Air heater efficiency of solar drying plant for agricultural products

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Abstract. This article presents the results of experimental studies of the main thermal characteristics of a solar collector, a heated air duct of an indirect type solar drying plant for agricultural products. The results of temperature measurement at the lower, middle and upper parts of the solar collector, at the entrance and output of the air heater at different solar radiation intensities during the day in different periods of the month in the city of Tashkent are given. The results of the calculation of the volume air flow through the air heater, the specific heat capacity of the solar collector on the basis of the profiled aluminum sheet, the specific heat capacity of the air heater and the heat flow of the air heater at different cold air inlet speeds and the intensity of solar radiation during the day, as well as the efficiency of the air heater. It is shown that the installation of the duct on the upper part of the solar collector with high heat capacity ensures natural convection and the achievement of high temperature of the heated air.

1 Introduction

Uzbekistan is one of the main producers of dried fruits and spices in terms of natural and climatic conditions, exporting to almost 72 countries of the world and near abroad. The main producer of these products are large plants and plants. In addition, the production of dried fruits is increasing in small and medium-sized farms located directly in agricultural production areas, thus reducing the technological losses of raw materials, transportation and storage costs. Such a reprocessing method, in turn, requires the development and deployment of new high-performance technologies and the technical means to implement them.

Solar dryers differ in their capabilities [1, 2]: direct, indirect and mixed, and degrees of technical characteristics.

A direct method of drying is the natural air-solar drying of agricultural products [3, 4]. Direct solar dryers have the material to be dried in a housing with a transparent lid on it. Heat is generated by the absorption of solar radiation on the product itself, as well as on the inner surfaces of the drying chamber. Short wavelength solar energy falls on uneven crop surface. Some of this energy is reflected back and the rest is absorbed by the surface depending on the color of the crops. The absorbed radiation is converted into thermal

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energy, and the temperature of agricultural products increases. This results in a loss of wavelength of radiation from the surface of the crop to the surrounding air through moist air. Evaporation of moisture occurs in the form of evaporation losses and therefore the crop is dried. Solar evaporation causes loss of taste and aroma characteristics [5, 6].

Indirect solar dryers are often referred to as distributed type solar dryers. Here, the plant is placed in trays or shelves inside a closed opaque drying chamber and is heated by circulating air heated during its flow through the solar collector [7-9]. In this method, the culture is not directly exposed to solar radiation, so there is a reduction in discoloration and cracking on the surface of the culture [10]. Thus, they are recommended for relatively sensitive products such as medicinal herbs, spices and fruits, where the vitamin C content will be adversely affected by direct exposure to solar radiation. Indirect dryers are less compact than direct solar dryers, but they tend to be more efficient.

Combined mixed-mode solar dryers combine the functions of direct (integral) type and indirect (distributed) types of solar dryers. The drying process uses a combination of solar radiation falling on the product and preheated air in a solar collector. Hybrid solar systems are usually product-specific and may include other forms of energy to speed up the drying process by using other heat sources in addition to solar heat.

2 Materials and methods

Solar collectors with a high absorption coefficient of solar radiation are found in low-potential solar heaters of heat absorption systems [11, 12] and indirect solar dryers with flat collectors due to the high specific heat coefficient and due to the practical absence of surface reflection of solar rays. In [13-17], various shapes (geometries) of solar collectors and heat storage material have been used to improve the efficiency and productivity of solar dryers.

Solar collectors with a low solar radiation absorption coefficient are associated with low specific heat coefficients of the collectors when using a cellular metal film made of strips of thin copper sheets or shavings [18-22] or perforated thin sheets.

The worst efficiency of the air heater is observed in the absence of natural convection of heated air when the air duct is located under the solar collector [23], the absence of the optimal ratio of the size of the inlet window of the incoming cold air to the length of the air duct [24].

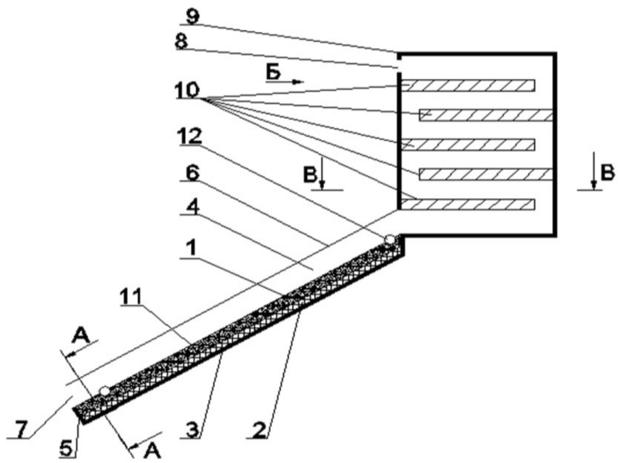
The aim of this work is to develop the design of a solar dryer, which allows for natural convection of heated air, increasing the efficiency of absorption of solar radiation and heat absorption, the efficiency of the air heater and the efficiency of the dryer.

Figure 1 shows a schematic diagram of a solar drying plant developed by us based on a collector consisting of a solid, black profiled aluminum sheet with a solar radiation absorption capacity of at least 0.90 – 0.94.

The solar drying apparatus [25, 26] comprises a vertically mounted drying cabinet with pallets, a heat absorbing solar collector from a profiled aluminum sheet and an air duct mounted on the top of the solar collector.

Experimental studies were carried out to determine the main thermal characteristics of the solar collector, the duct of the heated air and the temperature modes of the installation in the natural and climatic conditions of Tashkent.

The solar drying plant was installed at an angle to the horizon ~ 30 degrees. The intensity of solar radiation was measured by a pyranometer (Pyranometer CMP11, Serial no: 114874 (KIPP & ZONEN, Since 1830, Made in Netherlands).



1 - heat absorbing solar collector based on a single profiled aluminum sheet, 2 - thermal insulation coating, 3 - aluminium case, 4 - air duct above the solar collector, 5 - frame, 6 - top light transparent film, 7 - the bottom opening for the cold air entrance, 8 - outlet of used air, 9 - a suction cabinet, 10 - pallets, 11 - profiled aluminum sheet, 12-built pipes.

Fig. 1. Schematic diagram of the solar dryer.

3 Results and Discussion

Pilot study and calculation of thermal characteristics of solar collector and heated air duct

Figure 2 shows the results of the measurement of the intensity of solar radiation during the day at different weeks and months of the year in Tashkent. The maximum solar intensity is 950 W/m^2 by approximately noon.

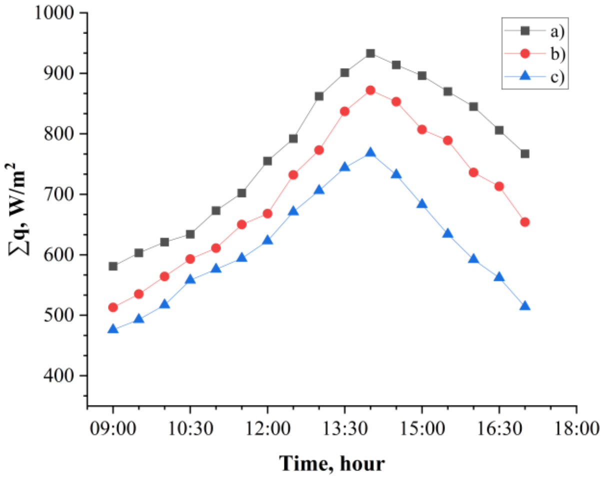


Fig. 2. The results of experimental studies of the temperature characteristics of the solar collector at ambient temperature, ta.t. = +30 °C (in the conditions of Tashkent).

An analysis of the results of experimental studies shows that at an ambient temperature of 30 ^{o}C and with an average value of incident solar radiation of 845 W/m^3, the maximum temperature of the solar collector (Figure 3) is 75–77 ^{o}C, the temperature of the heated air is at least 73 ^{o}C.

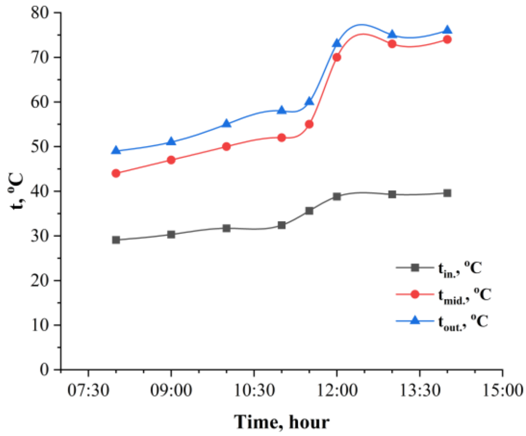


Fig. 3. The results of experimental studies of the temperature characteristics of the solar collector at ambient temperature, $t_{a.t.}$ = +30 °C (in the conditions of Tashkent).

The temperature was measured using a mercury thermometer of the type: thermometer (100250, TTZh-M version 10 ...... +200 °C; c.d. 2 °C, TU 25-2021.010-89 TT) and a contact thermometer of the type: thermometer (WTQ-288, 0-120 °C).

Under normal climatic conditions in Tashkent, the value of cold air velocity ω is in the range of 0,05÷3,0 m/s.

Figure 4 shows the results of measuring the temperature of the heated air near the inlet and outlet of the air heater at various cold air velocities.

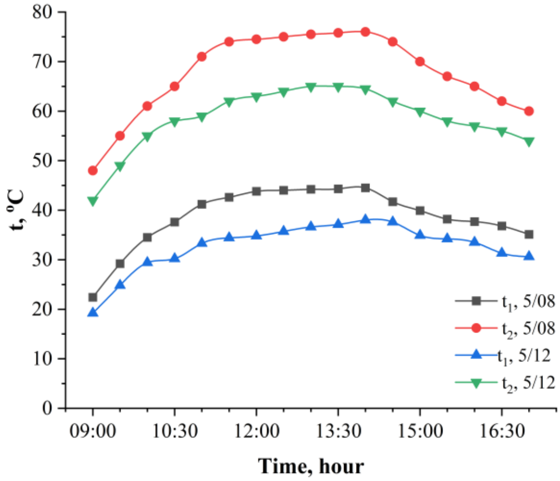


Fig. 4. Air temperatures near the inlet and outlet of the air heater.

Based on the analysis of the daily dynamics of meteorological parameters, the temperature at the inlet and outlet of the air heater, the heat flow of the air heater was calculated based on the following formulas proposed in [27, 28]:

$$Q_{eff.} = G_m \cdot c_p \cdot \Delta t$$
$$G_m = G_v \cdot \rho_{air} \quad (1)$$
$$Q_{eff.} = G_v \cdot \rho_{air} \cdot c_p \cdot (t_2 - t_1),$$

Where G_m - is the mass air flow, kg/s; c_p – is the isobaric heat capacity of air, kJ/(kg·°C); t_1 and t_2 - are the air temperatures at the inlet and outlet of the air heater, °C.

The cross section of the air heater inlet has the following parameters: height - a = 0.04 m; width - b = 90 cm = 0.9 m, area – 0.036 m^2. The volume flow of air through the air heater (Figure 5) was calculated using the formula: $G_v = \omega \cdot F_o$.

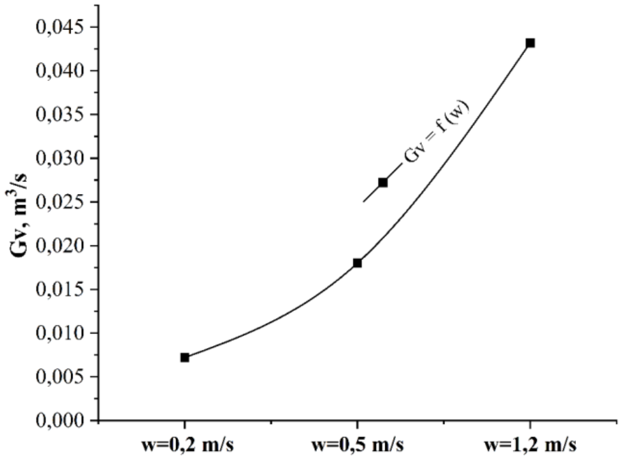


Fig. 5. The dependence of the volume air flow through the air heater at three inlet air velocities.

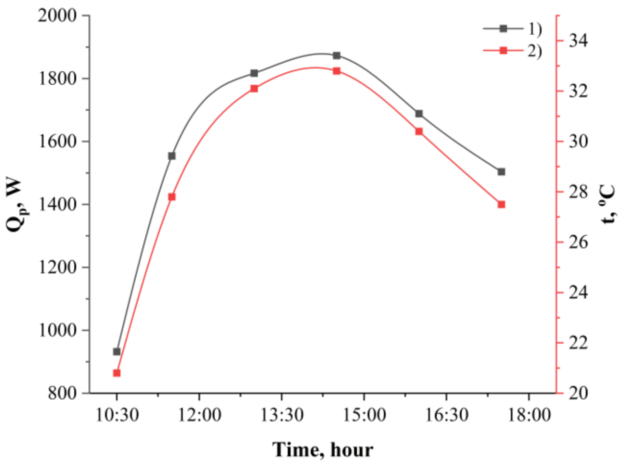


Fig. 6. Experimental results of temperature difference (1) of heated and cold air and calculation of heat flow (2) of air heater depending on radiation intensity during the day.

Figure 6 shows the experimental results of the temperature difference of the heated and cold air, as well as the calculated results of the heat flow of the air heater depending on the intensity of the solar radiation during the day.

Using the values of the flux density of the incoming solar radiation, the temperature of the inlet cold air and the heated air at the outlet of the air heater, the effective energy of the air heater was calculated using the formula [28]:

$$Q_{eff.} = G_v \cdot \rho_{air} \cdot c_p \cdot (t_2 - t_1) \quad (2)$$

Where ρ_{air} = 1.29 kg/m^3; c_p = 1.004 kJ/(kg·°C), c_p - air isobar heat capacity; t_1 - air inlet temperature of the air heater, respectively °C; t_2 - air outlet temperature of the air heater, respectively °C; t_1 = 43.5 °C; t_2 = 77 °C.

In the case of the falling radiant solar energy q_p = 922 W/m^2, the useful energy of the air heater was:

$$Q_{eff.} = 1872.65 \text{ W} \tag{3}$$

The specific heating capacity of a solar collector based on a profiled aluminum sheet is equal to:

$$q_{s.h.c.} = Q_{eff.} \; /F \tag{4}$$

The specific heat capacity of the air heater was:

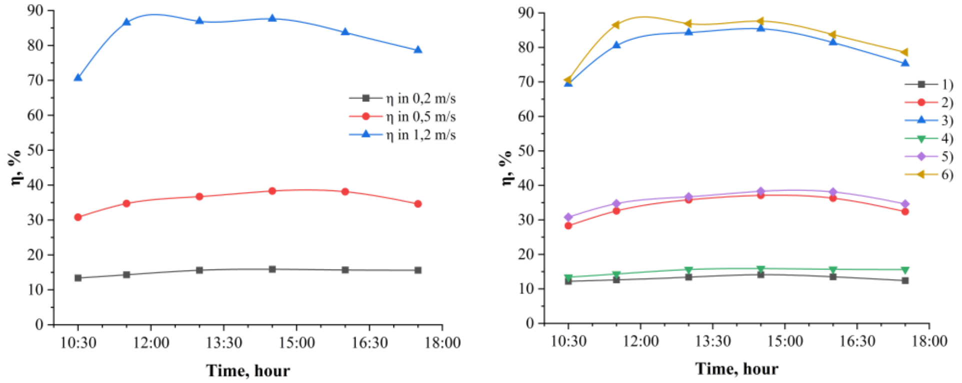
$$q_{s.h.c.} = \frac{Q_{eff.}}{F} = \frac{1872{,}65 \text{ W}}{2{,}32 \; m^2} = 807{,}18 \; \frac{\text{W}}{\text{m}^2} \tag{5}$$

At the surface area of the solar collector F = 2.32 m^2, Qp - the radiation falling on the surface of the collector was:

$$Q_p = q_p \cdot F = 922 \text{ W/m}^2 \cdot 2{,}32 \text{ m}^2 = 2139{,}04 \text{ W}. \tag{6}$$

The efficiency of the air heater was calculated using the formula:

$$\eta = \frac{Q_{eff.}}{Q_p} = \frac{G_\nu \; \cdot \; \rho_{air} \; \cdot \; c_p \; \cdot \; (t_2 - t_1)}{q_p \cdot F} \tag{7}$$



1) η in 0.2 m/s, X/2020; 2) η in 0.5 m/s, X/2020; 3) η in 1.2 m/s, X/2020; 4) η in 0.2 m/s, VIII/2021; 5) η in 0.5 m/s, VIII/2021; 6) η in 1.2 m/s, VIII/2021

a) b)

Fig. 7. The dependence of the efficiency coefficient of the air heater on the time at different incoming air speeds: a) during the day, b) in different periods of the year.

Figure 7 shows the results of experimental data on the dependence of the air heater efficiency on the time during the day and different periods of the year at different air velocities. As shown in the figures, the efficiency of the air heater located above the solar collector is on average 75-87% during the day, at different airflow speeds at the air inlet. In this case, the maximum value of the air duct efficiency is observed for several hours by noon and shows the high efficiency of the air heater of the solar drying plant.

4 Conclusion

The work [18] describes a solar-air collector type "hot cabinet". The solar collector consists of a thin sheet metal painted black with an area of 2,25 m^2. The air duct is located under the collector.

The heat-accumulating solar collector consisting of a thin sheet of metal has a low heat capacity, and the duct under the collector does not provide natural convection of the heated air, resulting in a solar-efficiencythe value of the air collector is low - up to 50 %.

In the work [20] a helium dryer containing an inclined air heater in the form of a tray is described. A heat-absorbing nozzle in the form of a cellular metal film made of strips of thin copper sheet is mounted on the top part of the tray.

The device provides that fresh air enters the heat-absorbing thin panel and, as it moves up the tray, is heated by means of heat transfer when the surface of the thin panel is streamlined. The disadvantage of the device is: low efficiency of air heating due to the low heat capacity of the cellular metal film from strips of thin copper sheet and the duct under the heat absorbing nozzle, as a result, there is no natural convection of the heated air.

In this operation, the solar collector is made of a single, profiled aluminum sheet painted black, which has an absorption capacity of solar radiation at least 0,90-0,94 and a high heat absorption coefficient, the surface temperature of the solar collector reaches about 75-77 °C. The installation of a 232 cm long air heater over a heat-absorbing collector compared to the size of the input window area (0,036 m^2) ensures the natural convection of the heated air under the action of the Archimedean force, to align and increase the temperature of the heated air, provides a high value of the heat flow at the output up to 2000 W and the temperature of the heated air up to 75 °C. The thermal insulation of the lower part of the panel and the low thermal conductivity of the side walls of the air-heating air conduit increase the efficiency of the heat absorption and efficiency of the air heater at 75-87 %.

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