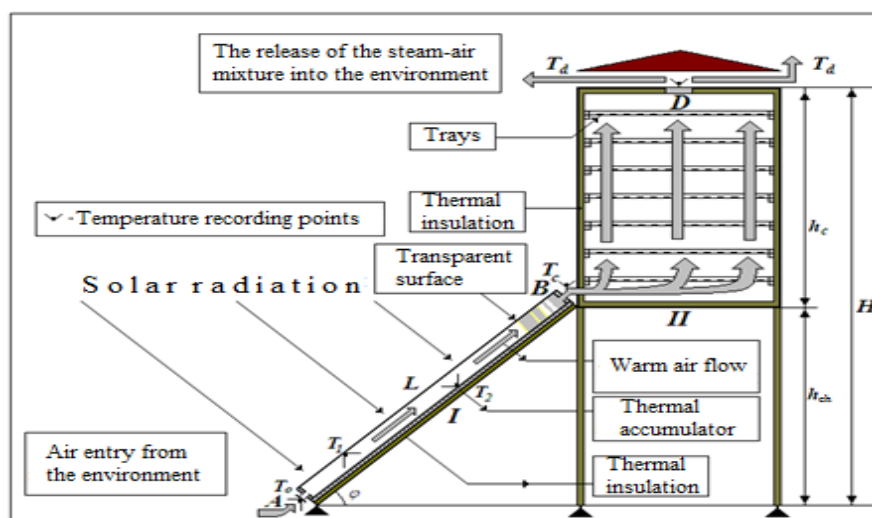


Figure 1. Scheme of indirect type solar dryer with natural air convection.

Predictions: flat collector chamber receives air from the environment and fills its original volume.

Predictions: The flat collector chamber receives air from the environment and fills its original volume V_c , while the air receives a certain amount of thermal energy from solar radiation:

$$A_1 = c_p \cdot m_c \cdot (T_c - T_a) \quad (1)$$

Where c_p – specific heat capacity of air at temperature $(0-50)^\circ C$ $c_p \approx 1.005 \frac{\kappa J}{\kappa g \cdot K}$; m_c – mass of air inside the collector chamber, $m_c = \rho_a \cdot V_c = \rho_a \cdot L_c \cdot M_c \cdot N_c$, κg ; ρ_a – air density in the initial position, $\frac{\kappa g}{m^3}$; L_c – collector length, m M_c – width, m N_c – collector height, m.

Predictions: when we open the manifold outlet, the air $A_1 = A_x$ energy, expands the volume in the interval $V_c \div V_x$ at constant air pressure $p = const$:

$$A_x = p \cdot (V_x - V_c) = p \cdot \Delta V \quad (2)$$

Aligning (1) and (2) we determine the volume V_x :

$$c_p \cdot m_c \cdot (T_c - T_a) = p \cdot (V_x - V_c),$$

$$V_x = \frac{c_p m_c (T_c - T_a) + p V_c}{p} \quad (3)$$

Hence the volume of the drying cabinet $V_{uk.}$ determined by the difference in volumes $V_{uk.} = V_x - V_c$ or like this:

$$V_{uk.} = \frac{c_p m_c (T_c - T_a)}{p} \quad (4)$$

It is known that the volume of the drying cabinet consists of the product of their three dimensions:

$$V_{uk.} = (L_x - L_c) \cdot M_x \cdot N_x = L_{uk.} \cdot M_c \cdot N_x \quad (5)$$

Where $L_{uk.}$ – the height of the desired drying cabinet, M_c – collector width, N_x – length. The scheme for calculating the dimensions of the drying cabinet is shown in figure 2.

Cabinet Base Width Dimension $M_{uk.}$ select according to the size of the width of the collector $M_c = M_{uk.}$, cabinet base length N_x we choose according to the size of the pallet in which the dried fruits are placed $N_{uk.}$. And finally, it will be possible to set the size of the height of the cabinet $L_{uk.}$.

3. Results and Discussion

Taking into account the angle of inclination of the collector bottom surface with respect to the horizon (figure 2), and also taking into account formulas φ (4) and (5), we establish a semi-empirical formula for determining the height of the drying cabinet:

$$h_{uk.} = L_{uk.} \cdot \sin \varphi = \frac{c_p \cdot m_c \cdot (T_c - T_a)}{p \cdot M_{uk.} \cdot N_{uk.}} \cdot \sin \varphi \quad (6)$$

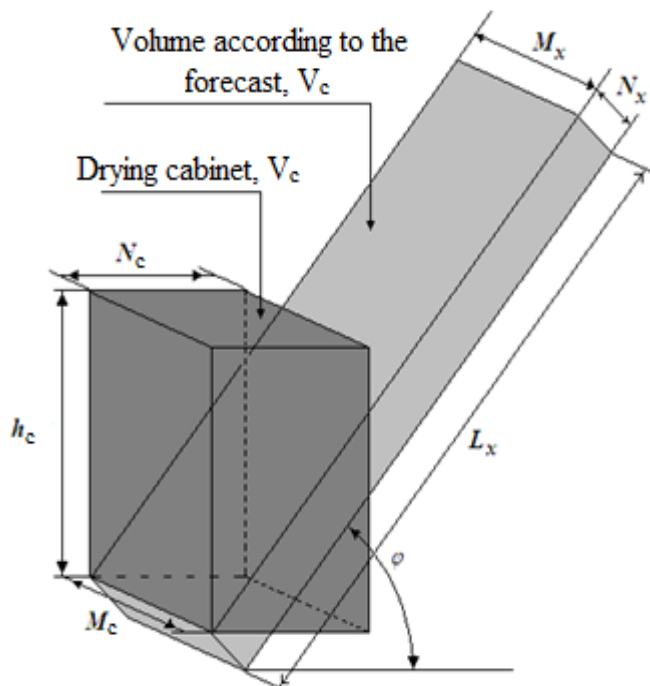


Figure 2. Scheme for calculating the dimensions of the drying cabinet.

To determine the output of warm air in the collector, of course, it is necessary to determine the mass of warm air entering the oven.

In the initial state, the mass of air collected in the volume of the collector:

$$m_c = \rho_a \cdot V_c = \rho_a \cdot L_c \cdot M_c \cdot N_c \tag{7}$$

The air of the received amount of thermal energy from solar radiation (1) does work, i.e. expands its volume (mass of air at $m_c = const$):

$$A_1 = c_p \cdot m_c \cdot (T_c - T_a) = m_c \cdot a \cdot L_x = m_c \cdot a \cdot (L_c + L_{uk.}) \tag{8}$$

From where we determine the acceleration of the rise of incoming air in the collector chamber from point A to point B :

$$a = \frac{c_p \cdot (T_c - T_a)}{(L_c + L_{uk.})} \tag{9}$$

At point B , for the air entering the collector, the following energy balance equation can be written:

$$m_c g h_c = m_c \frac{g^2}{2} \tag{10}$$

From where, we determine the speed of the incoming air into the collector (the rate of filling the collector chamber from the environment, in a unit of time, m/s):

$$g = \sqrt{2gh_c} \tag{11}$$

According to the law of free fall of the body, we determine the speed of the incoming air into the collector:

$$\mathcal{G} = a \cdot \tau_1 \quad (12)$$

Aligning (11), (12) we apply (9) and determine the time of mass lifting m_c air to point B :

$$\tau_1 = \frac{\sqrt{2gh_c}}{a} = \frac{\sqrt{2gh_c} \cdot (L_c + L_{uk.})}{c_a \cdot (T_c - T_a)} \quad (13)$$

In one second it will be possible to find the mass of air m' , included in the collector, in units of measurement kg/s from the following relation:

$$m' = \frac{1}{\tau_1} \cdot m_c = \frac{c_a \cdot (T_c - T_a) \cdot m_c}{\sqrt{2gh_c} \cdot (L_c + L_{uk.})} \quad (14)$$

Solar radiation falling on the transparent surface of a flat collector heats the air A_{air} and the battery inside it $A_{battery}$:

$$A_{air} = C_p^{air} \cdot m' \cdot (T_c - T_a), \quad (15)$$

$$A_{battery} = C_p^{battery} \cdot m_{battery} \cdot (T_{i+1} - T_i), \quad (16)$$

Where C_p^{air} – specific heat capacity of the air in the manifold at constant pressure when there is a temperature $(20-60)^\circ C$, $C_p^{air} = 1.005 \text{ kJ}/\text{kg} \cdot K$; $C_p^{battery}$ – specific heat capacity of the battery installed inside the collector; m' – the mass of air leaving the environment into the collector in one second (the velocity of the incoming air mass, kg/s ; $m_{battery}$ – mass of accumulating material, $\kappa 2$; T_i – and T_{i+1} – average temperature on the surface of the battery for each hour and after an hour, $^\circ C$.

Using equations (15) and (16), we can determine the thermal efficiency of the collector using the following semi-empirical formula:

$$\eta = \frac{C_p^{air} \cdot m' \cdot (T_c - T_a) + C_p^{battery} \cdot (T_{i+1} - T_i)}{R_o \cdot F_a} \quad (17)$$

Here R_o – total solar radiation falling on one square meter of a transparent surface, MJ ; F_a – collector transparent surface area, m^2 .

4. Conclusion

Thus, by selecting the initial dimensions of the flat-plate collectors and measuring the temperature of the outgoing and outgoing air from the collector, it is possible to determine the dimensions of the drying cabinet attached to the collector. It is also possible to establish the basic semi-empirical formulas for determining the thermal characteristics of kitchen dryers. This methodology was calculated for the design and construction of a potential dryer with natural air convection for drying apricots at the Bukhara State University.

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